Offshore wind farms in the Belgian part of the North Sea

State of the art after two years of environmental monitoring

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The first phase of the C-Power wind farm on the Thorntonbank (photo Jan Haelters/RBINS)

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Chapter 1. Executive summary: the monitoring results in a nutshell

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Photo Alain Norro / RBINS

1.1. Introduction

The European directive 2001/77/EG presently imposes each member state a target figure for its contribution to the production of electricity from renewable energy sources that should be achieved by 2010. For Belgium, this target figure was set at 6 % of the total energy consumption. Since a Royal Decree on 17 May 2004 assigned a zone for the production of electricity in the Belgian part of the North Sea (BPNS), two companies, C-Power and Belwind, were granted a permit to build and exploit a wind farm on the Thorntonbank (60 turbines, 300 MW) and Bligh Bank (110 turbines, 330 MW), respectively. A third company, Eldepasco, initiated the environmental permit procedure in 2009.

The permits include an obligation to establish a monitoring programme (1) to ensure the ability to mitigate the negative effects of the concerned activities (or even halt them in case of extreme damage to the marine ecosystem) and (2) to acquire an assessment and understanding of the environmental impact of offshore wind farms to support policy, management and the design of future offshore wind farms. The first phase of the monitoring programme started the year before the anticipated construction of the first wind turbines at the Thorntonbank (i.e. 2005) and will last for six years to allow the identification and quantification of possible effects. At the end of this first phase, an overview and discussion of the monitoring activities and outcomes are planned between MUMM, its monitoring partners and the wind farm industry. This workshop will be the first thorough evaluation of possible impacts of marine wind farms in Belgian waters.

1.2. Monitoring objectives

This report presents a compilation of the results of the monitoring activities in the year 2008. The report covers:

1. the evaluation of the appropriateness of the selected reference sites and reference conditions for both the C-Power and the Belwind project,
2. the various environmental data under surveillance, with an evaluation of the preliminary impacts due to the construction of six turbines at the Thorntonbank (C-Power project: comparison with data collected in 2005)
3. advices for future monitoring at the level of technicalities, scientific design, as well as research focus and strategies (C-Power and Belwind project).

1.3. Monitoring strategy

1.3.1. Environmental assets and monitoring design

The monitoring programme targets physical (i.e. hydrodynamics, underwater noise and electromagnetic fields[1]), biological (i.e. hard substrate epifauna, hard substrate fish, soft substrate

[1] The monitoring programme of each wind farm foresees two measurements of the electromagnetic fields (EMF) produced by the electrical cables in the wind farm and to the shore: once during the procution of a pilot phase, a second time when the entire park is completed and in production. EMF measurements at the Thorntonbank were postponed to 2009, as in 2008 only two of the six turbines of the pilot phase were in production. A condition in the permit states that all cables need to be at least 1 m below the seabed at all time for reasons of maritime safety. The resultant physical barrier is expected to reduce environmental impact on organisms that are influenced by EMF. Initial studies by COWRIE (Collaborative Offshore Wind Research into the Environment) have demonstrated that the EMF of submerged cables can influence elasmobranches. However, due to a high variation in response at the level of individuals and species, no straightforward impact of EMF could be quantified. Further research in this field is ongoing and MUMM awaits the conclusions of this study to fine tune its future activities related to EMF.

macrobenthos, soft substrate epibenthos and fish, seabirds, marine mammals), as well as socio-economical (seascape perception) aspects of the marine environment.

MUMM coordinates the monitoring activities and conducts the studies on underwater noise, hard substrate epifauna and fish, seabird radar detection, marine mammals, hydrodynamics and electromagnetic fields. MUMM further collaborates with different institutions to complement its expertise in the following domains: seabirds (INBO), soft substrate epibenthos and fish (ILVO), soft substrate macrobenthos and hard substrate fish (Marine Biology Section of Ghent University), underwater noise (Renard Centre of Marine Geology of Ghent University).

In general, the monitoring programme follows a Before-After/Control-Impact (BACI) design, in which the changes within the concession areas during construction and exploitation of the wind farms are and will be compared with the state before the construction started (i.e. reference condition) and the state of highly similar, though non-impacted reference sites. Such a design allows one to objectively quantify possible impacts due to the construction and exploitation of the wind farms once the natural variability both in space and time is duly taken into account. For some environmental assets (i.e. hard substrate epifauna and fish, marine mammals, and seascape perception) such BACI design could not be implemented in full and appropriate adaptations were made.

As a first priority, the environmental reference conditions of the concession area, as well as well-selected reference sites were characterized prior to impact (i.e. Thorntonbank: 2005; Bligh Bank: 2008). In 2008, the first phase of the environmental impact assessment at the Thorntonbank started. This report covers both the characterization of the environmental conditions at the Bligh Bank and the preliminary impact assessment at the Thorntonbank, where the first six wind turbines have been placed.

For more detailed information on specific research designs and methodologies, one is referred to the individual chapters.

1.3.2. Macro-environmental replication

As both monitoring programmes (i.e. C-Power and Belwind) are strongly intertwined, most conclusions from the research apply to both areas. This should be considered an advantage, rather than a disadvantage. Although small-scale variations in habitat do exist within and between both wind farms, both sites are (1) situated in offshore waters influenced by English Channel water, (2) situated in the vast sand bank area in front off the Belgian coast and (3) characterized by the dominance of medium to coarse sandy sediments. As such – from a macro-environmental perspective – both sites can be considered highly similar and hence (most probably) representative for the Belgian offshore water ecosystem. For many variables of interest, these sites might thus be considered replicates, increasing the reliability and generality of any observed impact.

The MUMM strategy therefore includes the integration of the monitoring exercises for the C-Power, Belwind and possible future concessions in the BPNS with a view (1) to increase the scientific reliability and generality of the findings, with a consequent added value for the wind farm industry (e.g. site-independent ecological adjustment of future wind farm design, construction and exploitation) and (2) to optimize the cost-efficiency of the wind farm monitoring programme in the BPNS.

This will in no way preclude the ability to evidence site-specific effects that may manifest themselves in relation to other variables such as distance from land, depth, water quality and the migration routes of target species.

1.4. Results from the monitoring year 2008

1.4.1. Reference sites and reference conditions

A first *conditio sine qua non* to allow a reliable BACI comparison is to select a proper reference condition and reference site. The reference condition has to describe the general, average state of the environment or has to describe a specific condition (e.g. at high water, during calm weather conditions or in autumn), including a quantification of the variances if possible. The reference site in its turn has to be representative for the impact site. In other words, the state of the reference site should be identical or at least similar to that of the impact site. Because of this important condition a lot of attention was paid to the evaluation of reference sites and conditions.

1.4.1.1. Reference site selection

1.4.1.1.1. Soft substrate macrobenthos[2]

Even though similarities between the Belwind concession area, the Belwind edge zone and reference site at the Gootebank regarding the response variables sediment characteristics, density, diversity, biomass, productivity and community composition are not that high (67 % of statistically tested response variables), the choice of the reference zone is considered relatively appropriate. Especially the similarity between the Belwind concession area and its edge zone is good: 84 % of tested response variables do not differ significantly. The similarity between the Belwind concession area and the Gootebank reference area is poorer: only 47 % of the tested response variables do not differ significantly. It will hence be important to possibly re-evaluate the suitability of the Gootebank as a reference area for the Belwind concession area and/or to select those response variables that do not show any significant difference. Within these areas, the macrobenthos is moderately rich, with maximum densities of 3500 ind./m² and maximum species richness of 26 spp./0.1m², and dominated by *Nephtys cirrosa* and *Spiophanes bombyx*, two wide-spread polychaete species in the BPNS. This species assemblage is transitional between the *N. cirrosa* and *Ophelia limacina* communities (sensu Van Hoey et al., 2004[3]) and typically inhabits medium sandy sediments (average median grain size: 409 µm; sediment mud content: 0.3 %), as found in this study.

1.4.1.1.2. Soft substrate epibenthos and fish

The selected reference sites for soft substrate epibenthos and fish monitoring are situated at the Gootebank and the reference part of the Thorntonbank (for C-Power) and the Oosthinder (for Belwind). After removal of the deviating Gootebank gully stations from the monitoring programme, relatively high similarities (Bray-Curtis similarity: 60-80 %) for epibenthos and fish assemblages were found between the reference and impact area, at least when differentiating between (1) sand bank top and gully samples, (2) spring and autumn samples and (3) the C-Power and the Belwind monitoring areas. The reference site selection for both concession areas can hence be considered appropriate. On average, fish densities proved to be 22 % higher in the gullies compared to the sand bank tops and 200 % higher in autumn compared to spring, whereas epibenthos densities were six times higher in the gullies compared to the sand bank tops. Perciforms and flatfish were dominant throughout the years, supplemented by locally and seasonally high densities of clupeids and gadoids. The epibenthos was generally dominated by brown shrimp (*Crangon crangon*), two brittle star species (*Ophiura* spp.), hermit crab (*Pagurus bernhardus*), flying crab (*Liocarcinus holsatus*), lesser bobtail squid (*Sepiola atlantica*) and squid (*Loligo vulgaris* and *Todaropsis eblanae*).

1.4.1.1.3. Seabirds

1. Based on the Jacob's selectivity index (JSI) for ten seabird species (monitoring period 2005-2007), suitable for future monitoring the C-Power site, the selected reference area for seabird monitoring was considered suitable. However, the seabird species-specific suitability for impact assessment differed substantially for the ten species (JSI = 0.01 – 0.86; 0 = homogenous distribution, ± 1 = absolute preference for one of the zones compared). Hence, based on (1) JSI, (2) seasonal variation in JSI and (3) the species-specific degree of association with fisheries activity, the ten species were further ranked according to their suitability for future monitoring. Auks (*Alca torda* and *Uria aalge*), terns

[2] This section only refers to the reference site selection for the Belwind concession area, since the C-Power reference site selection was already dealt with within an earlier C-Power T0 report (samples collected in 2005). See De Maersschalk *et al.*, 2006.

[3] Van Hoey, G., S. Degraer & M. Vincx (2004). Macrobenthic communities of soft-bottom sediments at the Belgian Continental Shelf. *Estuarine, Coastal and Shelf Science*, 59: 601-615.

(*Sterna hirundo* and *S. sandvicensis*), northern gannet (*Morus bassanus*) and little gull (*Larus minutus*) rendered the highest suitability for future monitoring of the impacts at the C-Power site.
2. Based on the absolute as well as standardized differences in bird densities of six species, suitable for future monitoring of the Belwind site (i.e. northern gannet, great skua (*Catharacta skua*), little gull, lesser black-backed gull (*Larus fuscus*), black-legged kittiwake (*Rissa tridactyla*) and common guillemot (*Uria aalge*)), a site including the Oosthinderbank and the Blighbank was selected as future reference site.

1.4.1.1.4. Marine mammals

Given the wide dispersal and mobility of marine mammals, the reference area for this part of the monitoring comprises the Belgian marine waters outside the wind farm areas. For mooring passive acoustic devices, reference locations at sufficient distances from the wind farm areas and in the vicinity of cardinal buoys are chosen.

1.4.1.2. Reference conditions

1.4.1.2.1. Underwater noise

The background underwater noise level recorded at the Bligh Bank site (95-100 dB between 10 Hz and 2kHz) was similar to the background noise levels recorded at the Thorntonbank site. The difference in level could be linked to slight differences in weather conditions at the time of the monitoring campaigns, differences in the sites themselves, differences linked to the season and water temperatures, differences in human-generated noise during the respective campaigns (e.g. shipping) and to a combination thereof. Also the larger distance to the noise-generating gas pipelines, which run through the Thorntonbank, has an influence. The measured level should be used as background levels for future monitoring of underwater noise during the construction and the operational phase.

1.4.2. Impact evaluation

1.4.2.1. Underwater noise

The increase in underwater noise levels recorded at the C-Power site during the monitoring campaigns of 2008 (i.e. during the construction phase) was minor (i.e. 5 to 25 dB higher at 50 Hz to 3 kHz) and can be compared to general shipping noise as temporarily present over a large part of Belgium’s marine waters and especially near ports and shipping lanes. It is therefore not considered of particular concern for marine mammals. However, for some relevant construction activities (e.g. placement of scour protection), the increase in underwater noise level could not be characterized yet.

1.4.2.2. Hard substrate fouling

1. One of the most direct and obvious impacts of the construction of six wind mills at the C-Power site was the fast and intense colonization of the concrete foundations, typical for the first phase of ecological succession. After 3.5 months, a surprisingly high species richness (49 spp.) was found, with a dense Bryozoan (*Electra pilosa*) cover, providing habitat for many other species, such as small crustaceans, polychaetes, blue mussel *Mytilus edulis* and queen scallop *Aequipecten opercularis*. Further succession might cover the expected formation of a *M. edulis* zone, as well as the possible settling of the Pacific cupped oyster *Crassostrea gigas* and tube forming polychaetes, such as the Ross worm *Sabellaria spinulosa*.
2. At present, three vertical zones can be distinguished: (1) an intertidal and splash zone, characterized by the dominance of *Telmatogeton japonicus* and the presence of four filamentous algae, (2) a shallow subtidal to low intertidal zone dominated by barnacles and the amphipod *Jassa* and (3) a deeper subtidal zone with a dense *E. pilosa* turf.
3. The presence of the exotic common barnacle *Balanus perforatus*, a southern warm-water species, and the alien titan acorn barnacle *Megabalanus coccopoma* in the barnacle zone exemplifies the advantage artificial hard substrates offer to southern and alien fouling species spreading into the North

Sea. During the coming years additional warm-water and non-indigenous species can be expected. This possible stepping stone effect, allowing species to spread over large distances through a series of short distance colonization events, is further particularly relevant for species like *Jassa* spp. and *T. japonicus*, which have no planktonic larval stage.

1.4.2.3. Soft substrate macrobenthos

1. A large-scale impact of six wind turbines on sediment characteristics and the macrobenthos of soft sediments of the concession area in the first year after implementation of the C-Power wind farm (1^{st} phase) was not detected and certainly remained subordinate to seasonal and yearly variability. Yearly variability (2005 versus 2008) seemed to be high, with generally higher densities and species richness in 2008: maximum 1300 ind./m² and 16 spp./0.1m² in 2005 versus 2500 ind./m² and 26 spp./0.1m² in 2008. This change could not be linked to the position of the six turbines. The extension of the wind farm and the possible longer-term effects, however, justify a continuation of the monitoring programme for soft-substrate macrobenthos. Such continuation will permit the evaluation and quantification of both the impact of wind farm construction and the following successive recovery, as well as the effect of the exclusion of fishing from the area. The latter is expected to become detectable only in the long run.
2. At a smaller scale, measurable impacts are expected, but these could not be detected due to the fairly large distance from a wind turbine to the closest sampling location (i.e. > 100 m).

1.4.2.4. Soft substrate epibenthos and fish

When comparing the data of 2005 and 2008, it is clear that the major driving forces of variation between the samples are (1) seasonality, (2) interannual differences, and (3) spatial differences (sandbank tops versus gullies). Significant differences due to the construction of the six present windmills have not been detected so far, and are rather expected to manifest themselves at the end of all construction works. However, this does not imply the absence of any effects. The results rather indicate that the (local) effects of the construction activities so far remain subordinate to the natural variability within the ecosystem. Consequently, the detection of possible effects depends primarily on detailed comparisons of impact stations versus reference stations per year and season, rather than on long term trends per station (although effects will also manifest themselves eventually in long-term analyses).

1.4.2.5. Seabirds

1. Compared to the C-Power reference area, densities of northern gannet in the concession area almost halved (± 0.63 → ± 0.38 ind./km²). Densities of common terns however strongly increased (± 0.06→ ± 0.35 ind./km²). Future monitoring will reveal if both changes can really be attributed to the presence of the wind turbines.
2. Based on a collision risk assessment, taking into account on (1) flying height, (2) estimated macro- and micro-avoidance rates and (3) the number of wind turbines encountered, the expected species-specific collision risk was estimated according to the worst case scenario. This exercise demonstrates the relatively low collision risk for species such as auks, terns and little gull (< 0.02 %), but also the more elevated collision risk for gulls, great skua and northern gannets (0.05-0.22 %).

1.5. Advices for future monitoring

1.5.1. Generalities

In general, three (possible) impacts of the construction of the first six wind turbines at the Thorntonbank were detected: a minor increase in underwater noise, the obvious introduction of hard substrate fauna into the concession area and a decrease and increase in densities of, respectively, northern gannet and common tern nearby the wind turbines.

Not detecting other impacts should be interpreted as:

1. a true absence of impact, due to
   a. no interference between the wind turbines and the environment,
   b. a negligible impact of only six wind turbines,
   c. a time-lag between wind turbine construction and environmental impact or
2. the present impossibility to demonstrate impacts, due to
   a. spatial scale issues as a result of a larger-scale monitoring programme versus potentially small(er)-scale impacts (e.g. soft substrate macro-, epibenthos and fish, seabirds, marine mammals)
   b. temporal scale issues, such as the incoherent timing of the measurements and construction activities (e.g. underwater noise, marine mammals)
   c. a limitation of the time window for possible impact detection (e.g. underwater noise, marine mammals)
   d. the current lack of appropriate measurements, due to technical constraints (e.g. hard substrate fauna, seabirds, marine mammals)

Based on the lessons learned from the monitoring exercise so far, suggestions for fine-tuning the technicalities, scientific design, focus and strategies for future monitoring are formulated. These suggestions have already partly been implemented in the monitoring programme of 2009.

1.5.2. Technicalities

1.5.2.1. Underwater noise

Although a need to fine-tune the underwater noise recording methodology was recognized, it proved very difficult to synchronize the monitoring campaigns with relevant, selected construction activities, due to repeated postponing of the construction works in the course of 2008. Adverse weather conditions make sound recordings impractical, which places additional constraints on this monitoring and calls for maximal flexibility in planning and resource mobilization.

1.5.2.2. Hard substrate fauna

1. A continuation of the monitoring of the three vertical zones, preferentially at “fixed” positions (scrape samples), is advised.
2. Next to (destructive) scrape sampling, also ROV videoing could be of use here. It is hence advised to test and evaluate ROV videoing for e.g. the search for egg deposits, engineered habitat structure and size quantification and counts of sheltering (small) fish.

1.5.2.3. Soft substrate macrobenthos

An increase in the number of sampling points will be difficult to achieve in the future, due to their close vicinity to wind turbines as the number of wind turbines increases. Other sampling strategies and techniques could be necessary in the future. Alternatively, diver-operated sampling or ROV observations may offer a solution. Careful reconsideration of monitoring locations and monitoring techniques at both the Belwind and C-Power site is therefore advised.

1.5.2.4. Soft substrate epibenthos and fish

1. During the construction activities of the six turbines it became clear that sampling epibenthos and demersal fish in their vicinity will present a challenge, since cables and other structures on the seafloor prevent the completion of the beam trawl tracks. Consequently, adaptations to the sampling strategy (mainly a shortening of the tracks) will be tested experimentally to evaluate their representativity and will then be implemented.
2. The impact monitoring of the C-Power wind farm will benefit from the establishment of a closed area within the sand extraction concession zone, so as to avoid interference with the effects of future

sand extraction and to assure a better suited reference area. Actions have been taken and approved on this matter.

1.5.2.5. Seabirds

1. Due to the prohibition to perform ship-based bird counts close to the turbines, the observed densities reflect seabird presence in the immediate surroundings of the C-Power turbines (buffer zone), rather than the occurrence in between the turbines. In terms of reliable monitoring, it is absolutely necessary that in coming years ship-based bird counts be allowed inside the complete wind farm.
2. Seabird radar research will help give a reliable measure of bird fluxes throughout the wind farm areas and thus allow a reliable assessment of the real loss of seabirds due to collision with wind turbines. These data should be supported by *in situ* visual flux counts, that will make it possible to quantify the micro-avoidance behaviour for the various species. MUMM has recently launched a call for tender for the purchase of an Automated Radar System (ARS) to investigate seabird fluxes through the wind farm areas in further detail. This ARS will first be tested onshore and subsequently be used in the wind farm area.

1.5.2.6. Marine mammals

1. Airborne surveys are an interesting tool for estimating the population of marine mammals.
2. In view of the existing technical and budgetary constraints of the current monitoring programme, the estimation of marine mammal densities should only be carried out during good observation conditions in future surveys.
3. Because a detection probability function, necessary for analysing data, could only be obtained on the basis of data gathered from a single bubble window, MUMM has taken administrative steps to equip the aircraft with a second bubble window.
4. As passive acoustic devices for the detection of harbour porpoises are considered useful for monitoring the effects of the construction and exploitation of offshore wind farms, a mooring system for Porpoise Detectors (PoDs) was developed. PoD deployment is foreseen from the beginning of 2009 onwards. The experiences in 2009 will be used to configure the optimal mooring method.

1.5.2.7. Seascape

To investigate the impact of the wind farms on the seascape, a two-step approach will be used: a landscape imagery part will aim at simulating the seascape impact and is to be used in a sociological landscape part. The pictures will be used to evaluate the people’s opinion on the seascape impact of offshore wind farms. In order to achieve these goals an inquiry will be held among people who are regularly staying at the coast side. This initiative is currently ongoing.

1.5.3. Scientific design

1.5.3.1. Underwater noise

The location of sampling stations for noise measurements should be appropriately adapted in the future, for instance to measure point sources, such as originating from pile driving activities. The variations observed between the T0 at the Thorntonbank and the T0 at the Bligh Bank (likely due to the proximity of pipelines at the former site) indicate that it is useful and necessary for underwater noise monitoring to establish T0 values for each site separately.

1.5.3.2. Hard substrate fauna

1. Attached fouling growth will attract predators, such as starfish and various crab species and a whole range of smaller less conspicuous species. How these changes will affect the general diversity of the settlement will require appropriate monitoring in the future (e.g. assisted by ROV videoing).
2. To evaluate the metapopulation dynamics one should not concentrate on only one pile, but should rather include several piles at various distances from each other (ideally combining several wind farms). Taking account of the limited resource available, within- and between-site-replicated sampling should focus on the barnacle-*Jassa* zone.

1.5.3.3. Marine mammals

1. More aerial surveys will be undertaken to obtain smaller confidence limits for abundance, density and group size estimates. Surveys will also aim at covering the whole of the Belgian waters, given that the number of transects is close to a minimum still useful for statistical analysis. This will permit the development of density surface models, revealing information on spatial and temporal variability, needed for the assessment of possible effects of the construction and operation of the offshore wind farms.
2. Complementary to the results of aerial surveys, the analysis of strandings and sightings data are useful to interpret spatial and temporal trends in the occurrence of porpoises in Belgian waters. The main advantage of such analysis is the wealth of historical data. Careful interpretation of these data is however necessary: the recent decreased number of washed ashore porpoises for instance is most probably due to the displacement of the bulk of the animals in offshore direction and should hence not be considered an indication of decreasing densities in Belgian waters.
3. The usefulness of C-Pods in monitoring marine mammal incursions in selected locations will be evaluated, together with the potential of single-array hydrophones for locating the animals.
4. The white-beaked dolphin is a very regular visitor to Belgian waters and an assessment of numbers and spatial and temporal distribution in relation to the wind farms will be useful.

1.5.4. Monitoring focus and strategies

1.5.4.1. Underwater noise

Future underwater noise monitoring activities will focus on pile driving and on those activities of which the noise characteristics are less well known and/or are expected to cause a significant increase in noise levels. Examples are the dumping of scour protection and cable laying. Measuring noise generated by a variety of types of activities will be beneficial to our knowledge in underwater noise, and was premature during the 2008 monitoring.

1.5.4.2. Hard substrate fauna

1. Monitoring response variables, such as species richness, species-specific densities and biomass, will allow the continued investigation and documentation of (1) the successional transitions, (2) the different stages along the succession gradient and (3) the gradual change of the impact of wind farms (e.g. increasing organic matter deposition close to the turbines) and as such the change within the ecosystem functioning due to the presence of the wind farm.
2. Given their possibly high nursery capacities for invertebrates, as well as (commercial) vertebrates, special attention should be given to the habitat engineering effects of species, such as the sand mason *Lanice conchilega*, *S. spinulosa*, the tall tubularia *Tubularia* spp., the hairy sea-mat *Electra* spp. and the alien *C. gigas*.
3. The combined presence of the two sibling species *Jassa herdmani* and *J. marmorata* provides a good model for the investigation of meta population dynamics, in which the extinction and colonization rates of both species at several piles may provide some first insights in the potential of wind farms to promote the spreading of (hard substrate) species with limited dispersion capacities (cf. sink-source dynamics).

4. The monitoring of the hard substrate fauna will further also include density and diversity, feeding behaviour and physiological condition of fish in the direct vicinity of the wind turbines. These fish constitute an important link between the hard substrate and the soft substrate fauna.

1.5.4.3. Soft substrate macrobenthos

1. An increase of the number of sampling locations in the area between the two C-Power concession sites is recommended as possible (large-scale) impacts of altered sediment transport are expected mainly in northeastern direction.
2. Knowledge on the possible edge effects of the colonized hard substrates on the surrounding soft sediments (including their spatial spread) would largely contribute to the understanding of possible changes within the soft substrate benthos. Therefore samples should be taken starting close to the wind turbines and at small intervals away from them. Further off, the interval can be enlarged.
3. Since wind farm sites are closed for bottom trawling fishery, the effects of cessation of this fishery on the macrobenthos should be assessed, including possible succession processes. Additionally, edge effects around the concession areas caused by a possible concentration of the fishery activities along the borders of the wind farms should be looked for.

1.5.4.4. Seabirds

1. The C-Power concession area is moderately valuable to northern gannet, common gull, lesser black-backed gull, great black-backed gull, black-legged kittiwake, common guillemot and razorbill. For the Belwind concession area those species are northern gannet, lesser black-backed gull, black-legged kittiwake and common guillemot. The C-Power concession area is of particular value to little gull, sandwich tern and common tern. For the Belwind concession area those species are great skua and little gull. Future monitoring will focus on these seabird species.
2. To better understand and predict the effects of existing and future wind farms, the migration behaviour and occurrence of the respective birds in the concession areas need to be investigated in detail. Research should also focus on displacement through avoidance behaviour, as well as migration flux and collision risk.

1.6. Future integrative approach

1.6.1. Cause-effect relationships: baseline and targeted monitoring

While the first aim of this report was to provide an overview of (1) what has been done so far, (2) what the major conclusions regarding impact detection are at this point and (3) what would be the major lessons learned for future monitoring, this part of the monitoring only represents a first step within the monitoring programme[4]. Whereas the current (baseline) monitoring design aims at an objective *a posteriori* evaluation of existing and possible resultant impacts of marine wind farms in Belgian waters, it is incapable to disentangle the processes behind an eventual impact. Since however knowledge of these processes help understanding the cause-effect relationships, an upgrade of the monitoring programme from a level of *a posteriori* phenomenon observation to a level of process understanding is needed. The ability to link environmental changes to an underlying cause-effect rationale (i.e. targeted monitoring) is not only a pre-requisite for effective regulatory application[5], but – as it provides baseline knowledge to comprehend impact processes – also permits (1) current and future impact mitigation, (2) better prediction of future impacts, as well as (3) moving away from site-specific observations to more generic knowledge.

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[4] Glasson, J., R. Therivel, A. Chadwick (2008). Introduction to environmental impact assessment. 3rd edition. Routledge, New York & Oxon. 423 pp.
[5] Rees, H.L., S.E. Boyd, M. Schratzberger, L.A. Murray (2006). Role of benthic indicators in regulating human activities at sea. *Environmental Science & Policy*, 9: 496-508.

Consequently, it is advised to feed the information taken from the baseline monitoring into the investigation of a selected set of hypothesized cause-effect relationships. Selection should here be based on the knowledge from and prioritization within the baseline monitoring and the Environmental Impact Study. Within the monitoring programme, it will hence be important to find an adequate effort and budgetary balance between baseline and targeted monitoring.

1.6.2. Evaluation of overall impact based on environmental indicators

After the quantification of the differential impacts of the construction and exploitation of marine wind farms, a next and most legitimate request would be to compare the overall impact of this anthropogenic activity with that of all the other marine activities. Such comparison would allow us to evaluate and/or scale the overall athe severeness of any anthropogenic activity. Here, environmental indicators may play an important role. These indicators generally combine several assets of the ecosystem into an integrative measure of ecosystem quality. They are considered quantitative proxies for ecosystem quality. As such, an array of well-challenged and intercalibrated indicators exists and will be used in the future to present an integrative view on the ecosystem quality change (*prior* versus *post hoc* or impact versus reference site) as a result of the construction and exploitation of marine wind farms. If the ecosystem quality change – based on environmental indicators – would be calculated for several anthropogenic activities, then a comparison of the change between the different activities would further allow us to scale the activities along an impact severity gradient.

The MUMM intention is to integrate the results of other, existing monitoring initiatives (e.g. aggregate extraction, dredging and dredged material disposal) with those from the marine wind farm monitoring initiative. This exercise would significantly contribute to an objective evaluation of the impact of the construction and exploitation of marine wind farms. The exercise will further allow to scale the magnitude of the overall impact, relative to the environmental state categories, as defined in the Water Framework Directive and to be defined in the European Marine Strategy Framework Directive.

1.6.3. Integrative monitoring: Conclusion

In conclusion, integrative monitoring is and will be narrowly intertwined with the ongoing monitoring programme. Herein, three priority items can be discerned:

1. Detailed observations of the Before-After/Control-Impact (BACI) changes of a selected set of response variables within each of the (main) ecosystem components (i.e. benthos, fish, seabirds and marine mammals) provide the knowledge necessary for impact detection and quantification (i.e. baseline monitoring). This selection should be based on the list of expected impacts as taken from the environmental impact study (EIS).
2. The information taken from the baseline monitoring should be exploited for a selected set of hypothesized cause-effect relationships in order to improve possible mitigation and prediction of (future) impacts.
3. A last priority item should cover the evaluation of the severeness of impact by (1) comparing the overall impact with those of other pressures and (2) scaling its magnitude according to the ES categories, using a suite of multimetric environmental indicators.

These items will be covered simultaneously as the information taken from both first priority items is directly fed into the third priority item.

Chapter 2. A brief introduction to offshore wind farms in the Belgian part of the North Sea

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Photo Jan Haelters / RBINS

2.1. Context

The European directive 2001/77/EG presently enforces each member state a target figure of the contribution of the production of electricity from renewable energy sources that should be achieved in 2010. For Belgium, this target figure is 6 % of the total energy consumption. Offshore wind farms in the Belgian part of the North Sea can contribute to achieve that goal.

With the Royal Decree of 17 May 2004 a zone in the Belgian part of the North Sea was assigned for the production of electricity. Since then two companies, C-Power and Belwind, were granted a permit to build and exploit a wind farm on the Thorntonbank and the Bligh Bank, respectively. C-Power will build a wind farm of 60 turbines with a total capacity of 300 MW. Belwind will start in 2009 with the construction of 110 turbines that have a total capacity of 330 MW. A third company, Eldepasco, started this year with the environmental permit procedure.

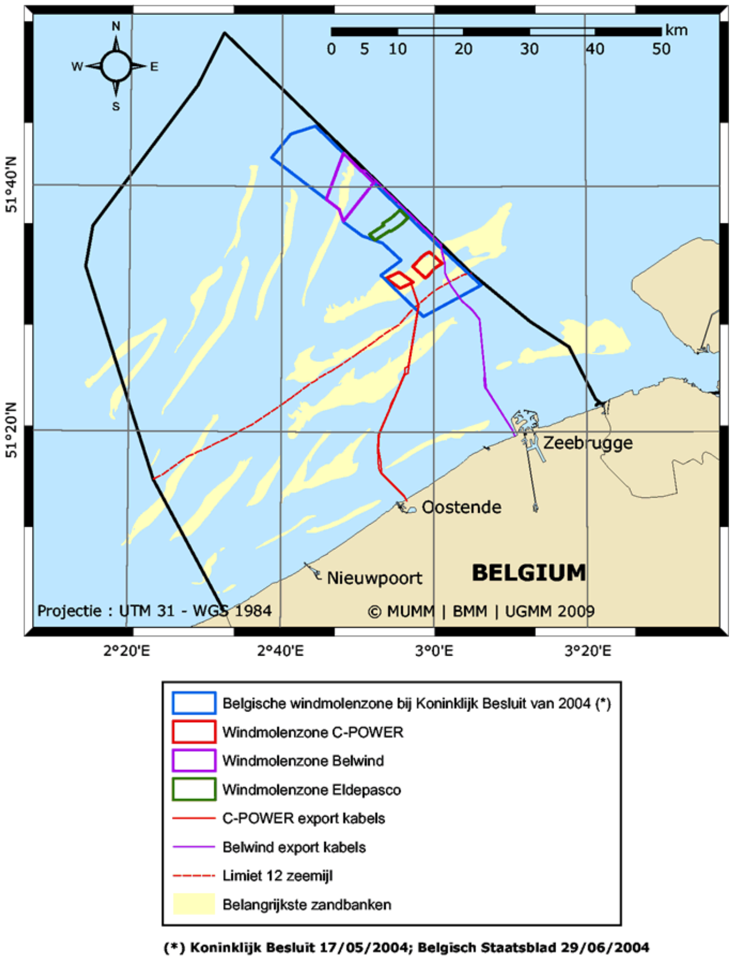

Figure 1. Zone assigned for the production of electricity by the Royal Decree of 17 May 2004.

The permit includes a monitoring programme to assess the impact of the project on the marine environment. The monitoring has two goals:

- the ability to mitigate or even halt the activities in case of extreme damage to the marine ecosystem;
- to understand the impact of offshore wind farms on the different aspects of the marine environment and consequently support the future policy regarding offshore wind farms.

2.2. Monitoring programme

The monitoring programme studies physical, biological and economical-social aspects of the marine environment. MUMM coordinates the monitoring and specifically covers underwater noise, hard substrate epifauna and fish (the latter in collaboration with Ghent University), radar detection of seabirds, marine mammals and hydrodynamics. MUMM further collaborates with different institutions to complete its expertise in the following domains: INBO (seabirds), ILVO (soft substrate epibenthos and fish), the Marine Biology Section of Ghent University (soft substrate macrobenthos), Renard Centre of Marine Geology of Ghent University (underwater noise). In some cases MUMM decided that the project developers are better placed to conduct some aspects of the monitoring.

For each of these ecosystem features, except for those related to hard substrates, the baseline situation of the Thorntonbank, alongside two reference sites, was described in 2005 (De Maersschalk *et al.*, 2006; Vanermen *et al.*, 2006; Henriet *et al.*, 2006). In 2008, the same was done for the Bligh Bank and the ecological impact assessment of the C-power project phase 1 (first six turbines) started. Furthermore, preliminary work for a landscape study and a study of flying birds with a specially designed radar system was executed.

In 2008 C-Power realized the phase I of its project, this means that 6 turbines were put in place. Because pile driving seemed to be impossible on the Thorntonbank, C-Power decided to build gravity based foundations (GBF). This is a hollow, concrete structure (Figure 2) that is filled with sand once it is placed on the seabed. Due to its weight, it remains stable. Before the GBF can be placed the seabed needs to be prepared. A foundation pit is dredged to remove the loose sand and to create a flat surface on dense sand. A foundation gravel layer (1 m) is placed in the foundation pit and then the GBF can be lowered on the exact location. The 6 GBF were set in place on the following dates: D1: 27/4; D2: 8/5; D3: 22/5; D4: 24/5; D5: 30/5 and D6: 29/5.

Figure 2. Transport of the first GBF from the port of Ostend to the Thortonbank (Photo R. Brabant/ RBINS).

After a GBF is put in place the foundation pit is backfilled with soft sediment and the GBF is filled with sand (infill). Finally, a scour protection is put around each GBF. This is a layer of stones that should prevent the erosion of the soft sediment.

In 2008, six turbines (RePower, 5MW) were placed on the GBF’s. At the time of writing, all six of them are delivering power.

2.3. References

De Maersschalk, V.; Hostens, K.; Wittoeck, J.; Cooreman, K.; Vincx, M. & Degraer S. (2006) Monitoring van de effecten van het Thornton windmolenpark op de benthische macro-invertebraten en de visfauna van zachte substraten. 136 pp.

Vanermen, N.; Stienen, E.W.M.; Courtens, W. & Van de Walle, M. (2006) Referentiestudie van de avifauna van de Thortonbank. 131 pp.

Henriet, J-P.; Versteeg, W.; Staelens, P.; Vercruysse, J. & Van Rooij D. (2006) Monitoring van het onderwatergeluid op de Thorntonbank: Referentieonderzoek van het jaar nul. 53 pp.

Chapter 3. Underwater noise emission during the phase I construction of the C-Power wind farm and baseline for the Belwind wind farm

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Photo Ward Van Roy / RBINS

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Abstract

The noise level under water was measured at the Bligh Bank before construction works started (reference level, T_0) and at the Thorntonbank during construction works (T_1). The reference underwater noise levels measured at the Bligh Bank were 95 to 100 dB (re 1µPa) between 10 Hz and 2 kHz, levels similar to those measured previously at the Thorntonbank site during similar weather conditions (wind force 2-3 Bft, sea state 1-2). Slight differences may be due to the noise generated by the Interconnector and/or Zeepipe pipelines near the Thorntonbank site (not detected during the Bligh Bank monitoring), to local characteristics in the underwater topography, to the ad hoc shipping traffic near the monitoring stations and to meteorological conditions. Levels during high and low tide did not show significant differences. Only limited effort could be spent at measuring underwater noise during the construction works at the Thorntonbank windfarm site. The levels measured were 5 to 25 dB higher than the background noise levels, similar to increases caused for instance by passing ships. However, no specific measurements related to the construction of offshore windfarms, such as cable laying or the laying of the scour protection could be measured. Future underwater noise measurements will be focused at such activities, and at pile driving. Also efforts will be made to fine-tune the technical aspects of the measurements and the analyses, and at assessing possible impacts of the noise measured.

Samenvatting

In 2008 werden onderwater-geluidsmetingen verricht op de Bligh Bank (referentiegeluid, T_0) en tijdens constructie-activiteiten op de Thorntonbank (T_1). Het referentieniveau van het geluid onder water op de Bligh Bank was 95 tot 100 dB (re 1 µPa) tussen 10 Hz en 2 kHz, een niveau gelijkaardig aan dit eerder gemeten op de Thorntonbank bij nagenoeg dezelfde weersomstandigheden (windkracht 2-3, staat van de zee 1-2). Kleine verschillen kunnen toegewezen worden aan het geluid van de Interconnector en/of Zeepipe pijpleidingen nabij de Thorntonbank (niet gedetecteerd in de metingen

op de Bligh Bank), de lokale verschillen in onderwatertopografie, het scheepvaartverkeer, en meteorologische omstandigheden. De onderwater geluidsniveaus bij hoog en laagtij vertoonden geen significante verschillen. Er konden door diverse omstandigheden slechts beperkt metingen uitgevoerd worden tijdens de constructiewerken op de Thorntonbank. De gemeten niveaus lagen 5 tot 25 dB hoger dan het achtergrond geluidsniveau, een verhoging vergelijkbaar met bijvoorbeeld voorbijvarende schepen. Tijdens specifieke constructieactiviteiten, zoals het plaatsen van de kabels of de erosiebescherming, konden echter geen metingen van het onderwatergeluid uitgevoerd worden. Toekomstige metingen zullen zich vooral richten op dergelijke activiteiten, en op het heien van palen. Daarnaast zullen inspanningen geleverd worden om technische aspecten van de metingen aan te passen, en om de mogelijke effecten van het onderwatergeluid op het ecosysteem in te schatten.

3.1. Introduction

Until recently, little attention was paid to the effects of underwater noise originating from human activities. This has changed, and human generated noise is now considered as an important form of pollution. Even if a lot of speculation still exists on the effects of increased levels of underwater noise on biota.

There has been an increasing research effort in the field of underwater noise due to the observation of negative impacts, especially on cetaceans, and due to an increasing use of sound in remote sensing methods, both in civil as in military applications, and the increasing level of offshore industrial activities in general.

As a first step towards assessing the possible effects of the underwater noise generated by the construction and exploitation of offshore wind farms in Belgian marine waters, measurements are and will be made of the level and characteristics of underwater noise before, during and after the construction activities (MUMM, 2004; MUMM, 2007, in Dutch). This monitoring report describes the results of the underwater sound and noise measurements performed in 2008 at the Thornton Bank offshore windfarm construction site (C-Power; T_1) and at the future Bligh Bank construction site (Belwind, T_0). An earlier report dealt with the underwater noise level at the Thorntonbank windpark site before the start of the construction works (Henriet *et al.*, 2006). The objective of the measurements is to qualify and quantify the physical changes in the marine environment, and to assess possible effects on biota, especially marine mammals.

3.2. Material and methods

Prior to the underwater noise measurements, a detailed measurement protocol was prepared by MUMM (Haelters *et al.*, 2008). The methodology is similar to the one used for the measurements of T_0 at the Thorntonbank site during 2005 and 2006, as described in Henriet *et al*. (2006). Below the practical implementation of the protocol as during the 2008 campaigns is described. Prior to the monitoring at the windfarm sites, the equipment was tested at MUMM's offices and in the port of Ostend.

3.2.1. Platform

As a platform for the measurements we chose small craft on which all instruments which could possibly interfere with the noise measurements can be turned off. In practice, we operated from a Rigid Inflatable Boat (RIB) which was deployed from the oceanographic vessel BELGICA. The BELGICA remained adrift at a distance of at least 2 nautical miles from the RIB during the measurements.

3.2.2. Acoustic measurement equipment

For the underwater noise measurements we used two calibrated Brüel & Kjær hydrophones type 8104, simultaneously deployed at different depths. These hydrophones are suitable for underwater noise measurements between 0.1 Hz to 80 kHz, and according to the calibration curves at frequencies of up to 120 kHz with higher measuring uncertainty. Only the results of the noise measurements of the hydrophone positioned at 15 m depth is reported. The hydrophone positioned at 10 m depth was used for making control measurements. A study of the T_0 situation at the Thornton sandbank (Henriet *et al.*, 2006) had demonstrated that the underwater noise at 10 and 15 m depth did not differ significantly.

For recording the underwater noise, we used a MARANTZ Solid State Recorder PMD671 operating with a sampling rate of 44,100 Hz. The noise was recorded in WAVE format (.wav) on Compact Flash cards of 2 GB (Sandisk Ultra II). A Brüel & Kjær Nexus 2692-0S4 amplifier between the hydrophones and the recorder allowed for correcting for the exact sensitivities of the hydrophones, and for the registration of a reference signal. The signal is amplified by the Nexus with 31.6 mV/Pa in the frequency range 10 Hz to 22.4 kHz. The Nexus generates a reference signal of 1.44 Vp (= 1 V RMS) at 159 Hz. This reference signal was recorded at each channel at the beginning and at the end of each measurement. All equipment was powered by batteries.

3.2.3. Recording position and depth

The position of the measurement platform was registered automatically at regular intervals of one or a few seconds by a GARMIN GPSMAP 60 Cx. Depth soundings were made at the beginning and at the end of each underwater noise measurement using a hand-held system (SPEEDTECH; 400 kHz). We did not make depth soundings during the measurements, given the possible interference with noise recordings.

3.2.4. Recording environmental variables

As underwater noise varies according to weather conditions, we described the environmental conditions for each of the measurements: general weather conditions, wind speed, wind direction and sea state. Environmental variables were recorded on board the BELGICA. Given the use of a RIB, campaigns were only organized if the foreseen sea state was 3 or less, and with a foreseen wind force of 3 Bft or less.

3.2.5. Registration of AIS data

Noise originating from ships constitutes an important part of the current background underwater noise level in seas and oceans. To avoid that such noise has a determining influence on our recordings, we only performed measurements for the T_0 surveys when no ships were visible in the immediate vicinity of the measurements. To assess the presence of ships in a wider surrounding during the measurements, we also inspected Automatic Identification System (AIS) data from an area of 5 nautical miles (NM) around the site where the underwater noise was measured. An AIS system on board ships sends information (such as name of the ship, type of ship, size, call sign, position, speed, heading,…) at transmission intervals ranging from 6 minutes for static ships, to 2 seconds for ships with a speed of 23 kts or more, or 14 kts or more when changing course. AIS systems are required on board of most ships, and from the 1st of July 2008 onwards on all ships larger than 300 GT. An analysis of the AIS data allows for the possible indication of interference of noise generated by ships with the background noise measurements. Given the distance of noise measurements from construction works during the T_1 monitoring, AIS data during T_1 are less important, although they were still inspected. The AIS receiver present on the roof of MUMM Ostend's offices (COMAR SLR-500) was used to register AIS data. This receiver covers the whole of Belgian waters and slightly beyond. The system records most AIS signals; some though may be lost at the furthest distance from Ostend, and during periods with a very high number of signals emitted.

3.2.6. Measurements

For each recording the RIB was put at drift at a predefined position, with the engine shut off. For each monitoring campaign (T_0, T_1, different wind farm areas), at least 3 measurements at different positions were made. The target length of each recording was around 20 minutes. Especially during construction works, the length of recordings could be lower. This is due to the fact that the monitoring platform is at drift during the measurements, and is not supposed to interfere with the vessels or platforms active at the construction site. The clock of the recorder was synchronized beforehand with the GPS-time (UTC). Specific events possibly influencing underwater noise, such as the passing of a ship or an activity at the wind farm site, were registered (place, time) and described. Unless technically not possible, hydrophones were put at depths of 10 and 15 m.

Noise at frequencies higher than 22.4 kHz cannot be measured with the equipment described here. However, propagation loss is frequency dependent; high frequency noise is attenuated more than low frequency noise (Fisher & Simmons, 1977; Thiele, 2002). At a distance of hundreds of meters to some km from the source, high frequency noise is attenuated completely, while low frequency noise can travel up to tens and even hundreds of kms.

3.2.7. Analysis of the recordings

After the transfer from the CF cards to a PC, the recorded data were processed in a similar way as described by Henriet *et al*. (2006). This includes a spectral analysis of the signal in the form of a third octave band spectrum of the underwater sound pressure level. The spectra were obtained using a routine built on the software programme MATLAB, and according to the norm IEC1260. As a general basis for the analysis, extracts of 500 s of every recording were used, while also shorter sections were chosen for analysis of specific events, such as during construction. Only a selection of the analyses is presented here.

The level of the reference signal generated by the amplifier is set at 1.44 V_p (= 1 V_{rms}) at a frequency of 159 Hz. As the signal is amplified by 31.6mVPa^{-1}, the dB value of the reference signal can be calculated as:

dB reference signal = $20 * \log(\frac{P_1}{P_{refwater}})$ in which:

$$P_1 = \frac{1V}{31.6mV / Pa} = 31.646Pa \text{ and } P_{refwater} = 1\mu Pa$$

which results in a value of 150 dB for the reference signal.

3.3. Underwater noise measurements at the Thornton Bank site

3.3.1. Overview of measurements

In the framework of the monitoring of the effects of the construction and exploitation of the offshore windfarm at the Thornton Bank, measurements were made of the underwater noise during the construction phase (T_1). These activities are very diverse and involve various types of vessels, dredgers, jacked-up pontoons and other workboats. An activity potentially generating a high level of underwater noise is the laying of the scour protection around the windmill foundations. Although the aim was to organize a campaign during that activity, this was not possible in 2008 due to the rapidly changing planning of this activity, and the limited availability of the BELGICA or alternative research platforms. Measurements during this activity are planned in 2009.

During 2008, the following campaigns were organized:

- BELGICA campaign 2008/16, 4 July 2008
- BELGICA campaign 2008/20, 10 September 2008.

Other campaigns were planned but could not take place due to technical problems or adverse meteorological conditions. In order to assess the possibility of additional noise produced by other shipping activities in and near the windfarm zone, the AIS data collected in a zone with a radius of 5 NM around the position of the D3 foundation were investigated.

3.3.1.1. 4 July 2008

The activities on site on 4 July 2008 were limited (figure 1). At foundation D3 pontoon PAULINE was present, next to two towing vessels: VIKING and AMSTELSTROOM. A platform was moored next to foundation D5. The AIS data revealed the presence of MSC RHONE and the JACOB MEINDERT in the vicinity of the windfarm zone.

Figure 1. On site at the Thorntonbank on 4 July 2008 (Photo: MUMM / RBINS).

Two underwater noise recordings of approximately 10 minutes were made, and one of approximately 20 minutes (table 1). The track of the RIB during and between the recordings is presented in figure 2. The wind was blowing from a south-westerly direction with a force of 3 to 4 Bft; the sea state was 2.

Table 1
Underwater noise recordings made on 4 July 2008 (BELGICA campaign 2008/16); time in UTC

File name	Start	End	Wind speed (Bft)	Wind direction	Sea state
Tho_01.wav	6:38:11	6:48:25	3-4	SW	2
Tho_03.wav	6:58:46	7:11:50	3-4	SW	2
Tho_04.wav	7:20:42	7:42:44	3-4	SW	2

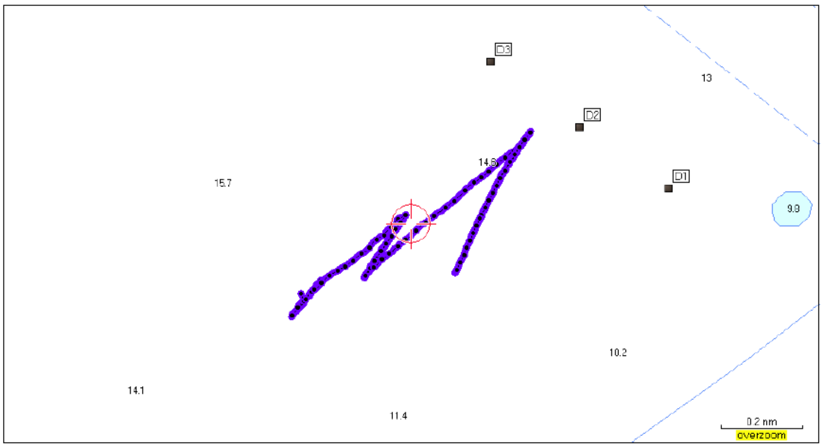

Figure 2. Track of the RIB during and between the underwater noise recordings on 4 July; the position of the foundations D1 to D3 is indicated on the map.

3.3.1.2. 10 September 2008

On 10 September 2008 BARGE 28 (cable work) was present close to foundation D1, as well as the NEPTUNE MARINER. An image of the activities the day before is given for illustration in figure 3. Besides these two vessels, the AIS data indicated the presence of the vessels MTS VAILANT, CLEMENTINE, SEA CRUISER 1 and (evidently) BNS BELGICA in or around the windfarm concession area.

Figure 3. Image of the activity at the Thorntonbank windfarm site on 9 September 2008, showing the cable barge which was also present on 10 September, when underwater noise measurements were made (photo MUMM / RBINS).

Measurements were made simultaneously under water (by MUMM) and above water (by C-Power), but this report only concerns these under water. Table 2 provides the basic information of the measurements; the track of the RIB during and between the recordings is presented in figure 4.

Table 2
Noise measurements made on 10 September 2008 (BELGICA campaign 2008/20) under water (UW) and above water (ATM), time in UTC

File name UW	Start UW	Start ATM	End UW	End ATM	Wind speed (Bft)	Wind direction	Sea state
Tho_05.wav	10:22:00	10:34:30	10:46:00	10:55:00	2-3	SW	1-2
Tho_06.wav	11:07:00	11:08:00	11:28:00	11:28:00	2-3	SW	1-2
Tho_07.wav	11:38:00	11:39:00	11:58:00	11:58:00	2-3	SW	1-2

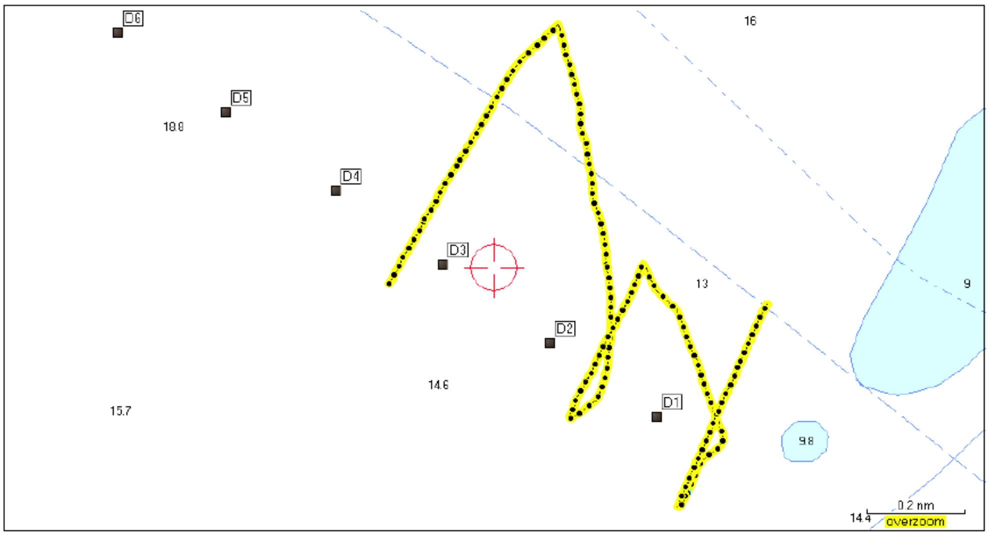

Figure 4. Track of the RIB during and between the underwater noise recordings on 10 September; the position of the foundations D1 to D6 is indicated on the map.

3.3.2. Results of the underwater noise measurements

In this section the raw data are presented together with the analyses. Figures 5 to 7 present a screenshot of the raw data of representative recordings made on 4 July and 10 September. The reference signal can be seen as a bar at the beginning and end of each recording. A rapid visual examination of these records indicates a relatively weak background noise level and discrete events with higher noise levels that can be attributed to the construction activities.

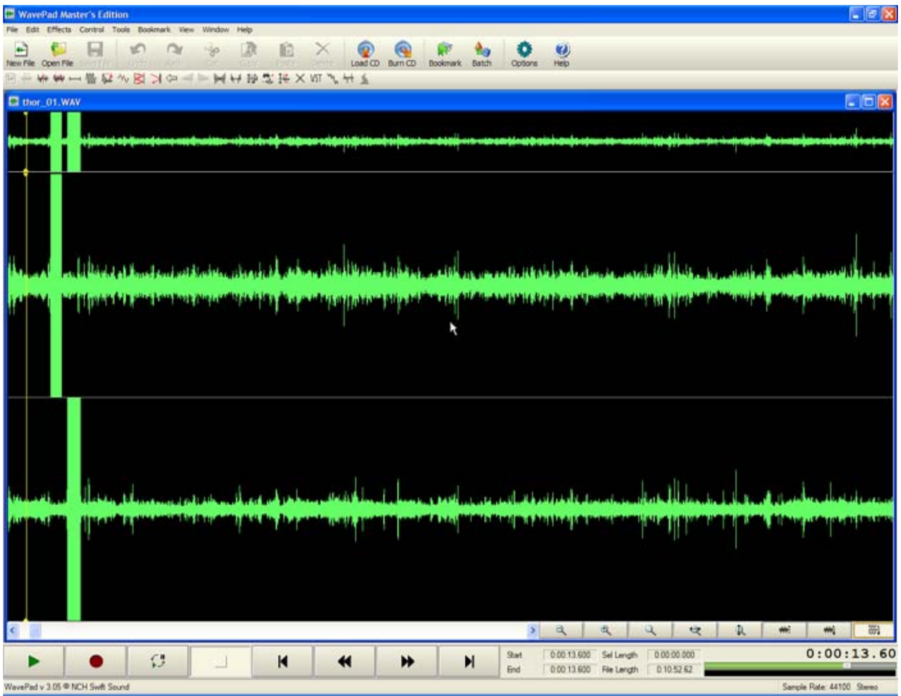

Figure 5. Raw data file Thor_01.wav, 4 July 2008. Middle graph: underwater noise level, upper hydrophone; lower graph: underwater noise level, lower hydrophone; the top graph is the sum of the two other graphs.

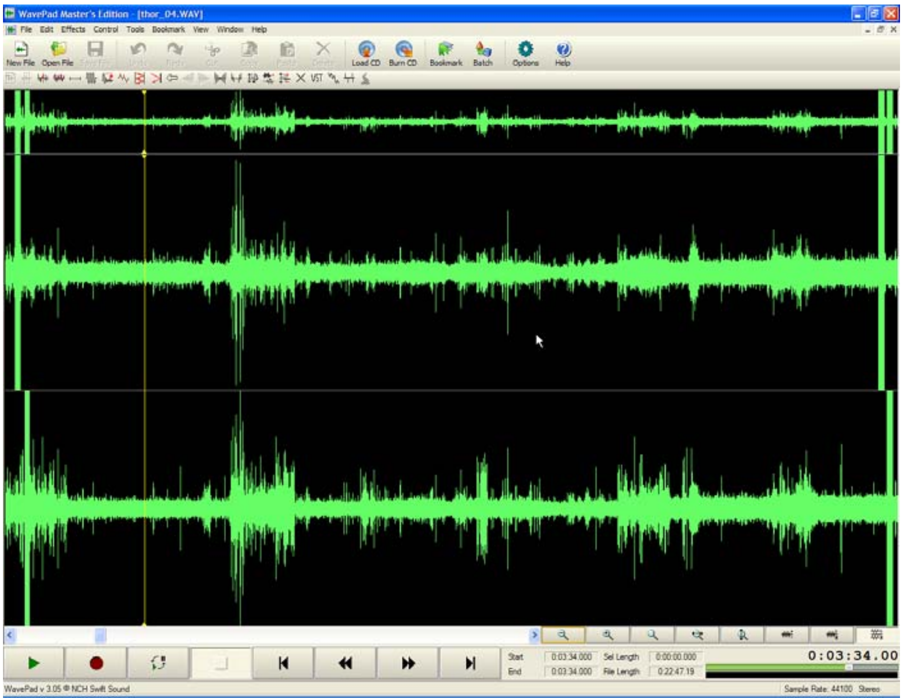

Figure 6. Raw data file Thor_04.wav, 4 July 2008. Middle graph: underwater noise level, upper hydrophone; lower graph: underwater noise level, lower hydrophone; the top graph is the sum of the two other graphs.

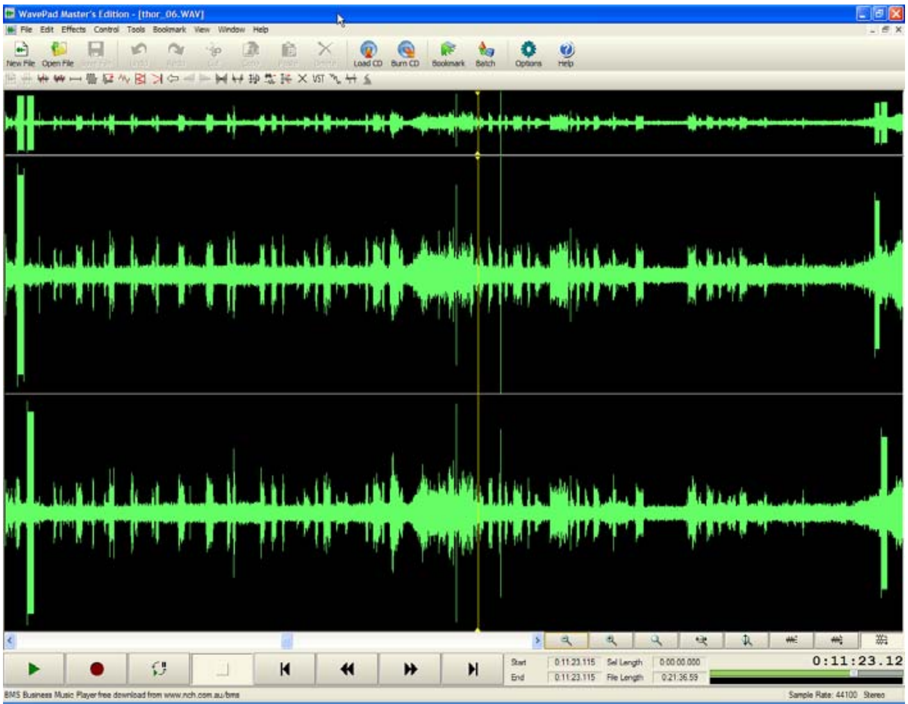

Figure 7. Raw data file Thor_06.wav, 10 September 2008. Middle graph: underwater noise level, upper hydrophone; lower graph: underwater noise level, lower hydrophone; the top graph is the sum of the two other graphs.

A number of spectral analyses are presented in figures 8 to 13. They indicate underwater noise levels (received levels) as measured – no effort was made to try to estimate the noise level at the source, given the relatively low increases in underwater noise. The measured noise level never exceeded the 150 dB reference level. A peak in underwater noise is observed below 1 kHz, as usual with noise generated by larger ships (OSPAR, 2009).

Figures 8 and 9 present the noise levels and the spectral analysis of a 500s segment of the second recording taken on 10 September 2008. Figure 9 indicates slightly higher underwater noise levels between 60 Hz and 2 kHz compared to the background noise levels measured by Henriet *et al.* (2006) (see figure 14).

Figure 10 is a section of 1.5 seconds of a recording made on 4 July (after 359 seconds into file Thor_04), and displays noise generated at the construction site. From the AIS record it appears that no other vessels were in the vicinity. The analysis (figure 11) indicates a noise level of nearly 120 dB (re 1µPa) at frequencies between 100 Hz and 2 kHz.

Figures 12 and 13 display a section of 11 seconds of a recording made on 10 September 2008 (after 290 seconds into the file Thor_06). The activity recorded is a maneuver of a tugboat and a barge in the vicinity of foundation D1. The spectral analysis indicates an amplitude of 110 to 115 dB between 50 Hz and 1 kHz. During this measurement, a merchant ship was present at around 5 NM from the measurement site, as indicated by the AIS data.

Slight differences were identified between the recorded signals of hydrophone 1 and 2. This can be attributed to the complex sound propagation in this shallow area, with the presence of an irregular underwater topography. While it is known that the stratification of water masses can be responsible for such differences, no stratification occurs in this part of the North Sea. This was confirmed by data obtained with a CTD probe (measurement of temperature and salinity at different depths).

In comparison to the T_0 situation presented in the report prepared by Henriet *et al.* (2006) (example presented in figure 14), our measurements reveal a slightly higher underwater noise level, with peaks that can be attributed to the activities of the vessels. At frequencies higher than 2 to 5 kHz, the signal is similar to the T_0 situation.

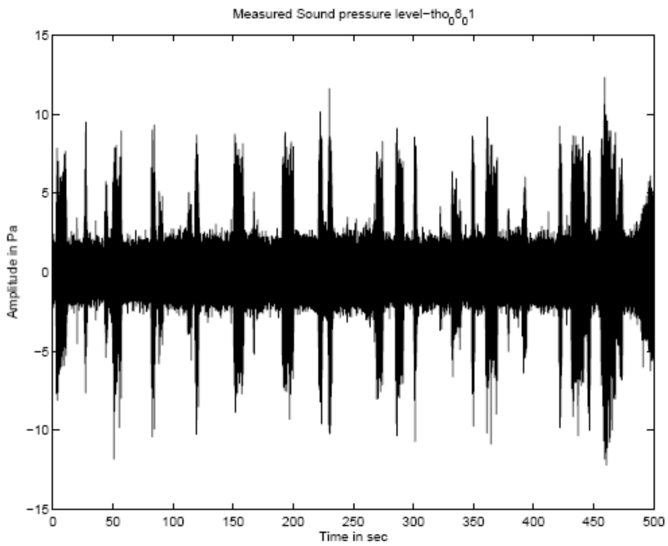

Figure 8. Amplitude (SPL – Sound Pressure Level) of a section of 500 s from the recording Tho_06_01 made on 10 September 2008.

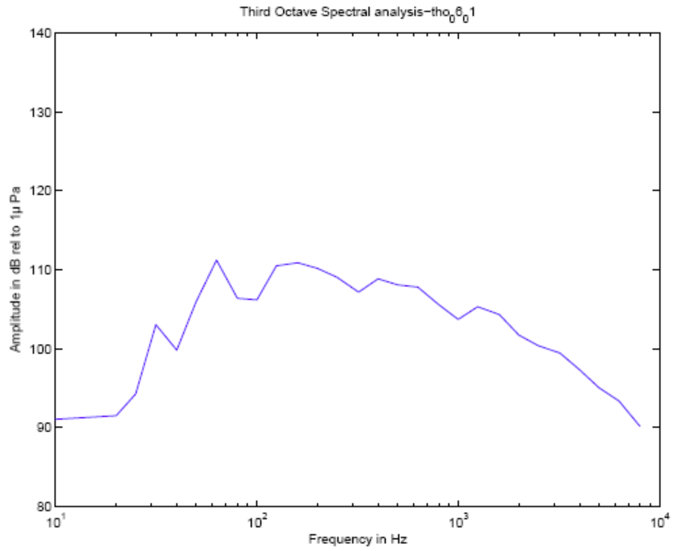

Figure 9. 1/3 Octave spectrum of the section of 500s from the recording Tho_06_01 made on 10 September 2008 (see figure 8).

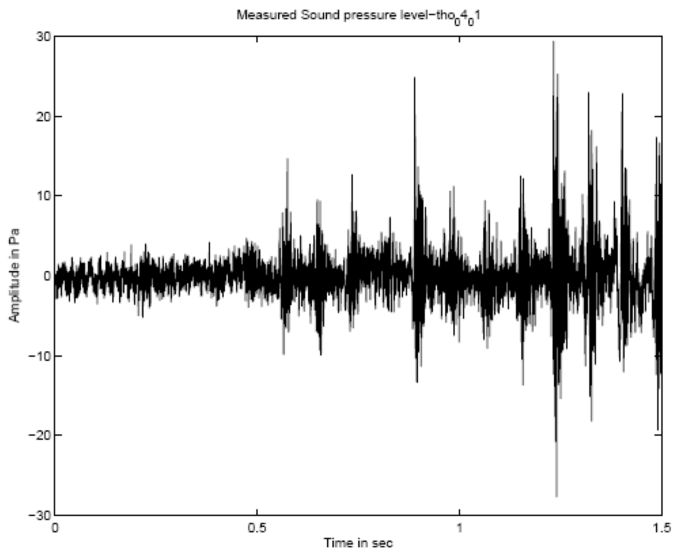

Figure 10. Amplitude (SPL – Sound Pressure Level) of a section of 1.5 seconds from the recording Tho_04_01 made on 4 July 2008.

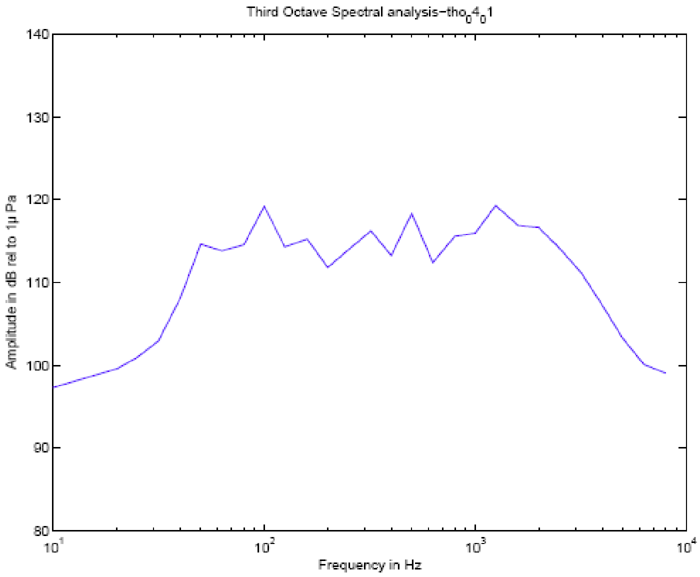

Figure 11. 1/3 Octave spectrum of the section of 1.5 seconds from the recording Tho_04_01 made on 4 July 2008 (see figure 10).

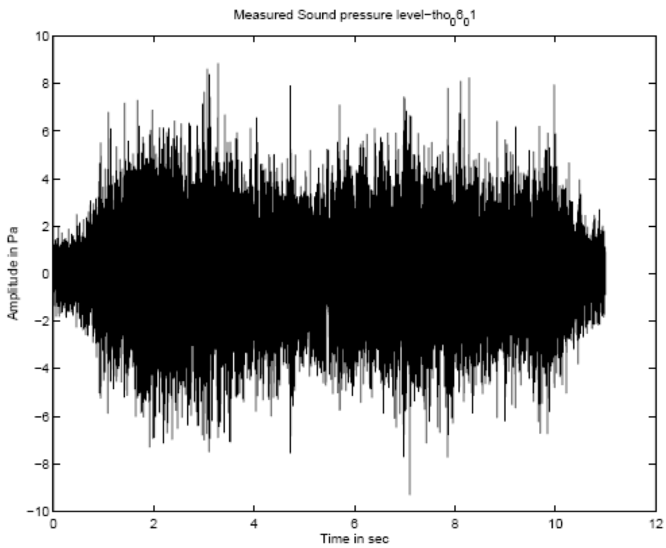

Figure 12. Amplitude (SPL – Sound Pressure Level) of a section of 11 seconds from the recording Tho_06_01 made on 10 September 2008.

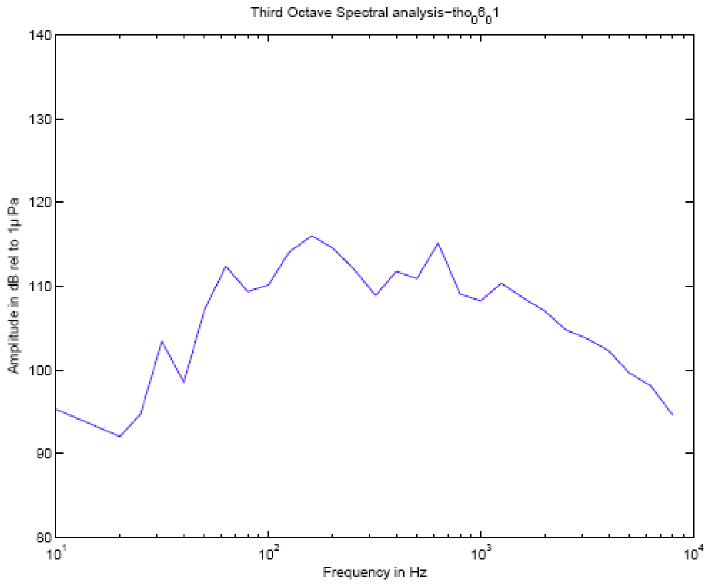

Figure 13. 1/3 Octave spectrum of the section of 11 seconds from the recording Tho_06_01 made on 10 September 2008 (see figure 12).

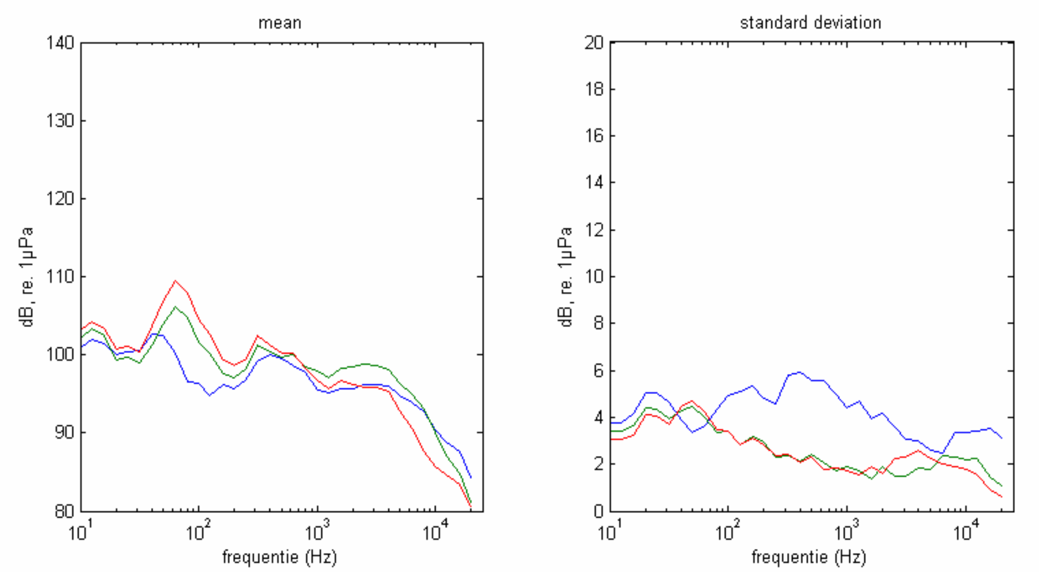

Figure 14. Left graph: example of the background underwater noise level at the Thorntonbank site, as measured by Henriet et al. (2006) using similar equipment as the equipment used during the monitoring described here, and in similar weather conditions. Three hydrophones were used at different depths: 1.5 m (blue), 8.5 m (green), and 16.5 m (red). Standard deviations are presented in the right graph.

3.4. Underwater noise measurements at the Blighbank site

3.4.1. Overview of measurements

In the framework of the monitoring of the effects of the construction and exploitation of offshore windfarms on the Blighbank, measurements were made of the underwater sound/noise level at this location before the start of the construction works (T_0). Underwater noise recordings were made at three locations within the future windpark area. In order to identify variations in the underwater noise levels due to water depth and current, recordings were made at low and at high tide in similar meteorological conditions.

Table 3 presents an overview of the measurements that were made on site on 3 July 2008, and includes the most relevant meteorological conditions. Measurements 1 to 3 and 7 were made at low tide, measurements 4 to 6 at high tide. Figure 15 presents the track of the survey platform (RIB) during and between the noise measurements. Noise measurement 7 (TEST_BEL, table 3) was made with the BELGICA approaching the measurement platform from approximately 1.5 NM to 0.1 NM.

Table 3
Underwater noise measurements made during the BELGICA campaign 2008/16 at the Blighbank. Time in UTC; 3 July 2008

File name	Position name	Start	End	Wind speed (Bft)	Wind direction	Sea state
BLI_01	BW-EAST	6:40:35	7:01:44	3-4	SW	1-2
BLI_02	BW-IN	7:24:35	7:45:12	3-4	SW	1-2
BLI_03	BW-WEST	8:02:15	8:23:01	3-4	SW	1-2
BLI04	BW-WEST	12:17:55	12:39:21	3	SW	1-2
BLI_05	BW-IN	12:51:59	13:12:47	3	SW	1-2
BLI_06	BW-EAST	13:27:09	13:47:40	3	SW	1-2
TEST_BEL	-	8:31:00	8:43:00	3-4	SW	1-2

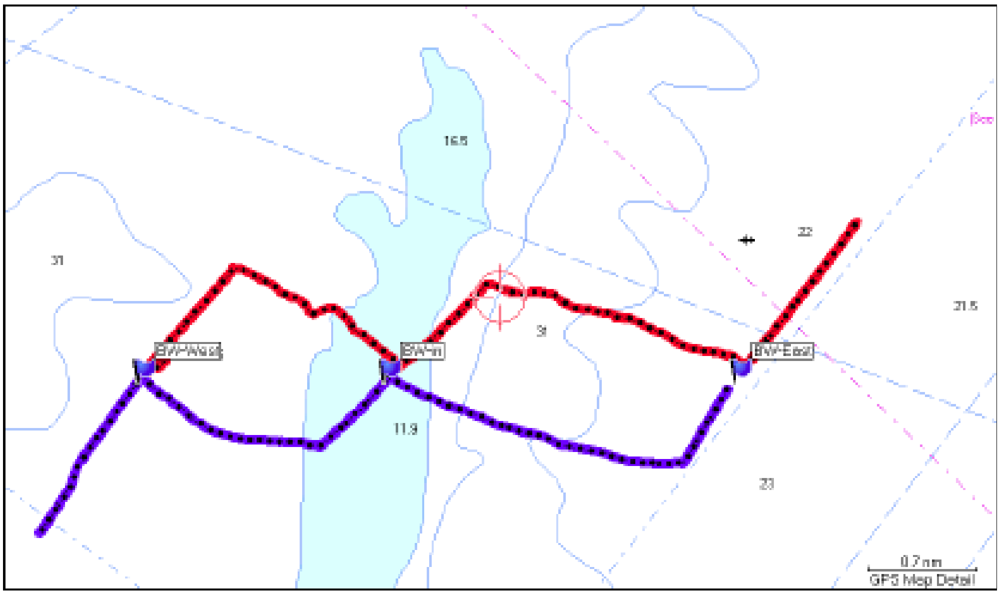

Figure 15. Track of the RIB during and between the noise measurements on the Bligh Bank on 3 July 2008. Blue lines correspond to measurements (files) 1 to 3, the red lines indicate measurements (files) 4 to 6.

In order to take noise produced in the zone by other maritime activity into account, Marine Automatic ID System (AIS) data were collected in a circle of 5 NM radius centered on the construction zone.

The presence of the following vessels was identified in the AIS data: INTERBALLAST I, ABEL TASMAN, UNION DIAMOND, CELANDINE, VLAANDEREN XXI, HYDRA and ARCO HUMBER. The latter vessel was present in the vicinity from 08:05h to 8:50h at a distance ranging from 5.5 NM to a minimum of 2 NM at 08:18h.

3.4.2. Results of the underwater noise measurements

Figures 16 to 18 present screen shots of the raw data of three of the measurements. The reference signal can be seen as a bar at the beginning and the end of each recording.

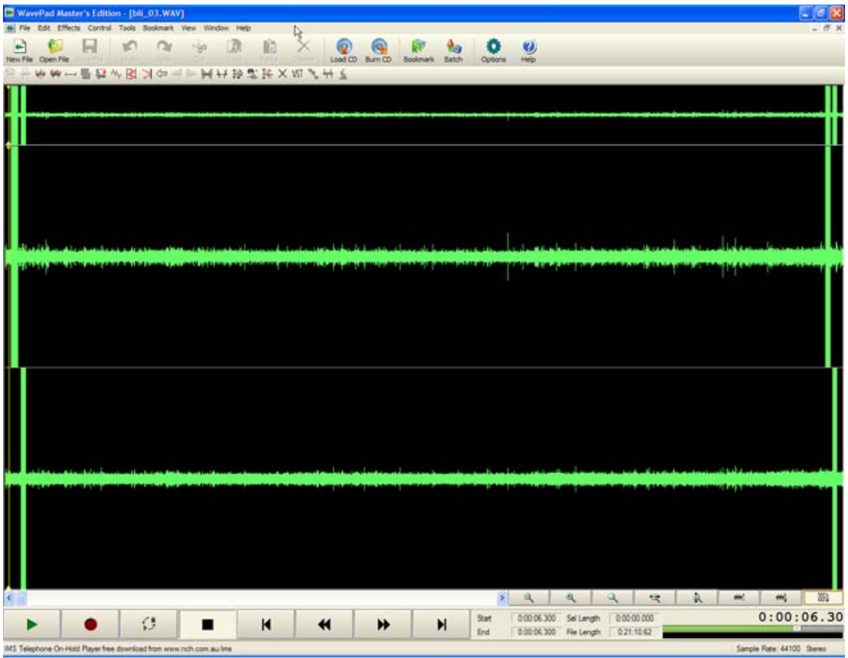

Figure 16. Raw data file Bli_03.wav, 3 July 2008. Middle graph: underwater noise level, upper hydrophone; lower graph: underwater noise level, lower hydrophone; the top graph is the sum of the two other graphs.

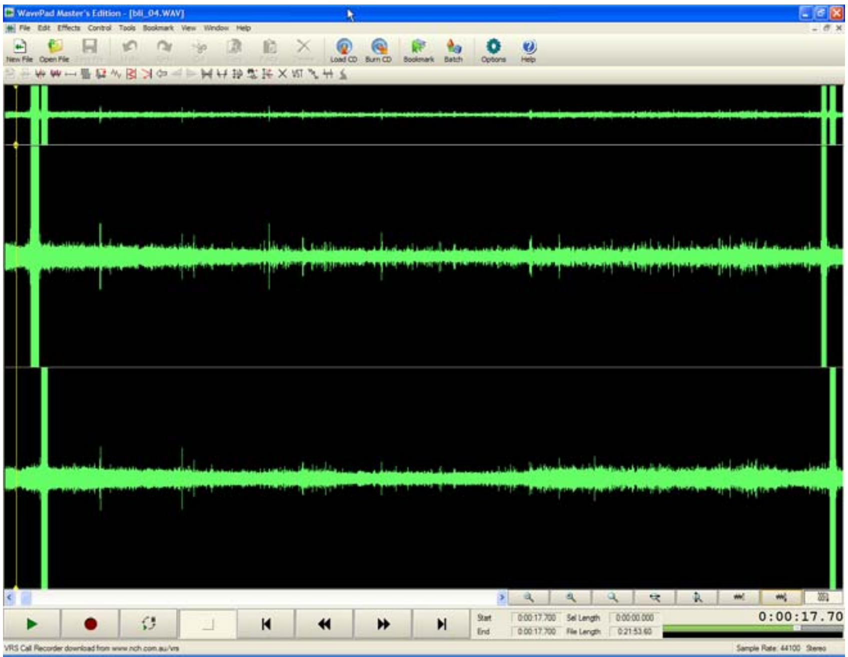

Figure 17. Raw data file Bli_04.wav, 3 July 2008. Middle graph: underwater noise level, upper hydrophone; lower graph: underwater noise level, lower hydrophone; the top graph is the sum of the two other graphs.

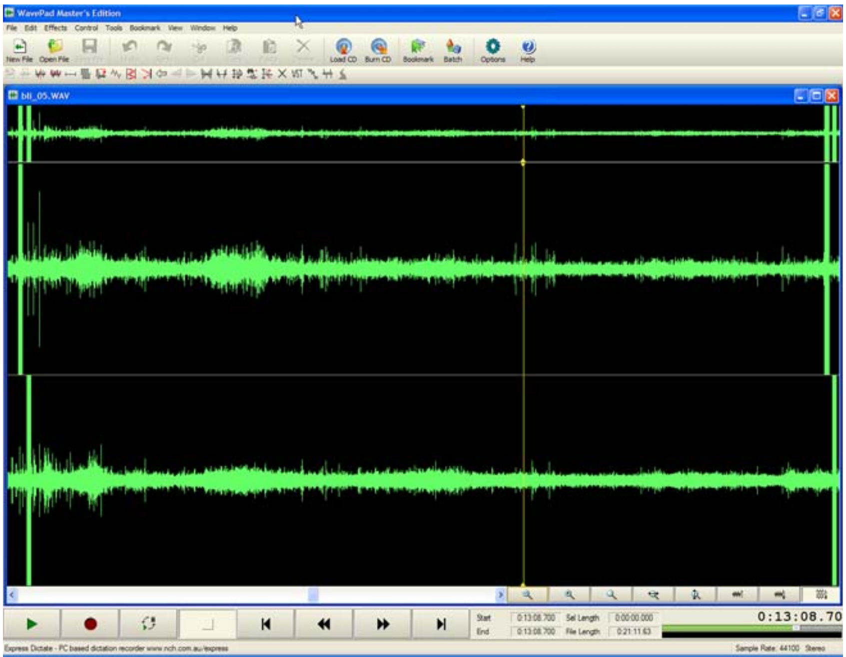

Figure 18. Raw data file Bli_05.wav, 3 July 2008. Middle graph: underwater noise level, upper hydrophone; lower graph: underwater noise level, lower hydrophone; the top graph is the sum of the two other graphs.

No difference was observed between noise levels recorded at low (figure 16) and high (figure 17 and 18) tide. The recorded background level is lower than the level recorded during the construction works at the Thornton Bank, although it still contains noise originating from shipping.

Figures 19 to 22 show the amplitude of the noise in the selected time intervals, and the respective results of the spectral analyses. They show slight variations, probably due to the irregular noise generated by distant shipping. Figure 20, presenting an analysis of a 500s segment of the record Bli_03_01 (figure 19), shows an amplitude of approximately 95 dB between 10 Hz and 2 kHz, without clear peaks.

In figure 22, a peak can be distinguished at 100 Hz. It can be attributed to propulsion/machinery noise. The range of noise produced by ships can be situated predominantly between 10 Hz to 30 kHz; peaks in noise are usually observed at frequencies below 1 kHz (OSPAR, 2009).The AIS data at that moment indicate the presence of two vessels at a distance of approximately 5 NM: the VLAANDEREN XXI and the CELANDINE.

Similar to the measurements with the CTD probe at the Thornton Bank, no water stratification, potentially affecting sound propagation, could be demonstrated. Small differences observed between the two hydrophones could be due to the topography.

In comparison to the T_0 situation at the Thorntonbank, presented in the report prepared by Henriet *et al.* (2006) (example presented in figure 14), our measurements reveal a similar level, although a peak at 1 kHz is not always present in the recordings at the Bligh Bank.

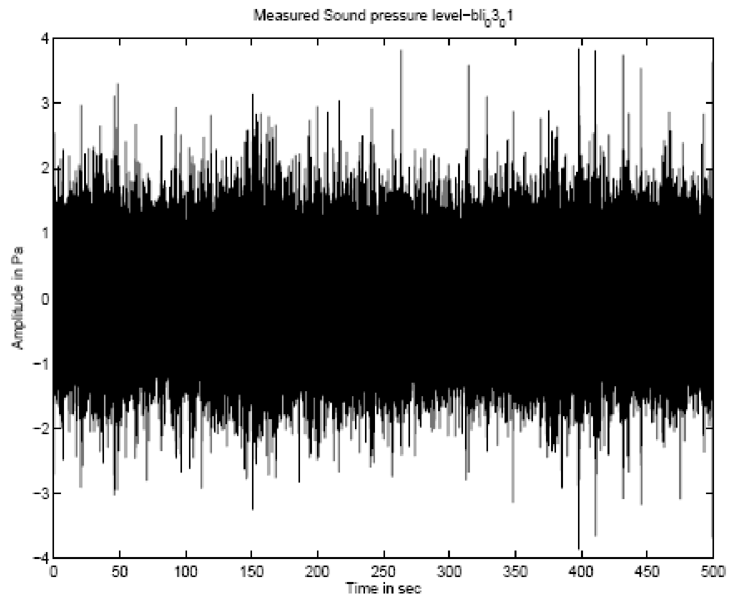

Figure 19. Amplitude (SPL – Sound Pressure Level) of a section of 500 s from the recording Bli_03_01 made on 3 July 2008.

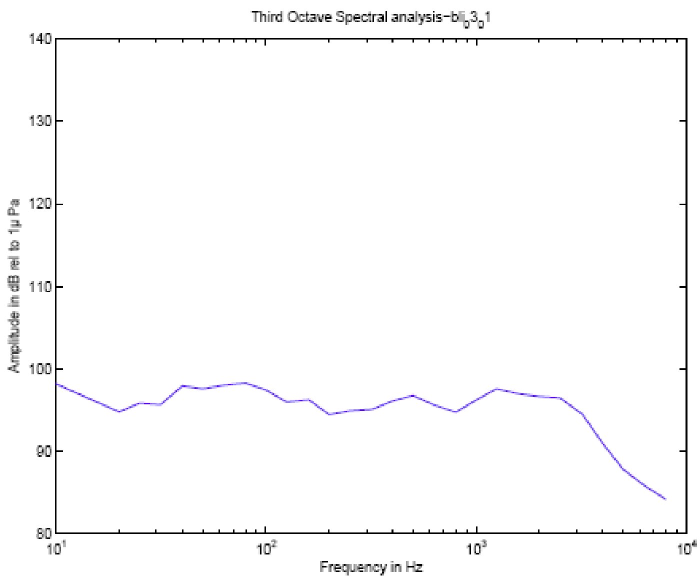

Figure 20. 1/3 Octave spectrum of a section of 500 s from the recording Bli_03_01 made on 3 July 2008 (see figure 19)

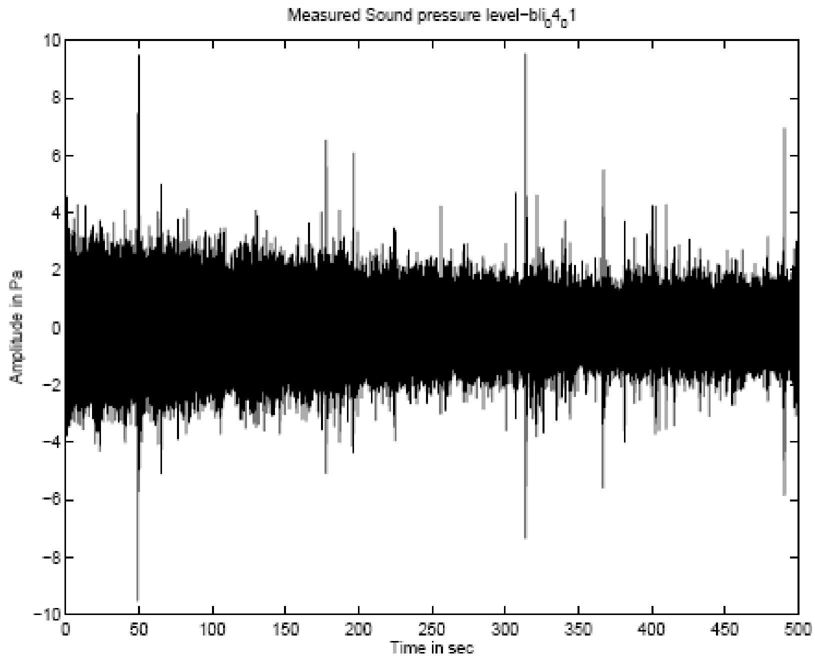

Figure 21. Amplitude (SPL – Sound Pressure Level) of a section of 500 s from the recording Bli_04_01 made on 3 July 2008.

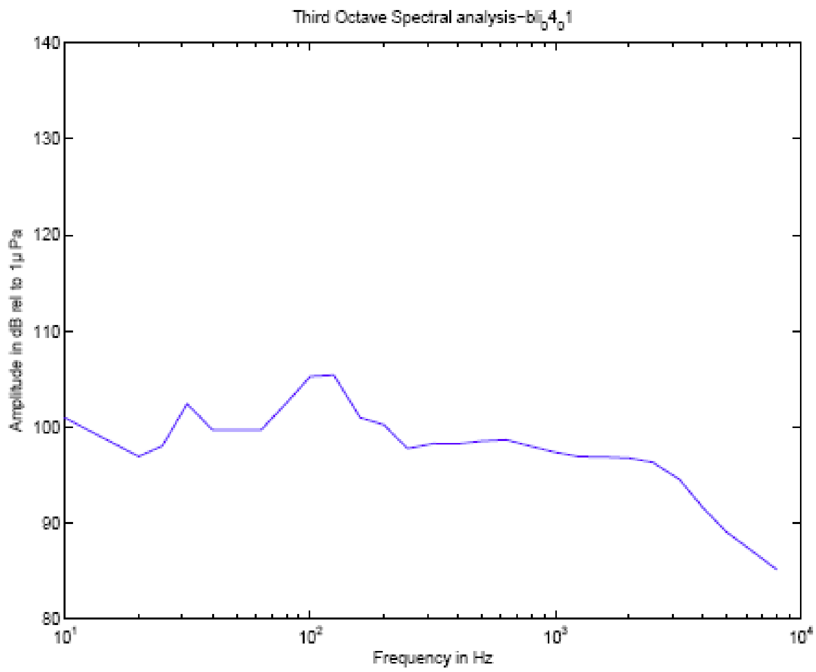

Figure 22. 1/3 Octave spectrum of a section of 500 s from the recording Bli_04_01 made on 3 July 2008 (see figure 21).

3.5. Discussion

3.5.1. Underwater noise levels (T_1) at the Thornton Bank

The recorded average sound pressure level at 50 Hz to 3 kHz is 5 to 25 dB (re 1µPa) higher than the noise levels recorded at T_0 during similar meteorological conditions (Henriet *et al*., 2006). The increase in noise level is relatively minor, and is consistent with the noise levels generated by normal ship traffic.

3.5.2. Underwater noise levels (T_0) at the Bligh Bank

The results of the measurements of T_0 at the Bligh Bank windfarm area indicate that the average background sound pressure level in that environment lies around 95 to 100 dB (re 1µPa) between 10 Hz to 2 kHz during weather conditions with wind speeds of 2 to 3 Bft and a sea state of 1 to 2. Noise levels during high and low tide did not differ significantly. Some of the recordings indicate the distant presence of ships. These underwater noise levels can be considered as the background noise level (T_0) in this area. Future underwater noise measurements during the construction and exploitation of the windfarm should be put against those values.

The results concur with the T_0 measurements performed during 2005 and 2006 at the Thornton Bank windfarm area (figure 14). A difference is that additional background noise at the Thorntonbank site, possibly originating from the Interconnector and/or Zeepipe pipelines, apparently did not show up in the measurements at the more distant and deeper location of the Bligh Bank site. It would be useful to characterize the underwater noise possibly generated by the Interconnector and/or Zeepipe pipelines.

During the limited number of underwater noise recordings, the additional noise originating from the construction activities at the Thornton Bank site, about 15 km away, apparently only contributed for a minor part to the background noise at the Bligh Bank, and this additional noise could not be discriminated from background noise and distant shipping noise.

3.6. Conclusions

3.6.1. Underwater noise levels at the Thornton Bank during construction works

The increase in underwater noise levels recorded during the monitoring campaigns in 2008 was minor, and can be compared to general shipping noise, as temporarily present over a large part of the Belgian marine waters, and especially near ports and shipping lanes. Future underwater noise monitoring activities will focus on those activities of which the noise characteristics are less well known and/or are suspected to cause significant increases in underwater noise levels. Examples are the dumping of scour protection and cable laying. Measuring noise generated by a variety of types of activities will be beneficial to our knowledge in underwater noise.

Besides the need to fine-tune the recording methodology, it proved very difficult to synchronize the monitoring campaigns with relevant, selected construction activities, due to repeated postponing of the construction works in the course of 2008. The fact that adverse weather conditions make underwater noise recordings not feasible with our current setup, places additional constraints on this monitoring, and calls for a maximal flexibility in planning and resource mobilization.

3.6.2. Background underwater noise level at the Bligh Bank

The background underwater noise level recorded at the Bligh Bank area was similar to the background noise level recorded at the Thornton Bank site. Differences can be linked to slight differences in weather conditions at the time of the monitoring campaigns, differences in the site itself, differences linked to the season and water temperatures, differences in human-generated noise during the respective campaigns (e.g. shipping) and to a combination thereof. Also the larger distance to the noise-generating gas pipelines, which run through the Thornton Bank, can have an influence. The level measured should be used as the background level for future monitoring of underwater noise during the construction and the operational phases of the windfarm project. The location of monitoring stations should be appropriately adapted in the future, for instance to measure point sources, such as originating from pile driving activities.

The variations observed between the T_0 at the Thornton Bank and the T_0 at the Bligh Bank, likely due to the proximity of pipelines at the former site, indicate that it is useful and necessary for underwater noise monitoring to establish T_0 values for each site separately.

3.7. Acknowledgements

Contributors to this report, and persons technically assisting during the monitoring campaigns, were Dietrich Vantuyckom, Jean-Pierre Deblauwe, Robin Brabant, Thierry Jacques, Joan Backers, Isabelle Noirot, Reinhilde Van den Branden and the crew of the BELGICA.

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Chapter 4. Early colonisation of a concrete offshore windmill foundation by marine biofouling on the Thornton Bank (southern North Sea)

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Photo Alain Norro / RBINS

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Abstract

During late spring of 2008 the first 6 windmills of the C-Power windmill park were built on the Thorntonbank, some 30 km off the Belgian coast. Within the coming years, more windmills will be implanted in various windmill parks in a designated area of the Belgian part of the North Sea (BPNS). With the construction of windmills, a new habitat of artificial hard substrate is being introduced in a region mostly characterized by sandy sediments. This will increase the habitat heterogeneity of the region and the effect of the introduction of these hard substrates – the so-called reef effect – is regarded as the most important change of the original marine environment caused by the construction of windmill farms. A monitoring programme was set up to sample the biofouling on the new hard substrates associated with the windmills. At the moment of sampling, only the sub- and intertidal parts of the turbine foundations, made of concrete, were available for colonisation as the scour protection was not yet fully deployed yet. Six semi-quantitative samples for epibiota were collected in the autumn of 2008. The subtidal samples were taken by scuba divers at four different depths all along the foundation of one of the windmills and a vertical video transect was made. Samples were taken by scraping the fouling organisms from a sampling surface area of 6.3 dm². The scraped material was collected in plastic bags that were sealed and transported to the laboratory for processing. After preservation of the sample, the organisms were indentified and an estimate of their density was made. After about 3½ months, the submersed part of the foundation was already totally and heavily colonised by epibionts and also the intertidal zone was almost completely covered. A clear depth zonation could be observed. A species list was compiled listing 49 species: 1 Protoctista, 4 algae and 44 invertebrates. The vegetation was restricted to the intertidal zone and rather sparsely developed. Only four species of mainly filamentous algae were present: *Blidingia minima*, *Ulva intestinalis*, *U. compressa* and *Bangia fuscopurpurea*. A total of 44 invertebrate species was identified in the samples. However, only a few species were really abundant. The most numerous (> 1000 ind/m²) or abundant species were the giant midge *Telmatogeton japonicus*, the amphipod *Jassa herdmani*, the barnacle *Balanus perforatus* and the bryozoan *Electra pilosa*. All other species were far less abundant with the exception of *Phtysica marina*, the only caprellid present (100-1000 ind/m²). Taking into account the short (i.e. 4-6 months) period of time available for colonisation of the foundation, the number of 49 spp. is considered high compared to other hard substrata in the Belgian part of the North Sea (BPNS) and included several uncommon species for the Belgian fauna. Four non-indigenous species were found: the slipper limpet *Crepidula fornicata*, the New Zealand barnacle *Elminius modestus*, the giant barnacle *Megabalanus coccopoma* and the giant midge *Telmatogeton japonicus*. All four species, already known from the area, are opportunists and early colonisers after disturbance, taking advantage of man-made structures and disturbed conditions to settle

Samenvatting

Op de Thorntonbank, ongeveer 30 km uit de België kust, werden in de late lente van 2008 de eerst 6 windmolens van het C-Power windmolenpark gebouwd. Tijdens de komende jaren zullen er, in de daarvoor speciaal voorziene zone in het Belgische deel van de Noordzee (BDNZ), nog meer windmolens gebouwd worden in verschillende windmolenparken. Met de bouw van windmolens wordt een nieuw habitat van artificiële harde substraten gecreëerd in een gebied waar voornamelijk zandige sedimenten voorkomen. Daardoor zal de habitat heterogeniteit van het gebied verhogen. De introductie van harde substraten - het zogenaamde reef effect - wordt beschouwd als de belangrijkste verandering die de oprichting van windmolenparken in het oorspronkelijke mariene milieu zal veroorzaken. Een monitoringprogramma werd uitgewerkt om de aangroei van organismen op de nieuwe harde substraten geassocieerd met de windmolens op te volgen en te bemonsteren. Op het moment van de staalnames waren alleen de intertidale en subtidale delen van de betonnen funderingen beschikbaar om stalen te nemen, want de erosiebescherming was nog niet volledig aangelegd. In de herfst van 2008 werden zes semikwantitatieve epibiota stalen genomen op een van de funderingen. De subtidale stalen werden genomen door scuba duikers die op vier verschillende dieptes langs de fundering bemonsterden. Daarnaast werd ook een videotransectopname gemaakt. Tijdens de staalnames werd een oppervlakte van 6.3 dm² afgeschraapt. Het afgeschraapte materiaal werd in een afsluitbare plastiek zak verzameld en overgebracht naar het laboratorium voor verdere verwerking. Na conservering van het staal werden de aanwezige organismen geïdentificeerd en hun dichtheden geschat. Na ongeveer 3½ maand bleek het subtidale deel van de fundering al volledig bedekt met een dichte begroeiing van epibionten en dat was ook het geval voor de intertidale zone. Er was een duidelijke dieptezonering waar te nemen. De soortenlijst bevatte 49 soorten: 1 Protoctista, 4 wieren en 44 ongewervelden. De algengroei beperkte zich tot de intertidale zone en was matig ontwikkeld. Ze bestond uit slechts 4, hoofdzakelijk filamenteuze, algen: *Blidingia minima, Ulva intestinalis, U. compressa* en *Bangia fuscopurpurea*. In totaal werden in de stalen 44 invertebraten geïdentificeerd, maar slechts een beperkt aantal soorten was echt talrijk. De algemeenste (> 1000 ind/m²) waren de chioronomide *Telmatogeton japonicus*, het vlokreeftje *Jassa herdmani*, het vulkaantje *Balanus perforatus*, een zeepok en *Electra pilosa*, een mosdiertje. Alle andere soorten waren veel minder talrijk, met uitzondering van *Phtysica marina*, de enige aanwezige caprellide (100-1000 ind/m²). Een soortenaantal van 44 is in vergelijking met andere harde substraten vrij hoog voor het BDNZ zeker gezien de beperkte kolonisatieperiode van de funderingen. Bovendien werden verschillende minder bekende soorten voor de Belgische fauna aangetroffen. Daarnaast bleken 4 niet–inheemse soorten aanwezig: het muiltje *Crepidula fornicata, Megabalanus coccopoma*, een grote roze zeepok, *T. japonicus* en de Nieuw-Zeelandse zeepok *Elminius modestus*. Het zijn alle vier opportunistische soorten die heel snel nieuwe, door de mens gemaakte of verstoorde substraten koloniseren. Ze waren reeds bekend van het BDNZ.

4.1. Introduction

With the construction of windmills in the Belgian part of the North Sea (BPNS), a new habitat of artificial hard substrate is being introduced in a region mostly characterized by sandy sediments. This will increase the habitat heterogeneity of the region and the effect of the introduction of these hard substrates – the so-called reef effect – is regarded as the most important change of the original marine environment caused by the construction of windmill farms (Petersen & Malm, 2006).

The structures will be colonised and successively develop fouling assemblages, which may or may not resemble epibioses on natural substrata. They will also allow the establishment of species previously not present in this environment dominated by soft sediment habitats, as well as for the further spread of non-indigenous species (stepping stone effect). It is also expected that certain warm water species will take advantage of the increased presence of hard substrate to further spread into the North Sea.

The data collected at the C-Power site will further comparison with other windmill parks in the North Sea and with other hard substrates (natural or artificial e.g. buoys).

The aim of this part of the monitoring programme is to gather data concerning the new habitat, in particular information on the epifouling assemblage zonation and its succession on the scour protection and the concrete foundation. Emphasis is laid on the colonisation of the structures by non–indigenous species, warm water species and reef-forming organisms.

4.2. Material and methods

The Thornton Bank is a 20 km long sandbank located in de BPNS, near the borderline between the exclusive economic zones of Belgium and the Netherlands. The bank lies some 30 km offshore and belongs to the Zeeland banks system (Cattrijsse and Vincx, 2001). The water depth is about 30 m. During 2008, 6 windmills were built on the bank. The 6 concrete foundations for these wind mills were established on a line, 500 m from each other, between 27 April and 29 May 20008. Each turbine foundation consists of a base slab, a truncated conical portion, a cylindrical portion and a platform (Demuynck and Gunst, 2008). The conical portion of the turbine foundation rises 14 m above the seafloor and has an outside diameter that varies from 14 m at the seafloor to 6.5 m at the top, i.e. the junction with the cylindrical part. Available for colonisation by subtidal and intertidal organisms are the conical part of the foundation and the sub- and intertidal portion of the cylindrical part, i.e. 651 m² subtidal and 92 m² intertidal surface area for windmill D5. Due to bathymetric variations within the wind farm area, minor deviations in subtidal surface area for the other windmills (about 17%) exist.

A monitoring programme was set up to sample the new hard substrates associated with the windmills (Kerckhof et al., 2008). Due to delay in the work on the C-Power wind park site, technical problems and adverse weather conditions during 2008, this programme could not be carried out in full as originally planned. Six samples for epibiota were collected in the autumn of 2008. From 2009 onwards a further elaboration and standardisation (cf. monitoring programme) is anticipated.

Since the scour protection was not yet present, only the concrete foundation of the windmills was available for sampling. During 2008 all sampling was done on the foundation of windmill D5 (co-ordinates WGS 84: 51°32,88’N - 2°55,77’E), constructed on 30 May 2008. On 12 September 2008, four subtidal semi-quantitative samples were taken by scuba divers at depths of 23,7 - 20,1 - 14,8 and 5,2 m (at present not standardised to MLLWS) and a vertical video transect all along the foundation was made. On 22 October 2008, the intertidal was sampled (two semi-quantitative samples), one at high and one at low tide and additional visual observations were made.

Samples were taken by scraping the fouling organisms from a sampling surface area of 6.3 dm². The scraped material was collected in plastic bags that were sealed underwater and transported to the laboratory for processing – fixation, preservation, sieving, measuring, sorting and identification. Sieving was done through a 0.65 mm mesh-sized sieve. The residual sediment was searched for small species, e.g. rissoids and juvenile macrofaunal organisms.

During the dives, the divers observed the fish fauna on an *ad hoc* basis: species were indentified but densities were not estimated. Two species were observed: shoals of pouting *Trisopterus luscus* and saithe *Pollachius virens*. In absence of targeted observations, no further analysis of the fish was included in this document. From 2009 onwards, a detailed investigation of the fish fauna associated with the hard structures is anticipated (see Chapter 5).

The biota were identified to species level, whenever possible. Densities were determined by counting the number of individuals per species for rarer species. For abundant species, the density was estimated according to density classes, covering four categories (0, 1-100, 100-1000 and > 1000 ind/m²). The abundance of colonial organisms and macro-algae was estimated as the degree of coverage, using three categories (0, present and abundant).

Depth of the subtidal samples was measured with pressure gauge from a Liquivision X1 dive computer as the depth from the water surface.

4.3. Results

4.3.1. General observations

After about 3½ months, the submersed part of the foundation was already totally and heavily colonised by epibionts and also the intertidal zone was almost completely covered. A clear depth zonation could be observed. A species list was compiled (Annex 1), listing 49 species: 1 Protoctista, 4 algae and 44 invertebrates.

The vegetation was restricted to the intertidal zone and rather sparsely developed. Only four species of mainly filamentous algae were present: *Blidingia minima, Ulva intestinalis, U. compressa* and *Bangia fuscopurpurea*.

A total of 44 invertebrate species was identified in the samples. However, only a few species were really abundant. The most numerous (> 1000 ind/m² or abundant) species were the giant midge *Telmatogeton japonicus*, the amphipod *Jassa herdmani*, the barnacle *Balanus perforatus* and the bryozoan *Electra pilosa*. All other species were far less abundant with the exception of *Phtysica marina*, the only caprellid present (100-1000 ind/m²).

4.3.2. Zonation

As became apparent from the distribution of the species over the six samples and additional observations (video), a zonation pattern of 3 distinct zones could be discerned.

A first zone comprising the high intertidal and splash zone yielded only a low number of 8 species and was dominated by the giant chironomid *Telmatogeton japonicus*, almost forming a monoculture and accompanied by patches of thread like algae (Figure 1).

The second zone, the transitional barnacle-*Jassa* zone, in the low intertidal – shallow subtidal consisted of a mixed assemblage of barnacles and the tube-dwelling amphipod *Jassa herdmani* (Figure 2). The latter covered most of the other encrusting species. This zone gradually changed in the following subtidal zone with the bryozoan *Electra pilosa*.

Finally an extensive subtidal zone covered the foundation from the base to a height of about 23 m above the seabed (samples 1-3), where the surface of the structure was dominated by *E. pilosa*, forming a dense, uniform turf (Figure 3). The subtidal zone was the species-richest with a total of 40 species, the number dropped down to 16 in the transitional zone and only 8 in the intertidal zone (Annex 1).

4.3.2.1. Intertidal – splash zone

In the high intertidal and splash zone only eight macroscopic species were present and the giant chironomid *Telmatogeton japonicus* almost formed a monoculture. The filamentous red alga *Bangia fuscopurpurea* formed scattered patches and the green alga *Blidingia minima* was present in limited numbers.

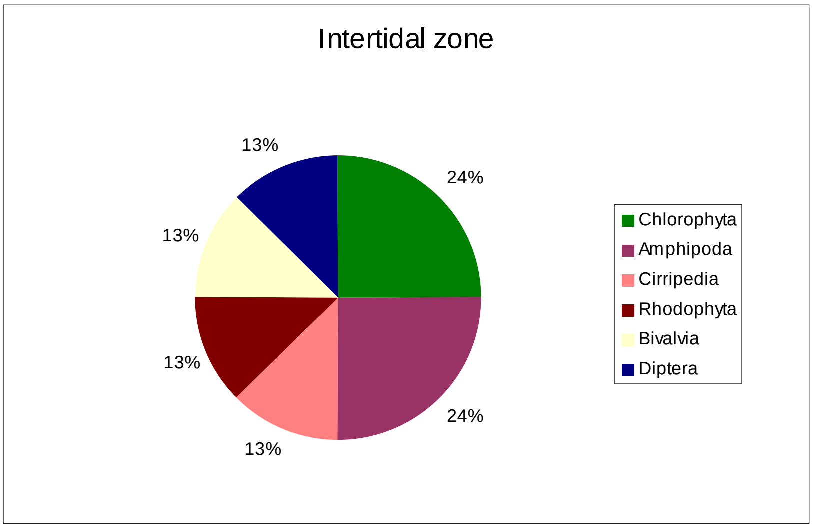

Figure 1. Species richness and diversity in the intertidal zone. Percentages indicate the relative species richness of the respective taxon (n = 2 samples).

4.3.2.2. Transitional barnacle-Jassa zone

The second zone, in the shallow subtidal – low intertidal, consisted almost solely of specimens of the warm water barnacle *Balanus perforatus* (diameter 1 – 15 mm), occasionally accompanied with solitary specimens of *Megabalanus coccopoma* (15 mm) and *Elminius modestus*. All barnacles were covered by *Jassa*-mats.

At the top, this barnacle zone was followed by a narrow *Ulva* belt, representing the upper limit of the barnacle-*Jassa* zone.

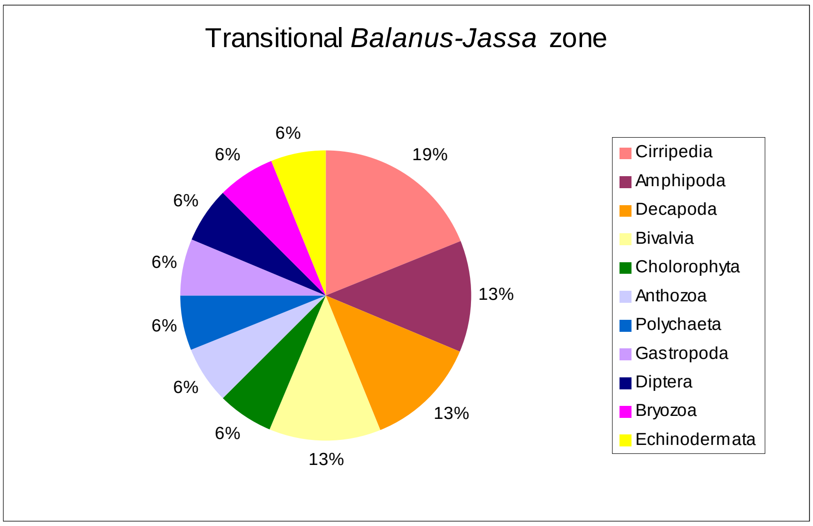

Figure 2. Species richness and diversity in the transitional barnacle-Jassa zone zone. Percentages indicate the relative species richness of the respective taxon (n =1 sample).

4.3.2.3. Subtidal zone

The Electra turf hosted several small mobile species: small crabs *(Pilumnus hirtellus, Pisidia longicornis, Macropodia linaresi)*, juveniles of larger portunid crabs *(Necora puber, Liocarcinus holsatus)*, small shrimps *(Hippolyte varians, Thoralus cranchii)*, small polychaetes (*Polynoidea* spp., *Myrianida (Autolytus)* spp.) and amphipods. In between the *Electra* turf, solitary specimens of the sea anemone *Sagartia troglodytes* were sampled. The *Electra* branches served as substrate for some tube dwelling amphipods (e.g. *Aora* and *Jassa*).

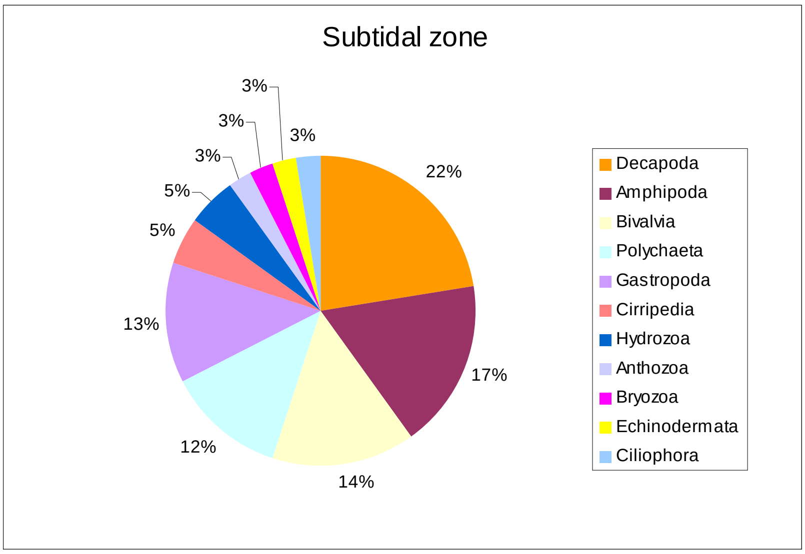

Figure 3. Species richness and diversity in the subtidal zone. Percentages indicate the relative species richness of the respective taxon (n = 3 samples).

Immature specimens of the tube dwelling polychaetes *Lanice conchilega* and *Pomatoceros triqueter* were present in rather limited numbers.

In general, most species were present as juveniles. Noteworthy were the rather high densities (100 – 1000 ind/m²) of juvenile *Aequipecten opercularis* (0.5 – 22 mm) and *Epitonium clathratulum* (0.5 – 2 mm).

Some larger mobile species such as the hermit crab *Pagurus bernhardus* and the swimming crab *Liocarcinus holsatus* were observed on the video.

The 3 samples from this zone contained a fairly large amount of sand and shell debris, even small stones, apparently trapped in the *Electra* turf.

A summarising scheme of the fouling zonation pattern is found in figure 4

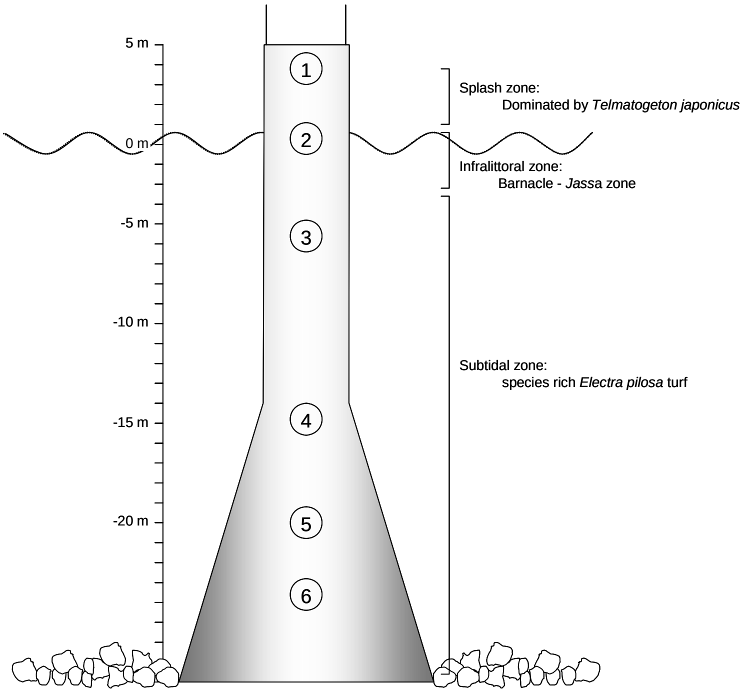

Figure 4. Schematic presentation of the fouling zonation pattern, with indication of the vertical distribution of the three zones and the position of the sampling locations (1-6).

4.4. Discussion

4.4.1. Epibiotic zonation and succession

Taking into account the short period of time available for colonisation of the foundation (3 ½ months), the species number (49 spp.) is considered high. In a study of the epifaunal assemblages of two shipwrecks at the BPNS, for example, Zintzen (2006) found 99 macrofaunal invertebrates in the scrape samples. van Moorsel (2001) recorded 44 macrofaunal invertebrates in a study of an artificial reef off Noordwijk, The Netherlands and on the FINO 1 research platform in the German Bight a total of 44 species was found in the scrape samples and another 7 identified on photographs (Orejas et al, 2005). This figure is even more remarkable, given the relatively low number of samples collected. It might thus be expected that an even higher percentage of the potentially fouling species pool, available in the BPNS (Zintzen, 2006), already reached the wind farm. It should however be noted that most species were present as juveniles.

The concrete foundations were placed in late spring. This means that the meroplanktonic propagules of those species with an early reproduction already disappeared from the water column by the time of the windmill construction. They were hence not able to colonise the foundations during this first year. Species breeding and settling in late summer and early autumn however were favoured during this first fase. This might explain the absence or poor presence of the indigenous barnacles *Balanus crenatus* and *Semibalanus balanoides*, both being typical early breeders, while the later breeding barnacles *B. perforatus* and *M. coccopoma* were commonly present.

Drastic changes in assemblage structure can thus be expected during the second year, when also the propagules of early reproducers will arrive onto the foundations.

4.4.2. Characteristics of the fouling assemblages

The colonisation of foundation D5 showed two characteristics typical for the first phase of an ecological succession: it started fast and was intense (e.g. Horn, 1974; Connell & Slatyer 1977). Most of the species, such as *E. pilosa*, *Pomatoceros triqueter* and *L. conchilega* are known to be pioneers and hence early colonisers. A number of species that could be expected were however not yet present or were present only in limited numbers. For example, only a limited number of juvenile blue mussels *Mytilus edulis* were found and dense aggregations were not yet established. Also, species like *Ectopleura (Tubularia) larynx*, the sea anemone *Metridium senile* and the starfish *Asterias rubens,* commonly present on other submerged hard substrates (e.g. Zintzen 2007, van Moorsel 2001) were not yet present. The whole fouling assemblage can thus be considered immature. It can be expected that these initial fauna of opportunistic species (r-strategists) will be gradually replaced by less opportunistic and more long-lived, slowly reproducing species (K-strategists). In this respect, the comparatively high diversity of this first batch of colonists was surprising.

It was not possible to study the initial colonisation process on the foundations proper. The first macroscopic colonists of new submerged substrates in a marine environment are in most cases hydroids including *Tubularia* spp. (Dean and Hurd, 1980). *Electra pilosa* was hence probably not the first macrofouler to the foundations. Circumstantial observations from the biofouling of other submerged structures, shortly deployed in and around the wind park, showed a heavy colonisation by Campanularia, identified as *Obelia longissima*. It might be hypothesised that this has also been the case for wind mill D5 and that gradually, the *Obelia* stolons became overgrown by *Electra*. Indeed inside the *Electra* stems often the remainders of the *Obelia* stolons were present, and in sample 2, alive colonies of this species were still present. The complete absence of *Tubularia indivisa* in our samples is rather remarkable, because this species, as its congers, is a typical pioneer species and one of the first species to colonise newly available hard substrata (Zintzen, 2008 and references therein). For instance, in August 2003 and only 2 weeks after construction of the FINO 1 research platform in de German Bight, the surface of the underwater structures were heavily colonised by *T. indivisa* (Schröder *et al.* 2006) and on shipwrecks in the BPNS, epifaunal assemblages were dominated by a high biomass of *T. indivisa*. Moreover, during 2007 the species was even not completely absent in de study zone as it was present on certain scientific equipment that had been deployed in the vicinity of the wind park between 17 June and 17 July (own observations). According to Zintzen (2008) *T. indivisa* shows large monthly variations in densities and biomass under an apparent repetitive seasonal cycle, but strongly dominated the epifauna present on wrecks in June (Zintzen et al. 2007).

The site is clearly under the influence of English Channel water (Otto *et al.* 2006; Zintzen, 2007). This water mass differs from the coastal water by having higher minimum temperatures and lower maximum temperatures, the salinity remaining fairly constant (about 35 psu) and the suspended particulate matter load also being lower compared to the coastal waters (Lacroix *et al*. 2007. On the foundation under consideration, several species indicative of offshore sites such as *A. opercularis*, *P. triqueter*, *Heteranomia squamula*, *Galathea* spp. and *Pussilina inconspicua* were present. Most of these species were also found on wrecks in the offshore Belgian and Dutch waters, under influence of the English Channel water (Zintzen, 2007; van Moorsel et al. 1991) and on hard substrates in the eastern English Channel (Müller, 2004). Data from offshore sites, such as shipwrecks, might thus be indicative of the future mature state of the epibiotic assemblages.

The presence of juvenile *A. opercularis* is noteworthy. The species was present as juveniles (the largest specimens measuring 22 mm) at rather high densities. The first life stage of this species lives attached by a byssus before moving from the hard substrates to the mobile substrates, where it starts its benthic life. Juveniles of *A. opercularis* were also reported from offshore wrecks in the Belgian and Dutch waters (Zintzen, 2008; van Moorsel et al. 1991). On Belgian shipwrecks *A. opercularis* occurred in high densities (mean value: 120 ind/m², specimens less than 15 mm) and uses the perisarc of *Tubularia* for attachment prior to commencing their benthic life (Zintzen, 2008).

Given the availability of coarser sediments, shell debris and even small stones at higher elevation (up to 10 m above seabed) onto the foundation, it is expected that strong currents occur in the vicinity of the foundations. It is however also possible that this sediment originated from activities prior to completion of the construction works, when large amounts of sandy sediments had to be moved. Most probably the coarser material in suspension is then trapped in the *Electra* turf, providing a habitat for typical mobile sediment-dwelling organisms. This explains the presence of a juvenile *Spisula solida* and a juvenile *Parvicardium* sp., both bivalves that typically belong to the soft bottom macrobenthic community. This explains also the presence of the sand mason *L. conchilega*, a predominantly benthic species or restricted to horizontal hard surfaces (Zintzen, 2008), all over the vertical gradient of the foundation. In such conditions, we might also expect the ross worm *Sabellaria spinulosa* to eventually colonise the foundations and form reefs. Also the gastropod *E. clathratulum* could be favoured by the presence of sediment on the vertical structures. Zintzen (2006) found densities of this species ranging from 32 to 144 ind/m² on horizontal surfaces where a thin layer of sediment occurred. The Epitonidae are carnivorous and known to feed on Anthozoa. On D5, this would be *Sagartia troglodytes*, as other species were not yet present.

In the intertidal we noted the presence of two sibling *Jassa* species *Jassa herdmani* en *J. marmorata*. *Jassa herdmani* was the only *Jassa*-species present on shipwrecks in Belgian waters although *J. marmorata* was looked for (Zintzen, 2007, 2008 and pers. comm.). Both species have been confused and often misidentified in the past, although they are morphologically distinguishable and their true status is ascertained. *Jassa marmorata* is rather common in Belgian waters on offshore sites e.g. buoys as well as intertidal hard substrates such as groins. The species lives in most cases together with *J. herdmani*, but is often outnumbered by the latter. This was also the case in our samples. It is possible that *J. marmorata* is more restricted to intertidal, wave beaten habitats. However, Leonhard and Pedersen (2006) only mention *J. marmorata*, which was even, regarded a species new to the Danish fauna, while Orejas et al. (2005) only mention *J. herdmani* on the FINO 1 research platform. Both the Danish and German study site are located in the German Bight.

4.4.2.1. Presence of non-indigenous species

Four non-indigenous species were found: the slipper limpet *Crepidula fornicata*, the New Zealand barnacle *E. modestus*, the giant barnacle *M. coccopoma* and the giant midge *T. japonicus*. All four species, already known from the area, are opportunists and early colonisers after disturbance, taking advantage of man-made structures and disturbed conditions to settle (Kerckhof et al. 2007).

Though being non-indigenous, *T. japonicus* is very common on exposed vertical offshore structures, such as buoys and pilings. On the buoys in the BPNS, it forms a distinct belt in the upper littoral and splash zone (Kerckhof, unpublished). This was also the case on the piling of D5. On buoys, densities can reach over 3000 ind/m² (Kerckhof, unpublished). The species was also present in high numbers on the pilings of the Danish Horns Rev offshore wind farm (Leonhard & Pedersen, 2006), where it formed a monoculture in the high intertidal and splash zone.

The presence of several specimens of the barnacle *M. coccopoma* is noteworthy. This species is known since 1978 in the North Sea (Kerckhof & Cattrijsse, 2001) and is now rather common on offshore buoys and other floating structures (Kerckhof et al 2007). This barnacle grows much larger than indigenous species, and can reach dimensions well over 4 cm (basal diameter). It readily overgrows other encrusting species. Although its possible occurrence on the pilings of the wind mills was expected, its rapid occurrence was somewhat surprising and possibly related to the availability of free space – this species settles in late Summer, early autumn (Kerckhof, unpublished) – and the relatively high water temperature during Summer of 2008. The species was also detected in the Dutch wind farm Egmond aan Zee in February 2008 (Wouter Lengkeek, bureau Waardenburg pers. comm.). Combined with the rising temperatures, this species might thus profit from the construction of offshore wind farms to extend its geographic distribution (cf. stepping stone effect).

4.5. Conclusion

Being fast and intense, the colonisation process of foundation D5 showed characteristics typical for the first phase of an ecological succession, but displayed a surprisingly high diversity compared to other artificial substrates that have been studied in the area. After only 3.5 months all substrate was densely covered by a Bryozoan *E. pilosa* turf, providing habitat for many species. The larvae of certain species, e.g. *M. edulis* and *A. opercularis*, need filamentous and thread like structures for the settling of their larvae prior to initiating their benthic life.

It is expected that the initial faunal composition will change. Overgrowth of the initial colonists will occur resulting in changes in the zonation and new communities. We can expect the formation of a mussel zone, probably also the settling of the oyster *Crassostrea gigas* and other tube forming polychaetes, such as *S. spinulosa*.

Attached fouling growth will attract predators, such as starfish and various crab species and a whole range of smaller inconspicuous species. How these changes will affect the general diversity of the settlement will require appropriate monitoring in the future.

The site is under the influence of English Channel water with a larval supply of more southern species. The dominance of *B. perforatus* in the barnacle zone is also an indication of a warming trend and the species is further spreading into the North Sea taking advance of the availability of hard substrate. The warming trend is further illustrated by the presence of *M. coccopoma*. Depending upon weather conditions during the following years the establishment and further spreading of additional warm water and non-indigenous species can be expected. However, the effect of the cold period in January 2009 could slow down this process.

A possible stepping stone effect is already apparent for several species, e.g. the already mentioned barnacles and other hard-substrate species. This effect is particularly relevant for such species like *Jassa* spp. and *T. japonicus* that have no meroplanktonic larval stage.

4.6. Suggestions for future monitoring

Based on this first glimpse on the fouling succession and potential of wind mill piles in the Belgian offshore waters, several suggestions to fine tune and better focus the future monitoring can be deducted.

First of all, a continuation of the monitoring of the three vertical zones, preferentially at "fixed" positions (scrape sample). The follow up of response variables, such as species richness, species-specific densities and biomass, will allow to investigate and document the successional transitions in detail. When compared to the epifouling of shipwreck and buoys in Belgian offshore waters, this information will allow to scale the different stages along the succession gradient. Such information is required to evaluate temporal variability within the impact of wind farms, e.g. food availability to benthos-eating fish (see Chapter 5), and as such the change within the ecosystem functioning due to the presence of the wind farm.

During the future monitoring and within the financial constraints, special attention should be given to the habitat engineering effects of species, such as *L. conchilega*, *S. spinulosa*, *Tubularia* spp., *Electra* spp. or the exotic *C. gigas*. These habitat engineers might promote the nursery capacities for certain invertebrate (e.g. *A. opercularis*), but also vertebrate species (e.g. fish). Together with the hard substrate itself, the bio-engineered habitat might further promote spawning of species, such as *Sepia officinalis* or squid. Most probably, next to (destructive) scrape sampling, also ROV videoing could be of use here. It is hence advised to test and evaluate ROV videoing for e.g. the search for egg deposits, engineered habitat structure and size quantification, counts of sheltering (small) fish.

Finally, the combined presence of the two sibling species *J. herdmani* and *J. marmorata* provide a good model for the investigation of meta population dynamics, in which the extinction and colonisation rates of both species at several piles may provide some first insights in the potential of wind farms to promote the spreading of (hard substrate) species with limited dispersion capacities (cf. sink-source dynamics). To allow such evaluation one should not concentrate on only one pile, but should rather include several piles at various distances from each other (ideally combining several wind farms). Within- and between-site-replicated sampling should however only focus on the barnacle-*Jassa* zone.

4.7. Acknowledgements

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Chapter 5. The importance of marine wind farms, as artificial hard substrates, on the North Sea bottom for the ecology of the ichthyofauna

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Photo Alain Norro / RBINS

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Abstract

The foundations of windmills act as secondary artificial reefs, attracting different kind of fish species. This monitoring aims to determine attraction and/or net production of the ichthyofauna on the artificial hard substrates of the wind turbines placed at the Thorntonbank. By answering specific research questions and integrating the results, the principal question " Do the secondary artificial reefs only attract fishes or do they produce them? " can be tackled. A wide fan of technologies will be used in this research. The ichthyofauna associated with the artificial reefs will be quantified using visual and destructive methods, for instance visual census with scuba divers, ROV underwater camera, hook and lines, gill nets and trammel nets. The functional relations between the ichthyofauna and the reef habitat have their influence on growth patterns and productivity. By integrating the techniques and linking the results it will be possible to (partly) unravel and visualize the attraction/production at the artificial reefs in the BPNS.

Samenvatting

De funderingen van windmolens doen dienst als secundaire riffen die verschillende vissoorten aantrekken. Deze monitoring beoogt het bepalen van de aantrekking en de netto productie van de ichthyofauna geässocieerd met de artificiële harde substraten van de windturbines op de Thorntonbank. Het beantwoorden van specifieke onderzoeksvragen moet het mogelijke maken om de hoofdvraag "trekken secundaire artificiële riffen enkel vissen aan of zorgen ze voor extra productie?" op te lossen. Er worden veel vershillende technieken gebruikt in dit onderzoek. Om de ichthyofauna geässocieerd met de windmolens te kwantificeren zullen zowel visuele technieken als destructieve methoden gebruikt worden, zoals visuele census met duikers, ROV onderwater camera, lijnvissen, kieuwnetten en warrelnetten. De functionele relaties tussen de ichthyofauna en het rif habitat hebben een invloed op de groeiprocessen en de productiviteit. Door de verschillende technieken en de resultaten te integreren moet het mogelijk worden om de vraag over attractie/productie op artificiële rifffen (gedeeltelijk) op te lossen.

5.1. Introduction

In the year 2008 the kick off for the construction of the first windmill farm at the Belgian part of the North Sea (BPNS) was given. Within a couple of years three windmill farms and more than a 100 windmills will be present in the Belgian North Sea waters. The foundations of these windmills will act as secondary artificial reefs, attracting different kind of fish species (Arena *et al*; 2007, Fabi *et al*. 2002, Santos & Monteneiro 2007).

Initially, high densities of fishes present at artificial reefs where related to an increased productivity. In 1983 an alternative hypothesis, stating that artificial reefs attract fishes due to behavioral preferences but do not increase productivity, emerged (Bohnsack 1989).

As many fishes have a complicated life cycle and are highly migratory it is hard to quantify 'possible' net production. For this reason it is important to interpret the dimensions and distribution areas of the populations of fish species involved and to stipulate factors influencing structure (densities) and functionality (production versus dispersion) to quantify net production.

5.2. Goals

This monitoring aims to determine attraction and/or net production of the ichthyofauna on the artificial hard substrates of the wind turbines placed at the Thorntonbank, which will act as secondary artificial reefs. These structures form patches of hard substrates on a sea bottom dominated by soft sediments. A shift in organisms can be expected (Danovaro *et al.* 2002). Nearby artificial hard substrates (ship wrecks) and sand banks without windmills will act as reference sites.

The main goals are:

- to follow-up evolution of fish communities, densities and biomass both on concession area as reference sites after deployment of wind turbines
- to determine which mechanisms/processes can result in an increase of fish production
- to determine (daily) migration patterns of some fish species

By answering these specific questions and integrating the results, the principal question " Do the secondary artificial reefs only attract fishes or do they produce them? " can be tackled (Lindberg 1997, Mason *et al.* 2007).

5.3. Project

5.3.1. Introduction

The fisheries industry in the North Sea knew a fast improvement in fishing techniques and technological devices to track fish schools in the last decennia, while the catch per unit effort (cpue) showed a strong downward trend (Myers & Worm 2003). This is a clear indication of the decline in fish stocks, which may be an indication for overfishing. Artificial reefs are often deployed to increase the abundance of (commercially) important fish species (Brickhill *et al.* 2005, Relini *et al.* 2007). The footings of the windmills which will be placed on the Belgian part of the North Sea (BPNS) will act as secondary artificial reefs.

5.3.1.1. Study site

Focus lays on the windmills placed at the Thornton ridge, to limit complexity and costs of the project. From 2006 onwards monitoring has been done on this ridge to reveal the impact of the wind farm on the macrobenthos of soft substrates (De Maersschalck *et al.* 2006).

To make a correct interpretation of the observed patterns, it is important to use some reference areas. These areas need to approach the impact area as close as possible in physico-chemical parameters. In this way changes in the area can be compared with eventual natural changes in time (Hurlbert 1984).

5.3.1.2. Ecology of the ichthyofauna associated with artificial hard substrates in the North Sea

Artificial reefs attract many different fish species (e.g. Arena *et al.* 2007, Fabi *et al.* 2002, Santos & Monteiro 2007, Lindberg *et al*., 2006, Mason *et al*., 2007). Different parameters play an important role: current patterns, shade, species interactions, light, density dependency, food availability, feeding efficiency and possible hiding places (Bohnsack 1989, Fabi & Sala 2002, Wilson *et al*. 2001, Zintzen 2007).

Fish species that are attracted to (artificial) reefs in the BPNS are: *Trispoterus luscus* (pouting), *Pollachius pollachius* (pollack), *Pollachius virens* (saithe), *Gadus morhua* (cod), *Dicentrarchus labrax* (seabass), *Myoxocephalus scorpius* (bull rout), *Parablennius sp.* (Blenny spec.), *Pomatoschistus minutus* (common goby), *Scomber scombrus* (mackerel), *Trachurus trachurus* (horse mackerel) (Zintzen 2007, Zintzen *et al.* 2006, Mallefet *et al.* 2007). It is not known what exactly attracts these species to the reefs.

5.3.1.3. Similar research

In the scientific literature little information is available from similar research. Many studies focusing on artificial reefs describe colonization processes or effects of these reefs on macro- and meiofauna in adjacent soft substrates (e.g. Danovaro *et al*. 2002, Fabi *et al*. 2002, Pizzolon *et al.* 2008). Mason *et al.* (2007) investigated, as in the present study, the functional relations between habitat, fish densities and trophic interactions. By using a wide fan of techniques and technologies and by integrating the results, functional relations between the ichthyofauna and the artificial hard substrate can be visualized/understood.

5.3.2. Material and method

5.3.2.1. Species community, density and biomass of fishes associated with artificial reefs

The ichthyofauna associated with the artificial reefs will be quantified using visual and destructive methods. In ideal circumstances sampling should take place simultaneously in the different research areas. Due to the limitations in logistic possibilities and the labour intensive work this is not possible.

1. Visual Census (Pizzolon *et al.* 2008, Ponti *et al.* 2002, Zintzen *et al.* 2006) is a non-destructive method using scuba divers to estimate species richness, densities, biomass and length of the fish present at the reef. This method is not species or length specific (as nets are), but the presence of divers can attract/ scare off the fishes present in the area (Nagelkerken *et al.* 2000). For the visual censes use will be made of a scientific team made up by MUMM and Vliz, pending their availability. Divers go down in teams by two and quantify the present fishes during half an hour, besides information about, length, behavior and habitat is notated.
2. With an ROV underwater camera observations will be made. Species and densities will be estimated using frozen panes (video stills) (Posey & Ambrose 1994). Determination will be done till highest possible taxon level.

3. Hook and lines (Relini *et al.* 2007, Santos *et al*. 1996), gill nets (Santos & Monteiro 2007) and trammel nets (Fabi *et al.* 2002) are some types of fishing devices that will be used for direct sampling. These destructive methods make measuring and weighing possible and information about the diet can be obtained. The length and species specificy are some of the disadvantages (Reubens, 2008). Nets of 100m in length and with different mesh sizes will be used. Fishes caught with lines and nets will be identified till species level, measured and the stomach of some selected species will be fixated on 4% formaldehyde. In the laboratory further analysis is done (see 3.2.2-3.2.4).

Both cod (*Gadus morhua*) and pouting (*Trisopterus luscus*) were selected for a detailed investigation. For these species habitat and food preferences, condition-index, behavior and migration patterns will be investigated in detail, doing stomach content analyses, stabile isotopes analyses, tagging experiments and in situ observations.

5.3.2.2. Food preferences of cod and pouting

For stomach content analysis all prey items present are identified till highest possible taxon level. For each individual fish species the fullness index (F.I.) will be calculated. F.I. can be used to visualize temporal changes in stomach content and differences in fullness between sites and length classes for a species (Hyslop 1980). Besides, the frequency of occurrence (%FO) will be used to visualize the relative importance of each prey species present in the selected environments (Hyslop 1980).

If possible, stabile isotope analysis will be done as well. This technique gives information about diet preference over a longer period of time (weeks to months), where stomach content analysis only gives diet information from the last few hours to days. The use of stable isotopes as tracers to know the prey and its origin has become widespread. The use is based upon the assumption that different prey sources may have different ^{13}C and ^{15}N signatures and that assimilation by consumers results in a fractionation of the isotopes (Bouillon *et al.* 2004, Lugendo *et al.* 2006). However, the results are often difficult to interpret, which makes a combination of both stable isotope and stomach content analysis a necessity (Cocheret de la Mornière *et al.* 2003).

5.3.2.3. Condition-index of cod and pouting

As mentioned above , available energy is used for basal metabolism, waste production and somatic growth. The energetic costs for catabolic processes and waste production are expected to be similar in the study and control area, as similar physico-chemical parameters are expected in the different areas, which makes that differences in growth should be directly affected by differences in food availability and food quality. In this way; diet, growth and the size of the gonads can be used as an indication for quality of the habitat (Mason *et al.* 2007). To measure the metabolic condition of a fish, ETS (Electron transport system) will be used. ETS enzyme assay is a method to estimate the time-averaged potential respiratory capacity of an organism by measuring the enzymatic activity of the rate-limiting step in oxygen use (ATP production) (Mason *et al.* 2007). The acquired information can be used to relate the metabolic condition of a fish to its habitat.

5.3.2.4. Behavior of cod and pouting

To have an idea of the importance of a certain habitat for a fish species it is interesting to know more about its migration behavior. In this respect some tagging experiments will be done using passive acoustic telemetry. After a transmitter is chirurgical implanted in the belly of an individual fish, the fish is released back into the water. When crossing a receiver, the information of the unique ID-code of the transmitter is stored on the receiver. This technology is very useful to gather lots of information over longer periods of time and reveals important migratory information. This technique has been taught by the Coastal Fisheries Research Group, University of Algarve.

5.3.3. Experimental design

Few studies investigating attraction versus production at artificial reefs could give a conclusive answer to their hypotheses due to lack of replication, low spatial distribution or lack of control areas (Brickhill *et al.* 2005). Often this is a direct consequence of the high costs of deploying artificial reefs.

With the construction of 60 offshore windmills built by C-Power, a unique situation is offered to answer some process orientated scientific questions in combination with a controlled monitoring.

The first year of study 2 footings, 2 wrecks (hard substrate control) and 2 soft substrate controls will be sampled with all previously mentioned techniques. From the second year onwards (after standardization of the sampling techniques) the sampling will be expended to 3 replicates per site (table 1). In 2011 3 replicates of the second construction phase will be added to compare with the initial colonization processes of the first construction phase.

A distinction is made between the footings of different construction phases as differences in community composition are expected to be present, related to the temporal distribution in construction.

Besides having enough replicates, frequent sampling is primordial. Yearly at least 4 campaigns should be done (March, June, September, December) to account for seasonality. This makes it possible to detect evidence of key events such as settlement, migration and mortality in the fish populations (Brickhill *et al.* 2005).

5.3.4. Ecological implications

5.3.4.1. Unravel attraction/ production

A wide fan of technologies will be used in this research to understand functional relations between the ichthyofauna and the reef habitat. These relations have their influence on growth patterns, productivity. By integrating the techniques and linking the results it will be possible to (partly) unravel and visualize the attraction/production at the artificial reefs in the BPNS.

5.3.4.2. Marine protected areas

The concession area of C-Power is prohibited for fisheries activities. In this way, this area can be considered a of marine protected area, which have shown their potential use as fish stocks protection areas in recent years (Roberts *et al.* 2001). A overview of studies concerning this matter has revealed that protection against fisheries activities quickly results in ascending biomasses, densities and lengths of exploited fish species and a rise in species richness (Halpern 2003). Although, the eventual positive effects of marine protected areas depend on the size of the area, the number of reefs and the period that fisheries activities are banned (Roberts *et al.* 2001). It is more interesting to have many small reefs than to have one big reef. The first would harbor more species in higher abundances (Bohnsack *et al.* 1994).

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Chapter 6. Monitoring of the effects of offshore wind farms on the endobenthos of soft substrates: Year-0 Bligh Bank and Year-1 Thorntonbank

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Photo’s Hans Hillewaert / ILVO

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Abstract

The consortia C-Power NV and Belwind NV obtained an environmental permit to build and exploit a wind farm in the Belgian part of the North Sea. The wind turbines for C-Power will be/are placed on the Thorntonbank (60 wind turbines, 300 MW). The ones for Belwind will be placed on the Bligh Bank (110 wind turbines, 330 MW). A research design has been drafted to monitor the environmental effects of the construction and exploitation of these wind farms in time. Stations on the Goote Bank, Bligh Bank and Thorntonbank were selected as a reference sites (no impact site).

To scientifically evaluate the ecological effects of a human disturbance on the environment, a BACI (Before After Control Impact) strategy is used. The baseline study (Year-0) of the Thorntonbank has been completed in 2005. In 2008, six wind turbines have been placed on the Thorntonbank. This monitoring project aims at evaluating the Year-0 situation of the Bligh Bank and the Year-1 situation of the Thorntonbank on the benthic environment and demersal fish during the construction and exploitation phase of the wind farms. Most samples at the Bligh Bank and Goote Bank are characterized by medium sand (350-500 µm), with low mud content (max. mean of 4.3 %) and low percentages of organic material (max. mean of 0.3 %), both in spring and autumn 2008. The macrobenthos densities are higher in autumn (max. 3500 ind./m²) in comparison with spring (max. 900 ind./m²). Species richness is rather low at all sampling locations (max. 26 species/0.1 m²) and a broad range in biomass (26 to 6000 mg/m²) is present both in spring and autumn. Productivity is low (less than 10 mg/day.m² in most samples). *Nephtys cirrosa* is the dominant species over all the stations on the Bligh Bank and Goote Bank and variation in community composition is of the same order of magnitude within and between sample locations. The macrobenthos of the concession area, the border zone and the reference site can be characterized as the transitional community between the *Nephtys cirrosa* and *Ophelia limacina – Glycera lapidum* community. Seasonal variations in density, diversity, biomass, productivity and community composition seem to be important. Most samples at the Thorntonbank and Goote Bank are characterized by medium sand (350-500 µm), low mud content (max. mean of 5.9 %) and low percentages of organic material (max. mean of 0.23 %). These sediment characteristics are comparable to the ones found in the baseline study performed in 2005. A broad range in densities (50-3500 ind.m²) and biomass (6-6000 mg/m²) is present for the macrobenthos, while species richness is rather low (max 26 species/0.1 m²). Productivity is low (less than 10 mg/day.m² in most samples). The dominant species over all the stations on the Thorntonbank and Goote bank are *Nephtys cirrosa* and *Spiophanes bombyx*. A clear distinction in community composition can be made between the samples of 2005 and the ones of 2008. Within each year, no further ecologically relevant distinction can be made between the sample locations. The macrobenthos

samples of the concession areas WTA and WTB, the border zone WTC and the reference sites WTR and BGR show a gradual transition from the *N. cirrosa* community to the *O.limacina - G. lapidum* community. The results indicate that the impact of the first six windmills on the endobenthos of soft sediments in the first year after implementation is rather low or could not be demonstrated yet. Seasonal and annual variations in densities, species richness, biomass, productivity and community composition seem to be more important at this moment. However, it has to be mentioned that the close vicinity of the windmills was not sampled properly. Therefore, slight modifications of the sample locations shall be made for future monitoring programs.

Samenvatting

De consortia n.v. C-Power en n.v. Belwind verkregen een milieuvergunning voor de bouw en exploitatie van een windmolenpark op het Belgisch deel van de Noordzee. De windturbines voor C-Power worden geplaatst op de Thorntonbank (60 molens, vermogen van 300 MW). De turbines voor Belwind zullen geplaatst worden op de Bligh Bank (110 molen, vermogen van 330 MW). Een monitoringsplan werd uitgetekend om de impact van de bouw en exploitatie van deze windmolens op het milieu na te gaan in de tijd. Er werden referentiegebieden aangeduid op de Goote Bank, Bligh Bank en Thorntonbank. Om op wetenschappelijke basis de ecologische gevolgen van een menselijke verstoring op het habitat na te gaan werd een BACI (Before After Control Impact) strategie gekozen. De baseline studie van de Thorntonbank werd uitgevoerd in 2005; in 2008 werden de eerste 6 windmolens geïnstalleerd. Dit monitoringsproject werd uitgeschreven ter uitvoering van de baseline studie (jaar-0) van de Bligh Bank en de jaar-1 studie van de Thorntonbank om de situatie te evalueren tijdens de constructie- en exploitatiefase van de windmolenparken voor de macrobenthische endofauna en demersale vissen. De meeste stalen van de Bligh Bank en Goote Bank worden gekenmerkt door medium zand (350-500 µm) met een laag slib gehalte (max. gemiddelde van 4.3 %) en een laag percentage organisch materiaal (max. gemiddelde van 0.3 %), dit zowel in de voorjaars- als najaarsstalen van 2008. Densiteiten van het macrobenthos zijn hoger in het najaar (max. 3500 ind/m²) in vergelijking met het voorjaar (max. 900 ind./m²). Soortenrijkdom is eerder laag in alle stalen (max. 26 species/0.1 m²). Een brede range in biomassa wordt waargenomen (26- 6000 mg/m²), zowel in het voorjaar als het najaar. De productiviteit is laag (minder dan 10 mg/day.m² in de meeste stalen). *Nephtys cirrosa* is de meest dominante macrobenthische soort, zowel in de voorjaars- als najaarsstalen. De variatie in gemeenschapssamenstelling binnen als tussen staalnamelocaties is van eenzelfde grootteorde. Het macrobenthos van het concessiegebied, de randzone en de referentiesite behoren tot de overgangsgemeenschap tussen de *Nephtys cirrosa* en *Ophelia limacina – Glycera lapidum* gemeenschap. Seizoenale variatie in densiteit, diversiteit, biomassa, productiviteit en gemeenschapssamenstelling blijkt een belangrijk gegeven te zijn. De meeste stalen genomen op de Thorntonbank en Goote Bank worden gekenmerkt door medium zand (350-500 µm), een laag slibgehalte (max. gemiddelde van 5.9 %) en een laag percentage organisch materiaal (max. gemiddelde van 0.23 %). De sedimentkarakteristieken van de huidige studie zijn vergelijkbaar met deze gevonden in de baseline studie uitgevoerd in 2005. Een brede range in densiteiten (50-3500 ind./m²) en biomassa's (6-6000 mg/m²) wordt waargenomen, terwijl soortenrijkdom eerder laag is (max 26 species/0.1 m²). De productiviteit is laag (minder dan 10 mg/day.m² in de meeste stalen). *Nephtys cirrosa* en *Spiophanes bombyx* zijn de meest dominante macrobenthische soorten op de Thorntonbank en Goote Bank. Een duidelijk onderscheid in gemeenschapssamenstelling kan gemaakt worden tussen de stalen genomen in 2005 en 2008. Binnen elk jaar is geen verdere opsplitsing tussen de staalnamepunten mogelijk. De stalen van de concessiegebieden WTA en WTB, de randzone WTC en de referentiesites WTR en BGR vertonen een graduele overgang van de *N. cirrosa* gemeenschap naar de *O. limacina-G. lapidum* gemeenschap. De resultaten van de huidige studie tonen aan dat de impact van de eerste zes windmolens op het endobenthos van zachte substraten in het eerste jaar na implementatie eerder laag is of nog niet kan worden aangetoond. Seizoenale en jaarlijkse variaties in densiteit, diversiteit, biomassa, productiviteit en gemeenschapssamenstelling blijken op dit moment belangrijk te zijn. Er dient echter vermeld te worden dat er in de dichte nabijheid van de sokkels geen stalen genomen konden worden. Om dit te verhelpen, zullen in de toekomstige monitoringsprogramma's kleine aanpassingen in de staalnamelocaties gemaakt worden.

6.1. Introduction and objectives

The consortia C-Power NV and Belwind NV obtained an environmental permit to build and exploit a wind farm, a transformer platform and the submarine electricity cables necessary to transport the generated power from the North Sea to the shore. The wind turbines for C-Power will be placed on the Thorntonbank (60 wind turbines, 300 MW). The ones for Belwind will be placed on the Bligh Bank (110 wind turbines, 330 MW). A research design has been drafted to monitor the environmental effects of the construction and exploitation of these wind farms in time.

To scientifically evaluate the ecological effects of a human disturbance on the environment, a comparison between data gathered before (Year-0) and after (Year-1) the disturbance is crucial (BACI design). The baseline study (Year-0) of the Thorntonbank has been completed in 2006 (De Maersschalck *et al.*, 2006). In 2008, six wind turbines have been placed on the Thorntonbank. This monitoring project aims at evaluating the Year-0 situation of the Bligh Bank and the Year-1 situation of the Thorntonbank on the benthic environment and demersal fish during the construction and exploitation phase of the wind farms.

Constructing and exploiting activities of a wind farm may heavily impact the benthos (organisms living within and upon the sea bottom). The macrobenthos (organisms larger than 1 mm living in the sediment) play a central role in the marine ecosystem. The distribution of their communities stands in close relation to sedimentological, bathymetrical and hydrodynamical characteristics. Geophysical changes in the concession area (e.g. construction, the creation of new habitat, change of original habitat) will therefore influence the community structure of these benthic macro-invertebrates. This makes macrobenthos an ideal ecosystem component for evaluating the ecological effects of a wind farm on the marine environment.

As benthic macro-invertebrates are part of the diet of demersal fish communities, any change in the macrobenthic community due to construction, exploitation and dismantling of a wind farm will lead to possible changes in the demersal fish community. Besides these human disturbances, other changes in the environment will possibly influence the benthic macro-invertebrates as well. The introduction of hard substrates in the area, which is dominated by soft sediments, will attract a different fauna of macro-invertebrates and fish, which might alter the current state of the soft substrate communities (e.g. by predation). The exclusion of beam trawl fishery inside and an increase in fishing activities just outside the concession area will influence the benthic macrofauna as well.

Given the expected impact on the benthic macrofauna and the demersal fish of soft substrates, it is important to pay attention to these ecologically and socio-economically important ecosystem components during an ecological evaluation of the direct and indirect effects of the wind farms. This evaluation includes the effects of the closure of the concession area for beam trawl fishery and sand exploitation.

The main objectives of this study are:

- To determine the Year-1 situation of the macrobenthos on the Thorntonbank and to identify the possible effects of the construction and exploitation of the first wind turbines.
- To investigate the Year-0 situation of the macrobenthos on the Bligh Bank as a basis for the effect assessment of the construction and exploitation phase of the wind farm (inclusive the effects generated by closing the area for beam trawl fishery and sand exploitation) and to identify a suitable reference area.
- To enclose the complex functional-ecological part of the macrofauna and demersal fish by integrating the results of the synchronous studies of the benthic epifauna and demersal fish fauna.

Attention is required for:

- The global impact of the construction of the wind farm on the soft substrate benthos, including sand shift and sedimentation.
- The global recovery of soft substrate benthos after construction of the wind farm: what dynamic equilibrium state is achieved in a certain period of time?
- The importance of the two possibly most important impacts during succession, being exclusion of beam trawl fishery and possible change in substrate type due to changing current patterns.
- Possible edge effects of the colonized hard, artificial substrates on the endobenthos of soft substrates.

6.2. Materials and methods

6.2.1. Methodology

The Bligh Bank (Year-0) and its reference area (Goote Bank) were sampled in spring (8-10 April) and autumn (14-17 October) 2008. The Year-1 situation of the Thorntonbank was sampled in autumn 2008 and the Goote Bank samples were taken as reference framework for this as well, next to the Year- 0 samples of the Thorntonbank as reported in De Maersschalck *et al*., 2006. This means that in total 78 and 132 samples have been taken at fixed sample stations (Figure 1) during spring and autumn of 2008 respectively (Table 1 & 2). Not all samples taken in autumn at the Bligh Bank concession area (BBC) and the Bligh Bank reference area (BBR) were used for analysis as time was restricted. Based on random selection respectively 10 and 11 samples were chosen to work on. As some sample stations on the Thorntonbank in the Western concession area (WTA) and the border zone (WTC) were in close vicinity of the wind turbines or electricity cables, not all stations could be sampled. 6 and 12 samples could be taken for WTA and WTC respectively. During the Year-0 campaign of the C-Power wind farm, a stratified random sampling design was used.

The sample stations on the sandbanks offer information on the direct impact of construction (loss of habitat, change in community structure by introduction of hard substrates, protection of populations by banning fishery inside the wind farm…). The sample stations in the gullies and the reference stations could show the possible effects of the (increased) fishery pressure in the vicinity of the functioning wind farm instead.

Table 1
The sample locations with their respective codes and the sampled stations in 2008

Sample location	Code	Station numbers
Thorntonbank - Western concession area	WTA	1-11
Thorntonbank - Eastern concession area	WTB	1-19
Thorntonbank - North-Western border zone	WTC	1-6
Thorntonbank - South-Eastern border zone	WTC	7-15
Thorntonbank - reference area: border zone	WTR	1-3 en 13-15
Thorntonbank - reference area: top	WTR	4-12
Goote Bank - reference area: border zone	BGR	1-4 en 13-16
Goote Bank - reference area: top	BGR	5-12
Bligh Bank - concession area	BBC	5,7,8,13,20, 24,25,27,30,31
Bligh Bank - border zone	BBR	1,2,4,6,8,9,12,14,16-18

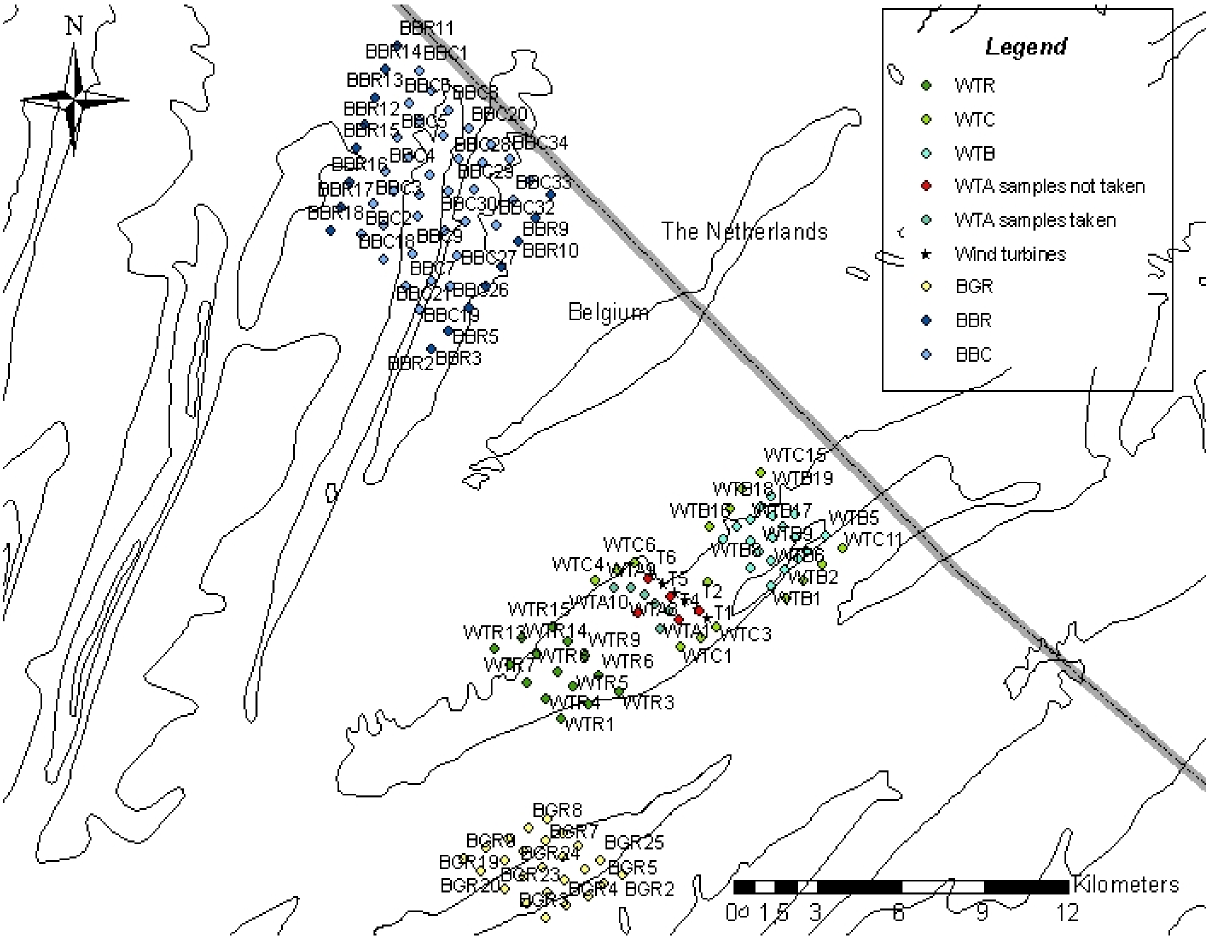

Figure 1. The sample stations of 2008: Bligh Bank (BBC, BBR), Thorntonbank (WTA, WTB, WTC, WTR) and Goote Bank (BGR).

Table 2
Number of stations at each sample location during the 2005 and 2008 campaigns

Sample location	Number of stations			
	Spring 2005 (Year-0 C-Power)	Autumn 2005 (Year-0C-Power)	Spring 2008 (Year-1 C-Power) (Year-0 Belwind)	Autumn 2008 (Year-1 C-Power) (Year-0 Belwind)
WTA	11	11	/	7
WTB	19	19	/	19
WTC	15	15	/	13
WTR	15	15	/	15
BGR	16	15	25	25
BBC	/	/	35	35
BBR	/	/	18	18
Total	76	75	78	132

The macrobenthos was sampled from the research vessel the '*Belgica*' using a Van Veen grab (sampling area: 0.1 m²) (Figure 2). Before opening the Van Veen grab, one core sample (diameter 27 mm) was taken for physical-chemical analysis while the depth of the anoxic layer (change in color from 'grey-yellow' to 'gray-black', indicating the start of the H_2S layer) was measured with a ruler. The collected sediment was then rinsed over a sieving table (mesh width 1 mm) (Figure 3) and the remaining residu was collected and fixed with an 8% formaldehyde-seawater solution.

Figure 2. Van Veen sampling on board of Belgica RV and sieving over a mm sieve (before fixation of the sample) (photo's Marijn Rabaut).

6.2.2. Analyses

6.2.2.1. Abiotic analysis

The distribution of macrobenthic communities is controlled by the type of sediment (e.g. median grain size and mud content), which is related to an even bigger set of environmental conditions like current velocity and the level of organic material in the sediment (Gray, 1974; Creutzberg *et al.*, 1984; Buchanan, 1984; Snelgrove and Butman, 1994). Thanks to this correlation, the characterization of the sediment is important for the ecological evaluation of the direct and indirect effects of the wind farms.

The grain size partition has been determined with a Malvern Mastersizer 2000G, hydro version 5.40. It uses a laser diffraction method with a measuring range of 0.02 – 2000 µm so the median grain size and the proportion of the Wentworth fractions can be determined. The fractions are given as volume percentages (> 4µm to >1600µm):

- < 4µm: clay
- 4-63µm: silt
- 63-125 µm: very fine sand
- 125-250µm: fine sand
- 250-500µm: medium sand
- 500-850µm: coarse sand
- 1000-2000µm: fine gravel – mostly shell material
- 2000µm: coarse gravel – mostly shell material

The total amount of organic material was determined per sample by weighing the difference between the dry weight (24 hours by 100°C) and the weight after 24 hours by 500°C (Heiri *et al.*, 2001).

6.2.2.2. Biotic analysis

6.2.2.2.1. Macrofauna analysis

The samples were stained with *'Rose Bengal'* and rinsed over a 1 mm sieve. The macrobenthic organisms were then extracted, identified upon the species level where possible and counted. A higher taxonomic level was permitted when the species level could not be defined. Nematoda, Pisces and rare species (all species found in less than three samples with less than two individuals per sample) were excluded from the analyses as they are not efficiently sampled with a Van Veen grab or not standard remain on a 1 mm sieve. The standardized species list can be found in Annex 2 – Systematic species list of macrobenthos.

The most recent systematic-taxonomic literature as well as species lists for the BPNS were consulted:

- Amphipoda: Lincoln, 1979
- Bivalvia: Tebble, 1966; De Bruyne, 1994
- Cumacea: Jones, 1976
- Decapoda: Adema, 1991
- Isopoda: Naylor, 1972
- Polychaeta: Hartmann-Schröder, 1996
- Other: Hayward & Ryland, 1995; Fish & Fish, 1996; Degraer *et al.*, 2006

Afterwards, the organisms were stored per species and per sample in a 4% neutralized formaldehyde solution at the Marine Biology Research Group (Biology Department, Ghent University).

6.2.2.2.2. Diversity

For the analysis of diversity, Hill's diversity indices were calculated (Hill 1973). Hill defined a set of diversity numbers of different order, each giving weight to a certain set of species (Heip *et al.*,1998). In this study, the most frequent indices (order 0, 1, 2 and infinity) are given. N_0 attributes the same weight to all species, independent of their abundance. It can be seen as the species richness, the number of species in the sample. N_1 gives less weight to rare species while N_2 gives more weight to abundant species. N_{inf}, also called the "dominance index", only takes into account the most common species. The diversity numbers of different orders lay emphasis on different aspects of the community. Giving these diversity numbers of different orders is therefore good practice to characterize a community. For more detailed information and the actual formulas, Hill (1973) and Heip *et al.* (1998) can be consulted.

6.2.2.2.3. Biomass

The total biomass per species was obtained in three ways. The first method involved the conversion factors of Brey (2001). These allow a determination of the ash free dry weight (AFDW) biomass through a conversion of the wet weight (WW). The biomass of Amphipoda, Mysida, Decapoda and *Nephtys cirrosa* was calculated with a second method: length/weigth regressions. When neither conversion factors nor regressions existed for a certain species, a third method was used: weight loss by cremation. Per sample and per (higher) taxon, every organism was placed in either an aluminium cupel (smaller organisms) or a small clean porcelain cup (bigger organisms). They were dried for 24 hours by 110°C in an oven. After cooling in an exsiccator, the cupels and cups were weighed (dry weight, DW) and put in a muffle furnace (2 hours by 480°C). They were cooled again in an exsiccator before their final weighing (ash weight, AW). The ash free dry weight (AFDW) is the difference between the dry (DW) and ash weight (AW).

6.2.2.2.4. Productivity

To estimate the daily production of the benthic macrofauna, the general allometric equation defined by Edgar (1990) was used. This equation relates daily macrobenthic production P (µg/day) to ash-free dry weight B (µg) and water temperature T (°C). As the water temperature varied between 14.5 °C and 15.4 °C, a mean temperature of 15°C was used for all samples. Productivity estimations of macrobenthic communities are important for the evaluation of food availability for demersal fish. However it is rarely estimated due to methodological and sampling difficulties. Using Edgar's method, productivity can be estimated. The productivity will be underestimated in some samples as the ash-free dry weight of some individuals was below the detection limit and was registered as 0 µg.

6.2.2.3. Data analysis

The following data were collected per sample station: date, location, depth, time, weather conditions, sediment composition, species, number of individuals per species and total biomass per species.

The number of individuals per sample and per species was converted to number of individuals per m² (abundance). A few values were determined following standardized methods for macrobenthos of the Belgian part of the North Sea (Degraer, 1999). These values are: diversity (species richness and Hill's diversity indices), density (ind./m²), biomass (g ash free dry weight (AFDW)/m²) and productivity (method of Edgar, 1990).

The values of statistical variables were calculated with the programs Statistica 7 (Mann-Whitney U tests, Wilcoxon Matched Pairs Test) and primer v6 (Plymouth Routines in Multivariate Ecological Research) (Hill's diversity indices). Distribution figures were created with the program ArcView GIS.

Amongst the univariate statistical procedures, we chose the non parametric tests, because it is very likely that the conditions for parametric tests are not fulfilled.

The community structure of the macrobenthos and the relationships with other communities are best analyzed in a multivariate way (e.g. ordination, classification) taking into account the relationship between the macrobenthos and the abiotic environment. The multivariate analyses are done with the program Primer v6. Similarity between different samples is based on the occurrence or absence of species and their densities (Bray-Curtis similarity). The Bray-Curtis similarity matrices were used to build up non-metric multidimensional scaling (MDS) plots. MDS plots give reliable information on relationships between data points. The stress value indicates how well the relationships are represented. Only results with a stress value lower than 0.2 are reliable (Clark 1993). Simper analysis allows us to detect which species contribute to the distinctness of certain communities as it gives similarity and dissimilarity percentages.

6.2.3. Data storage

All data acquired are available within the BMDC database of MUMM (http://www.mumm.ac.be/datacentre/).

6.2.4. Display of results

All numbers are depicted as average ± standard error (SE). The sample locations and stations are abbreviated as in Table 1.

6.3. Results

6.3.1. Abiotic analysis

6.3.1.1. Median grain size

The mean median grain size lies between 350 and 500 µm for all of the sample locations (Table 3). The median grain size is lower during autumn than spring on the Bligh Bank and the Goote Bank. Regarding autumn, the values on the Thorntonbank were found in a lower range than on the Bligh Bank whereas the mean median grain size value of the Goote Bank was intermediate.

Table 3
Mean median grain size (d50) ± SE (µm) for each sample location during spring and autumn

	Spring		Autumn	
Sample location	Mean median grain size (µm)	SE	Mean median grain size (µm)	SE
BBC	441.51	63.06	431.94	50.66
BBR	480.74	98.16	455.49	61.01
BGR	377.60	40.06	370.68	83.44
WTA	-	-	374.58	26.85
WTB	-	-	386.16	41.56
WTC	-	-	393.57	71.87
WTR	-	-	362.73	95.02

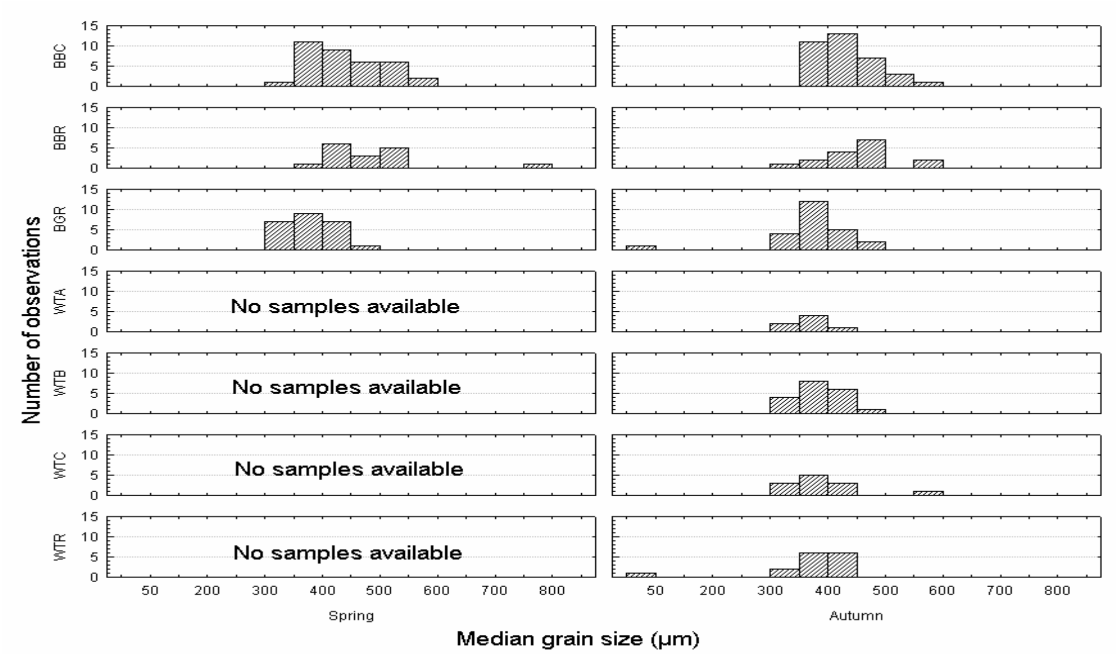

Figure 3. Distribution of median grain size (µm) at the different sample locations.

The distribution of the median grain size at the different sample locations with a seasonal distinction can be found in Figure 3. The spring and autumn observations have a comparable range. Two samples have a very low median grain size (WGR9: 25.7 µm and WTR14: 41.6 µm) which is reflected in the two observations lower than 50 µm. One spring sample, BBR 8, has a very high median grain size (799.1 µm).

When comparing the Bligh Bank locations (BBC and BBR) with BGR (reference location), we notice the dissimilarities in median grain size distribution. BBC and BBR both have some stations with higher median grain size than BGR during spring and autumn. Table 4 confirms these findings as a significant difference in median grain size can be seen during both spring and autumn between BBC and BGR (Mann-Whitney U-test, spring: $p = 0.000122$ – autumn: $p = 0.000288$) and between BBR and BGR (Mann-Whitney U-test, spring: $p = 0.000017$ – autumn: $p = 0.000268$). There seems to be no difference in median grain size between seasons on the Bligh Bank.

The Thorntonbank locations (WTA, WTB, WTC and WTR) show a higher similarity in median grain size with BGR than the Bligh Bank locations. Table 5 shows no significant differences in median grain between any of the Thorntonbank locations and the Goote Bank.

Table 4
Significance of the differences based on median grain size in spring (above grey cells), autumn (beneath grey cells) (Mann-Whitney U-tests, $p<0.05$: significant difference) and between spring and autumn (grey cells) (Wilcoxon Matched Pairs Test, $p<0.05$: significant difference) for the Bligh Bank and the Goote Bank

	BBC	BBR	BGR
BBC	0,544496	0.167466	0.000122
BBR	0.135679	0,534926	0.000017
BGR	0.000288	0.000268	0,607053

Table 5
Significance of the differences based on median grain size (left side beneath grey cells) in autumn for the Thorntonbank and the Goote Bank (Mann-Whitney U-tests, $p<0.05$: significant difference)

	WTA	WTB	WTC	WTR	BGR
WTA		0.664612	0.498963	0.860116	0.850107
WTB	-		0.871132	0.903378	0.883341
WTC	-	-		0.625586	0.568351
WTR	-	-	-		1.000000
BGR	-	-	-	-	

A spatial representation can be seen in the median grain size bubble plots in Annex 3 – Bubble plots.

6.3.1.2. Mud content

The mean mud content never exceeds 6% (Table 6). During spring, no mud could be detected on the Bligh Bank and Goote Bank (Table 6 and Figure 4). The same applies for BBC, WTA and WTB during autumn.

Table 6
Mean mud content (%) ± SE (%) for each sample location during spring and autumn

	Spring		Autumn	
Sample location	Mean mud content	SE	Mean mud content	SE
BBC	0	0	0	0
BBR	0	0	0.3079	1.23150
BGR	0	0	4.2679	18.9481
WTA	-	-	0	0
WTB	-	-	0	0
WTC	-	-	0.2177	0.65190
WTR	-	-	5.8540	22.42960

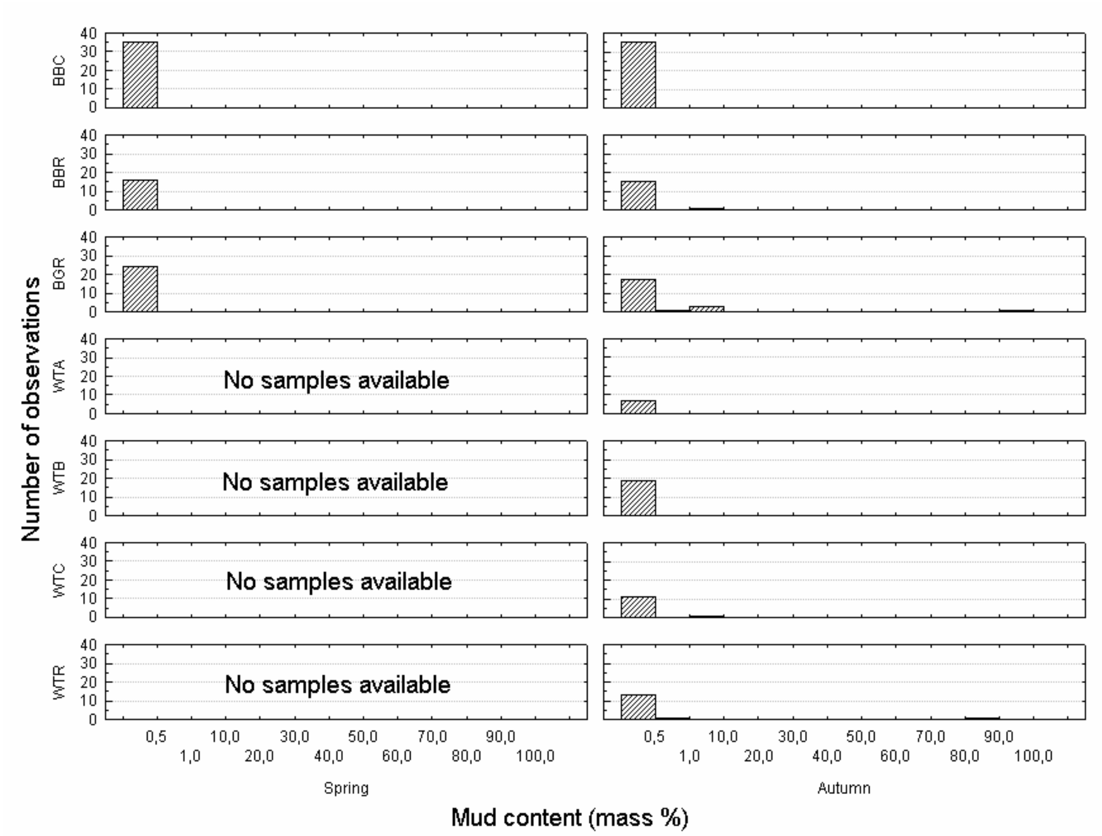

Figure 4. Distribution of mud content (%) at the different sample locations. The observations lower than 0.5% are from samples without any mud.

Figure 4 shows some very high observations of mud content in BGR and WTR during autumn: samples BGR9 (93.133%) and WTR 14 (86.928%). Statistically speaking, no trends could be detected for the Bligh Bank during spring because of the absence of mud (Table 7). In autumn, there is a significant difference in mud content between BBC and BGR (Mann-Whitney U-test, autumn: $p = 0.005190$) in which BGR has a high mud content than BBR. There is also a seasonal significant difference in BGR (Wilcoxon Matched Pairs Test, $p = 0.043115$) with higher mud content in autumn.

Table 8 reveals only one significant difference for the Thorntonbank, between WTB and BGR (Mann-Whitney U-test, autumn: $p = 0.036930$) with higher mud content in the samples of BGR.

Table 7
Significance of the differences based on mud content in spring (above grey cells), autumn (beneath grey cells) (Mann-Whitney U-tests, $p<0.05$: significant difference) and between spring and autumn (grey cells) (Wilcoxon Matched Pairs Test, $p<0.05$: significant difference) for the Bligh Bank and the Goote Bank.

	BBC	BBR	BGR
BBC	-	-	-
BBR	0.139136	-	-
BGR	0.005190	0.238984	0.043115

Table 8
Significance of the differences based on mud content (left side beneath grey cells) in autumn for the Thorntonbank and the Goote Bank (Mann-Whitney U-tests, p<0.05: significant difference)

	WTA	WTB	WTC	WTR	BGR
WTA		-	0.267120	0.322749	0.196775
WTB	-		0.070463	0.106186	0.036930
WTC	-	-		0.874566	0.627221
WTR	-	-	-		0.531624
BGR	-	-	-	-	

6.3.1.3. Total organic matter

The mean total organic matter lies between 0.10 % and 0.35 % for all of the sample locations (Table 9). Seasonal variation can only be seen on the Bligh Bank and the Goote Bank. There seems to be less total organic matter during autumn than during spring (Table 9 and Figure 5).

Table 9
Mean total organic matter (%) ± SE (%) for each sample location during spring and autumn

	Spring		Autumn	
Sample location	Total organic matter	SE	Total organic matter	SE
BBC	0.2123	0.0660	0.1800	0.0969
BBR	0.2207	0.0662	0.1544	0.0539
BGR	0.3111	0.1079	0.2283	0.1252
WTA	-	-	0.1599	0.0201
WTB	-	-	0.1488	0.0268
WTC	-	-	0.2013	0.0516
WTR	-	-	0.2203	0.2253

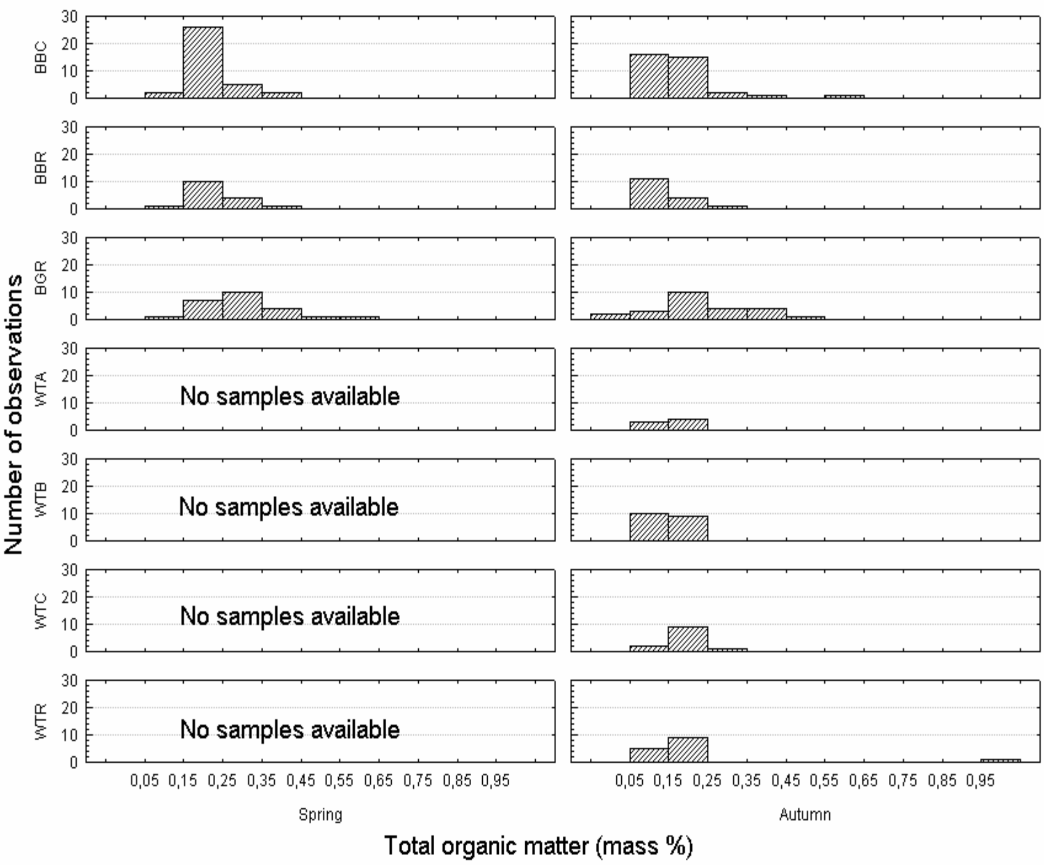

Figure 5. Distribution of total organic matter at the different sample locations

The distribution of the total organic matter at the different sample locations with a seasonal distinction can be found in Figure 5. As can be noticed in Table 9, the total organic matter during autumn seems to be lower than during spring. The observations in BGR (autumn), lower than 0.05, are from samples (BGR22 & BGR 23) from which no information on total organic matter is available due to mislabeling in the laboratory. The very high observation of total organic matter in WTR (autumn) comes from sample station WTR14 (1.0249 %).

When comparing the Bligh Bank locations (BBC and BBR) with BGR (reference location), we notice the dissimilarities in total organic matter distribution. BBC has more stations with high values for total organic matter than BBR both in spring and autumn. BGR shows a larger range in total organic matter than BBC and BBR during both spring and autumn. Table 10 confirms these findings as a significant difference in total organic matter can be seen during both spring and autumn between BBC and BGR (Mann-Whitney U-test, spring: $p = 0.000107$ - autumn: $p = 0.000985$) and between BBR and BGR (Mann-Whitney U-test, spring: $p = 0.002619$ - autumn: $p = 0.001032$). There are differences in total organic matter between seasons on all the locations on the Bligh Bank and Goote Bank (Wilcoxon Matched Pairs Test, BBC: $p = 0.008776$ - BBR: $p = 0.015086$ - BGR: $p = 0.000255$).

The Thorntonbank locations (WTA, WTB, WTC and WTR) show a higher similarity in total organic matter amongst each other than with BGR. Table 11 shows significant differences in total organic matter between WTA and WTC (Mann-Whitney U-test, autumn: $p = 0.042523$), WTB and WTC (Mann-Whitney U-test, autumn: $p = 0.002053$), WTB and BGR (Mann-Whitney U-test, autumn: $p = 0.002627$) (Table 12).

Table 10
Significance of the differences based on total organic matter in spring (above grey cells), autumn (beneath grey cells) (Mann-Whitney U-tests, p<0.05: significant difference) and between spring and autumn (grey cells) (Wilcoxon Matched Pairs Test, p<0.05: significant difference) for the Bligh Bank and the Goote Bank

	BBC	BBR	BGR
BBC	0,008776	0.490060	0.000107
BBR	0.208177	0,015086	0.002619
BGR	0.000985	0.001032	0,000255

Table 11
Significance of the differences based on total organic matter (left side beneath grey cells) in autumn for the Thorntonbank and the Goote Bank (Mann-Whitney U-tests, p<0.05: significant difference)

	WTA	WTB	WTC	WTR	BGR
WTA		0.370164	0.042523	0.597027	0.065365
WTB	-		0.002053	0.193340	0.002627
WTC	-	-		0.130371	0.853549
WTR	-	-	-		0.071169
BGR	-	-	-	-	

6.3.2. Biotic variables

6.3.2.1. Density and Diversity

6.3.2.1.1. Density

All samples taken in spring at the Bligh Bank and the Goote Bank are characterized by low densities (max. 900 ind./m²). In autumn a broader range in densities is found, varying from low to higher densities (max. 3500 ind./m²). However, besides BGR most of the samples have low densities. Significant lower densities in spring compared to autumn can be found at locations BBC (Wilcoxon Matched Pairs Test, $p = 0.005062$) and BGR (Wilcoxon Matched Pairs Test, $p = 0.000144$). The concession area BBC as well as the border zone BBR and the reference site BGR show a comparable range in densities in spring, with the broadest range in the reference site and smallest in the concession area. Significant differences in densities can be found between BBC and BBR (Mann-Whitney U-test, p = 0.021397) and between BBC and BGR (Mann-Whitney U-test, p = 0.043514). In autumn, the concession area and the border zone have a comparable range in densities, while the reference site has a much broader range. No significant differences could be found between the sample locations in autumn (Mann-Whitney U-tests, p>0.05) (Figure 6 and Table 12).

For the Thorntonbank, a broad range (varying from low to high densities) is present at all sites. The range is broadest at the eastern concession area WTB (100-3500 ind./m²) and smallest in the western concession area WTA (70-1500 ind./m²). In autumn no significant differences in density were found between the different sampling locations at the Thorntonbank and the Goote Bank (Mann-Whitney U-tests, p > 0.05) (Figure 6 and Table 13).

Table 12
Significance of the differences based on total density in spring (above grey cells), autumn (beneath grey cells) (Mann-Whitney U-tests, p<0.05: significant difference) and between spring and autumn (grey cells) (Wilcoxon Matched Pairs Test, p <0.05: significant difference) for the Bligh Bank and the Goote Bank

	BBC	BBR	BGR
BBC	0,005062	0.021397	0.043514
BBR	0.971895	0,182315	0.657828
BGR	0.116641	0.087927	0,000144

Table 13
Significance of the differences based on total density in autumn for the Thorntonbank and the Goote Bank (Mann-Whitney U-tests, p<0.05: significant difference)

	WTA	WTB	WTC	WTR	BGR
WTA		0.257075	0.453463	0.370331	0.119722
WTB	-		0.865475	0.515147	0.279879
WTC	-	-		0.293915	0.382812
WTR	-	-	-		0.129539
BGR	-	-	-	-	

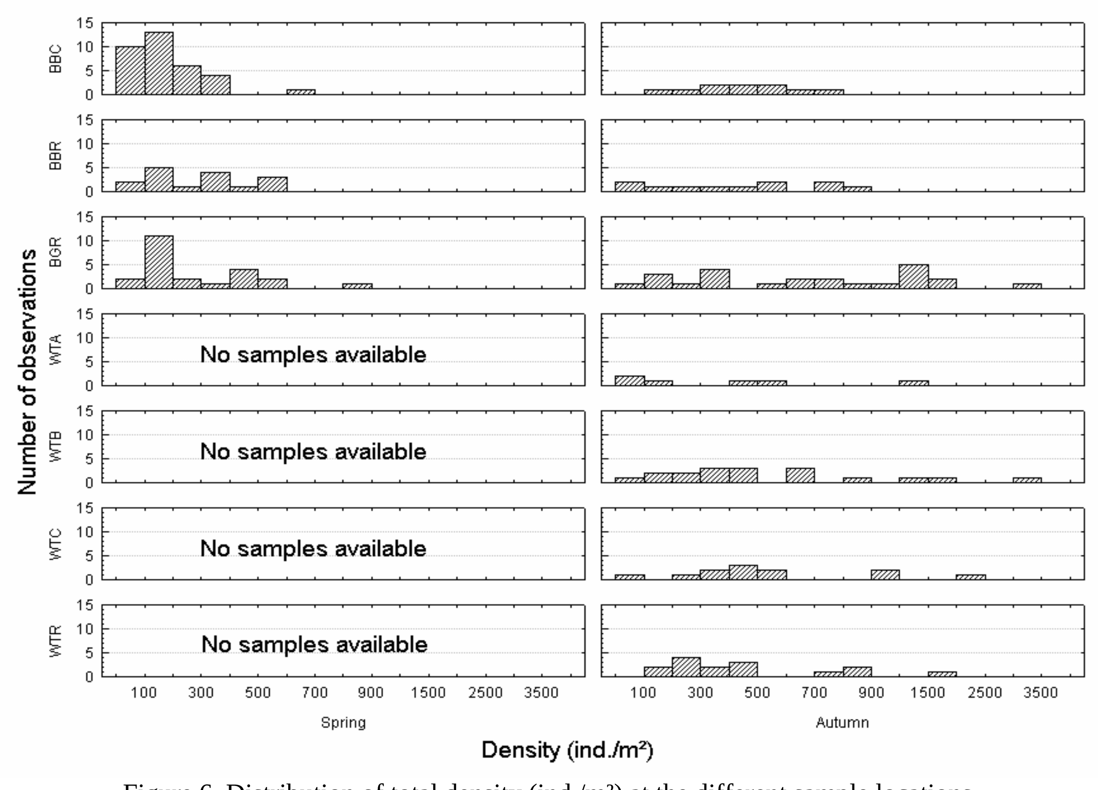

Figure 6. Distribution of total density (ind./m²) at the different sample locations.

6.3.2.1.2. Diversity – N0

For the species richness (N_0), a comparable but less pronounced result as for density is found at the Bligh Bank and the Goote Bank. Higher species richness can be found during autumn (max. 18 to 26 species/0.1 m²) than during spring (max. 16 to 18 species/0.1 m²). Significant differences in species richness are found between spring and autumn at BBC (Wilcoxon Matched Pairs Test, p = 0.009345) and BGR (Wilcoxon Matched Pairs Test, p = 0.000155). In spring a comparable range in species richness is found at the Bligh Bank and the Goote bank. However, at BBC most samples have a low species richness, while at BBR and BGR the species richness is more evenly distributed over the range. Significant differences in species richness are found between BBC and BBR (Mann-Whitney U-test, p = 0.023946) and between BBC and BGR (Mann-Whitney U-test, p = 0.009540). In autumn, BGR has a broader range in species richness than BBC and BBR, which have a more comparable range. No significant differences in species richness are found between these sites in autumn. (Mann-Whitney U-test, p >0.05) (Figure 7 and Table 14).

For the Thorntonbank and Goote Bank, a lower number of species is found at the western concession area WTA (max. 12) than at the other sites (max. 20 to 26). The range is also narrower at WTA. BGR has the highest species richness and the broadest range, with N_0 fairly evenly distributed over the range (Figure 8). Except for WTB, significant differences in species richness are found between WTA and the other sites at the Thorntonbank and the Goote Bank (Table 15).

Table 14
Significance of the differences based on species richness (N_0) in spring (above grey cells), autumn (beneath grey cells) (Mann-Whitney U-tests, p<0.05: significant difference) and between spring and autumn (grey cells) (Wilcoxon Matched Pairs Test, p<0.05: significant difference)for the Bligh Bank and the Goote Bank

	BBC	BBR	BGR
BBC	0,009345	0.023946	0.009540
BBR	0.375149	0,358952	0.818518
BGR	0.805025	0.181191	0,000155

Table 15
Significance of the differences based on species richness, N_0 in autumn (right side, above grey cells) for the Thorntonbank and the Goote Bank (Mann-Whitney U-tests, p<0.05: significant difference)

	WTA	WTB	WTC	WTR	BGR
WTA		0.065629	0.029845	0.015201	0.010157
WTB	-		0.172147	0.455290	0.076471
WTC	-	-		0.658392	0.469145
WTR	-	-	-		0.271222
BGR	-	-	-	-	

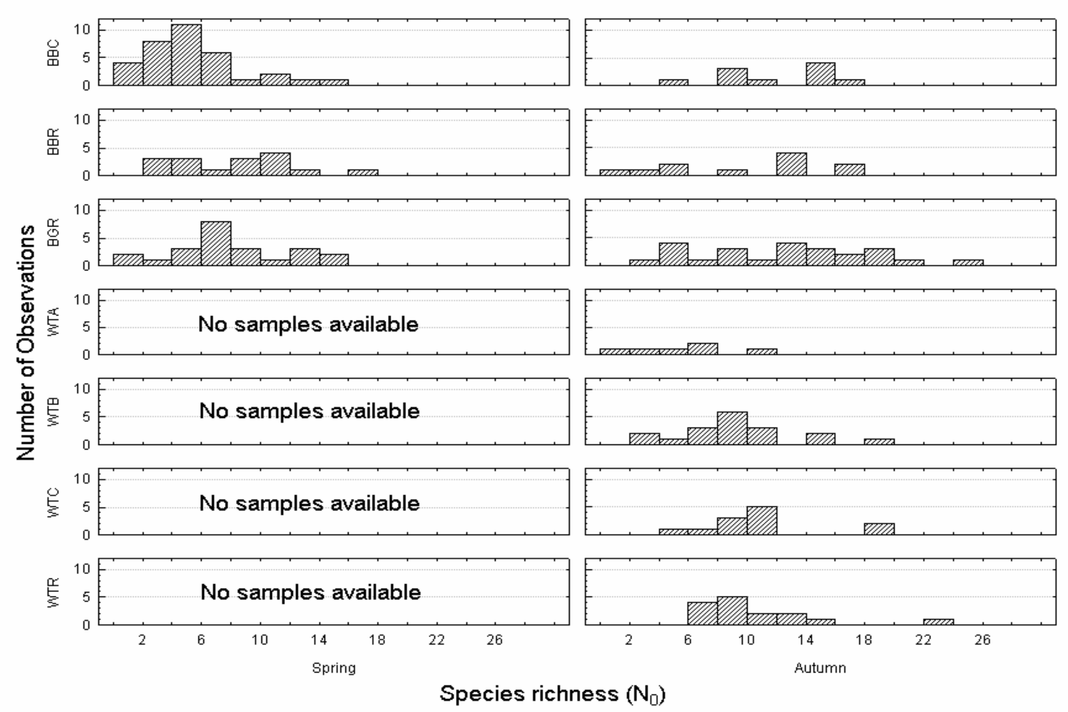

Figure 7. Distribution of species richness (N_0) at the different sample locations.

6.3.2.1.3. Diversity – N1

On the Bligh Bank and Goote Bank, both between the different sites and between spring and autumn, a fairly comparable range in values for N_1 is present. In autumn, little higher values can be found than in spring. In spring, many samples have a low value for $N_{1,}$ which contributes to an uneven distribution of N_1. In autumn, except for BGR, a more evenly distribution of N_1 values is present. Significant differences in N_1 are present between BBC and BBR (Mann-Whitney U-test, p = 0.018769) and BBC and BGR (Mann-Whitney U-test, p = 0.023764) in spring. BBC (Wilcoxon Matched Pairs Test, p = 0.009345) and BGR (Wilcoxon Matched Pairs Test, p = 0.030815) differ significantly between spring and autumn in N_1 values (Figure 8 and Table 16).

On the Thorntonbank, it is noticed that a narrow range in the N_1 value is present at the western concession area WTA (between 0 and 6). The other sites on the Thorntonbank and Goote Bank have a broader distribution of N1, ranging from 0 to 10 and 14 (Figure 10). Significant differences in N_1 are present between WTA and all other sites on the Thorntonbank and Goote Bank as well as between WTB and WTC and BGR and WTC (Table 17).

Table 16
Significance of the differences based on species richness (N_1) in spring (above grey cells), autumn (beneath grey cells) (Mann-Whitney U-tests. p<0.05: significant difference)and between spring and autumn (grey cells) (Wilcoxon Matched Pairs Test. p<0.05: significant difference)for the Bligh Bank and the Goote Bank

	BBC	BBR	BGR
BBC	0,009345	0.018769	0.023764
BBR	0.231267	0,533695	0.775246
BGR	0.064023	0.943345	0,030815

Table 17
Significance of the differences based on N_1 (right side, above grey cells) in autumn for the Thorntonbank and the Goote Bank (Mann-Whitney U-tests, p<0.05: significant difference)

	WTA	WTB	WTC	WTR	BGR
WTA		0.038766	0.001997	0.001077	0.002637
WTB	-		0.008674	0.039319	0.274436
WTC	-	-		0.204560	0.029165
WTR	-	-	-		0.260237
BGR	-	-	-	-	

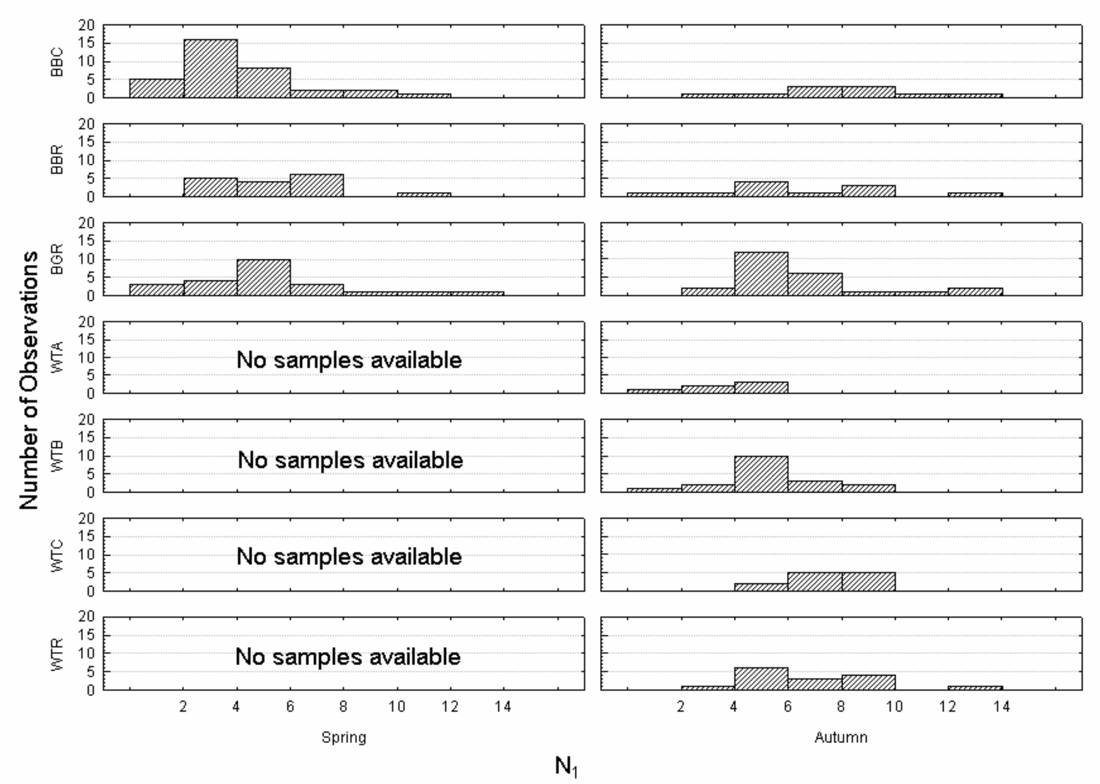

Figure 8. Distribution of species richness (N_1) at the different sample locations.

6.3.2.1.4. Diversity – N2

For N_2 in spring on the Blight Bank, both the concession area and the border zone have the same range of values (ranging from 1 to 9). On the Goote Bank, the maximum is somewhat higher (11). No significant differences can be found between the different sites on the Bligh Bank and Goote bank in spring (Mann-Whitney U-tests, p > 0.05). In autumn some differences in range can be observed between the sites, with BBC having the broadest range (0 to 11). A significant difference in N_2 value in autumn is observed between BBC and BGR (Mann-Whitney U-tests, p = 0.049367). If spring and autumn are compared, a significant difference is present for BBC (Wilcoxon Matched Pairs Test, p = 0.006911) (Figure 9 and Table 18).

As with the previous diversity indices, WTA has a smaller range than the other sites at the Thorntonbank and the Goote Bank. WTC also has a small range, but with a higher maximum than WTA. BGR has the broadest range and the highest maximum for N_2. Between WTA and WTC (Mann-Whitney U-test, p = 0.001443) as well as between WTA and WTR (Mann-Whitney U-test, p = 0.003094) and WTA and BGR (Mann-Whitney U-test, p = 0.029437), significant differences in N_2 are present. Significant differences are also present between WTB and WTC (Mann-Whitney U-test, p = 0.005924) and between BGR and WTC (Mann-Whitney U-test, p = 0.012407) (Figure 9 and Table 19).

Table 18
Significance of the differences based on species richness (N_2) in spring (above grey cells), autumn (beneath grey cells) (Mann-Whitney U-tests, $p<0.05$: significant difference)and between spring and autumn (grey cells) (Wilcoxon Matched Pairs Test, $p<0.05$: significant difference)for the Bligh Bank and the Goote Bank

	BBC	BBR	BGR
BBC	0,006911	0.075371	0.081784
BBR	0.259876	0,328066	0.977222
BGR	0.049367	0.522432	0,201452

Table 19
Significance of the differences based on N_2 (right side, above grey cells) in autumn for the Thorntonbank and the Goote Bank (Mann-Whitney U-tests, $p<0.05$: significant difference)

	WTA	WTB	WTC	WTR	BGR
WTA		0.125195	0.001443	0.003094	0.029437
WTB	-		0.005924	0.055338	0.576052
WTC	-	-		0.171793	0.012407
WTR	-	-	-		0.078253
BGR	-	-	-	-	

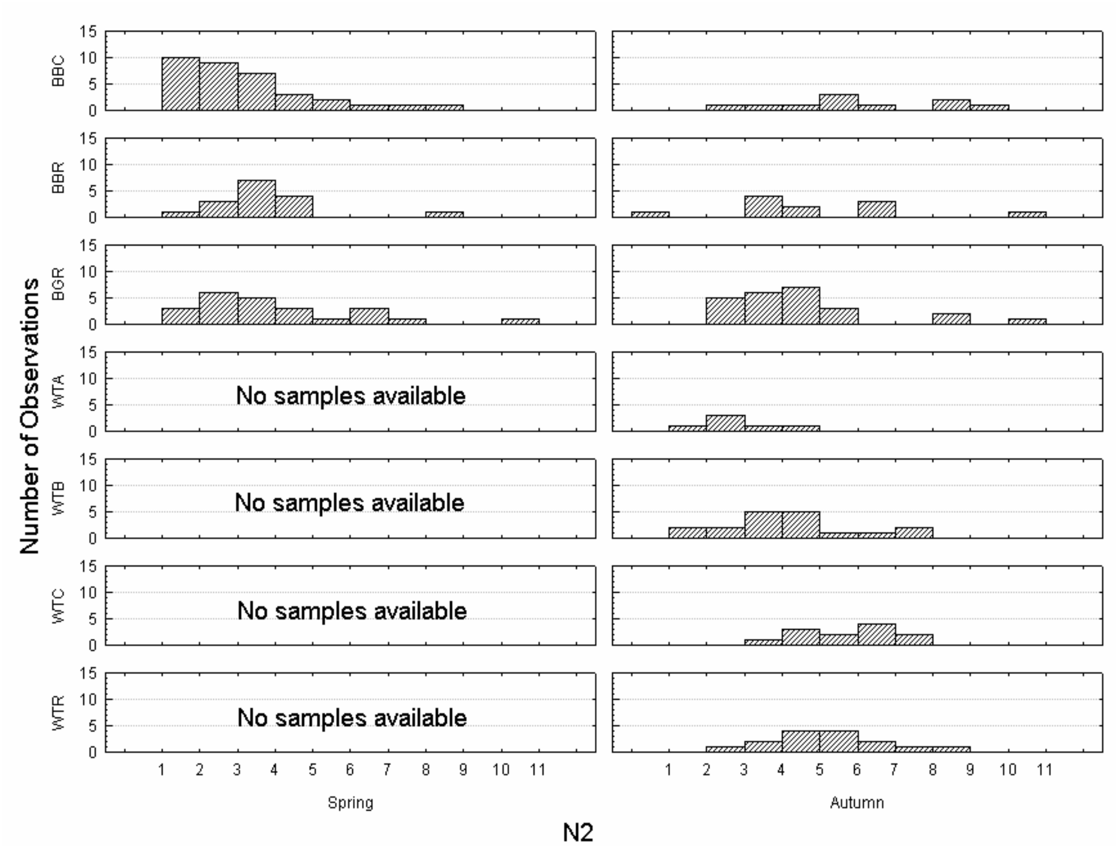

Figure 9. Distribution of species richness (N_2) at the different sample locations

6.3.2.1.5. Diversity – N_{inf}

Some differences in distribution range of N_{inf} are observed both between the different locations at the Bligh Bank and Goote Bank and between spring and autumn for those locations. The range of the concession area BBC is the same in spring and autumn (1 to 5) but is smaller than the range of BGR both in spring and autumn (from 1 to 7 and 6 respectively). BBR has a smaller range in spring than in autumn. Most sample stations at BBC and BBR in spring have a rather low value for N_{inf}. In autumn the values are more evenly distributed. No significant differences are found between the sites, neither in spring nor in autumn. No seasonality in N_{inf} values is present.

WTA is characterized by low values and a small range for N_{inf}. BGR and WTC have the broadest range, while WTC has the highest maximum (7). Significant differences in N_{inf} are present between WTA and WTC (Mann-Whitney U-test, p = 0.003691) as well as between WTA and WTR (Mann-Whitney U-test, p = 0.003971). Besides, WTB (Mann-Whitney U-test, p = 0.009798) and BGR (Mann-Whitney U-test, p = 0.009749) significantly differ from WTC (Figure 9 and Table 21).

Table 20
Significance of the differences based on species richness (N_{inf}) in spring (above grey cells), autumn (beneath grey cells) (Mann-Whitney U-tests, p<0.05: significant difference) and between spring and autumn (grey cells) (Wilcoxon Matched Pairs Test, p<0.05: significant difference)for the Bligh Bank and the Goote Bank

	BBC	BBR	BGR
BBC	0,202623	0.095686	0.149880
BBR	0.672655	0,061885	0.988606
BGR	0.167558	0.194486	0,447032

Table 21
Significance of the differences based on N_{inf} (right side, above grey cells) in autumn for the Thorntonbank and the Goote Bank (Mann-Whitney U-tests, p<0.05: significant difference)

	WTA	WTB	WTC	WTR	BGR
WTA		0.333606	0.003691	0.003971	0.276029
WTB	-		0.009798	0.067854	0.779747
WTC	-	-		0.317093	0.009749
WTR	-	-	-		0.080574
BGR	-	-	-	-	

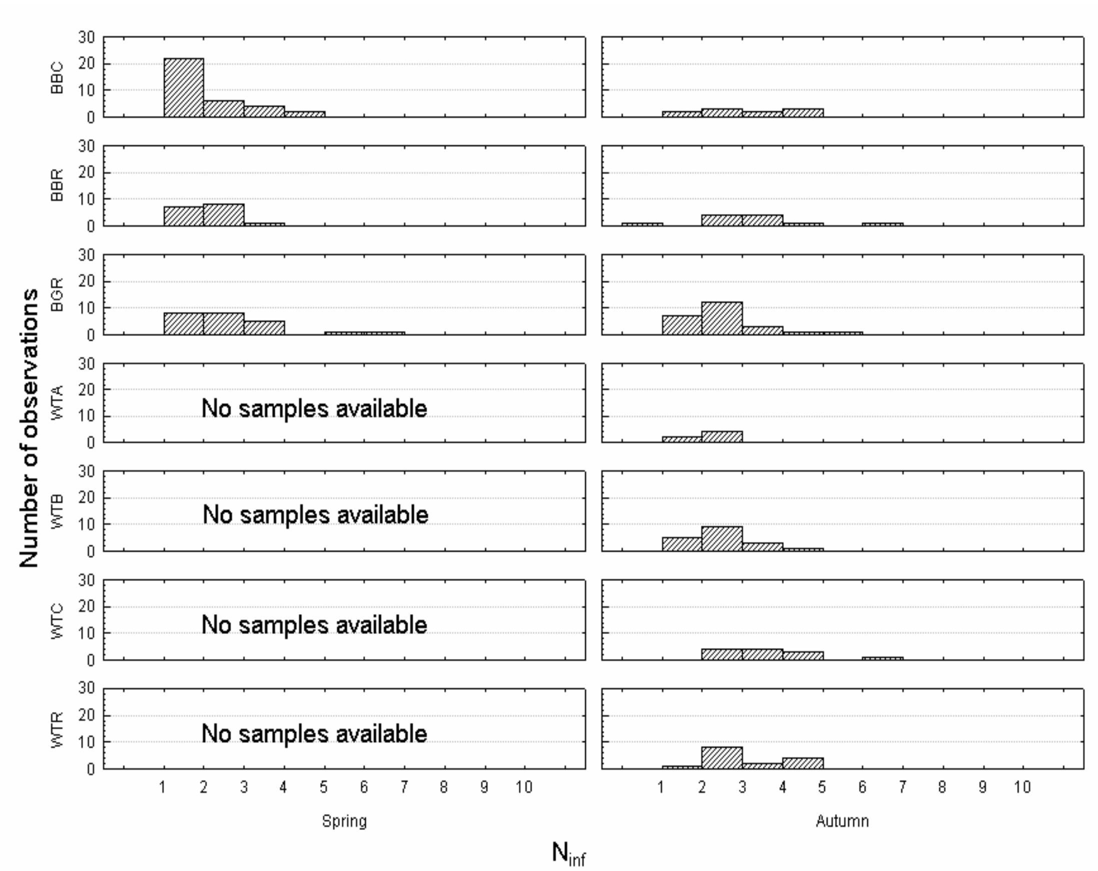

Figure 10. Distribution of species richness (N_{inf}) at the different sample locations

6.3.2.2. Biomass and Productivity

For the Bligh Bank and the Goote Bank, both in spring and autumn broad ranges in biomass are found at all locations, varying from 26 to 6000 mg/m². In spring more than 50% of all samples have a biomass lower than 1000 mg/m². In autumn more samples with a higher biomass are present. Only between BBC and BGR in autumn significant differences in biomass are present (Mann-Whitney U-tests, p = 0.045155). At BGR, seasonality has an effect on biomass as a significant difference is found between spring and autumn (Wilcoxon Matched Pairs Test, p = 0.026400) (Figure 11 and Table 22).

At the Thorntonbank and Goote Bank broad ranges in biomass are present (6 to 6000 mg/m²). Exept for BGR, most samples at each location have a biomass lower than 2000mg/m². Only BGR and WTR differ significantly in biomass (Mann-Whitney U-test, p = 0.026230) (Figure 11 and Table 23).

Table 22
Significance of the differences based on the biomass in spring (above grey cells), autumn (beneath grey cells) (Mann-Whitney U-tests, p<0.05: significant difference) and between spring and autumn (grey cells) (Wilcoxon Matched Pairs Test) for the Bligh Bank and the Goote Bank.

	BBC	BBR	BGR
BBC	0,168808	0,092071	0,216387
BBR	0,204970	0,722108	0,886480
BGR	0,045155	0,374361	0,026400

Table 23
Significance of the differences based on biomass (right side, above grey cells) in autumn for the Thorntonbank and the Goote Bank (Mann-Whitney U-tests, p<0.05: significant difference)

	WTA	WTB	WTC	WTR	BGR
WTA		0,423711	0,707933	0,102082	0,716655
WTB	-		0,799496	0,492117	0,121046
WTC	-			0,204560	0,364904
WTR	-				0,026230
BGR	-	-	-	-	

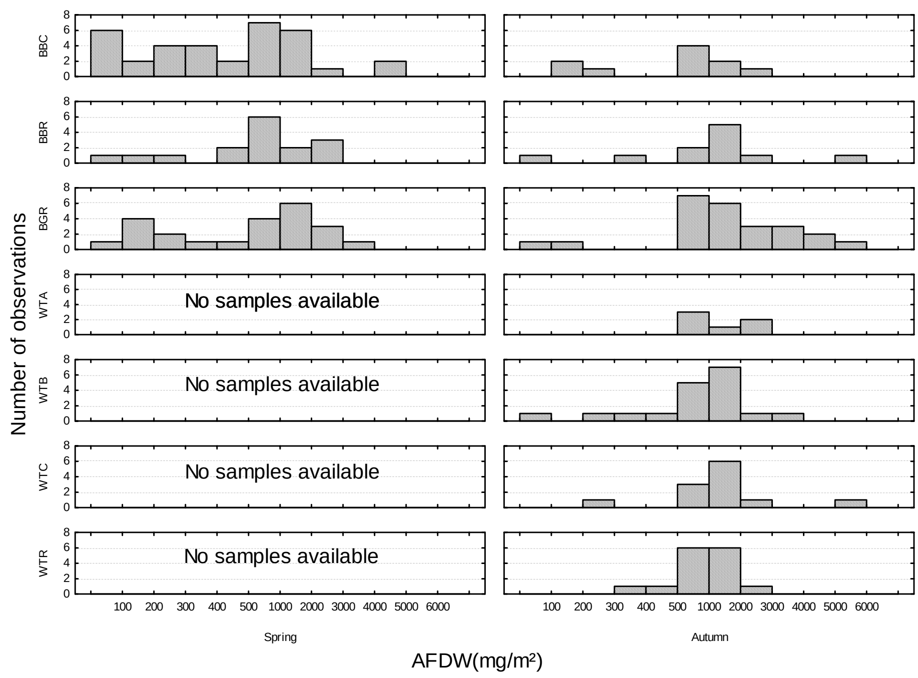

Figure 11. Distribution of biomass, AFDW (mg/m²) at the different locations

Most samples at the Bligh Bank and Goote Bank, both in spring and autumn, have a daily productivity lower than 10 mg/day.m^2. In spring highest productivity lays between 40 and 50 mg/day.m^2, in autumn it is between 30 and 40 mg/day.m^2. In spring, BBC and BGR have the same range. In autumn, all three locations have a comparable range. No significant differences in productivity are found between the locations BBC, BBR and BGR, neither in spring, nor in autumn. At BGR, productivity differs significantly between seasons (Wilcoxon Matched Pairs Test, p = 0.005306) (Figure 12 and Table 24).

At the Thorntonbank and Goote Bank, most samples have a low productivity, less than 10 mg/day$\cdot$m^2. The highest daily production is found at WTC (between 70 and 80 mg/day$\cdot$m^2) which also has the broadest range. BGR and WTR differ significantly in their daily productivity (Mann-Whitney U-test, p = 0.008616) (Figure 12 and Table 25).

Table 24
Significance of the differences based on productivity in spring (above grey cells), autumn (beneath grey cells) (Mann-Whitney U-tests, p<0.05: significant difference) and between spring and autumn (grey cells) (Wilcoxon Matched Pairs Test, p<0.05: significant difference)for the Bligh Bank and the Goote Bank

	BBC	BBR	BGR
BBC	0,332880	0.261416	0.370994
BBR	0.778196	0,328066	0.863979
BGR	0.150928	0.286423	0,028534

Table 25
Significance of the differences based on productivity (right side, above grey cells) in autumn for the Thorntonbank and the Goote Bank (Mann-Whitney U-tests, p<0.05: significant difference)

	WTA	WTB	WTC	WTR	BGR
WTA		1.000000	0.261055	0.350202	0.132690
WTB	-		0.235886	0.278077	0.162143
WTC	-	-		0.078984	0.591320
WTR	-	-	-		0.008616
BGR	-	-	-	-	

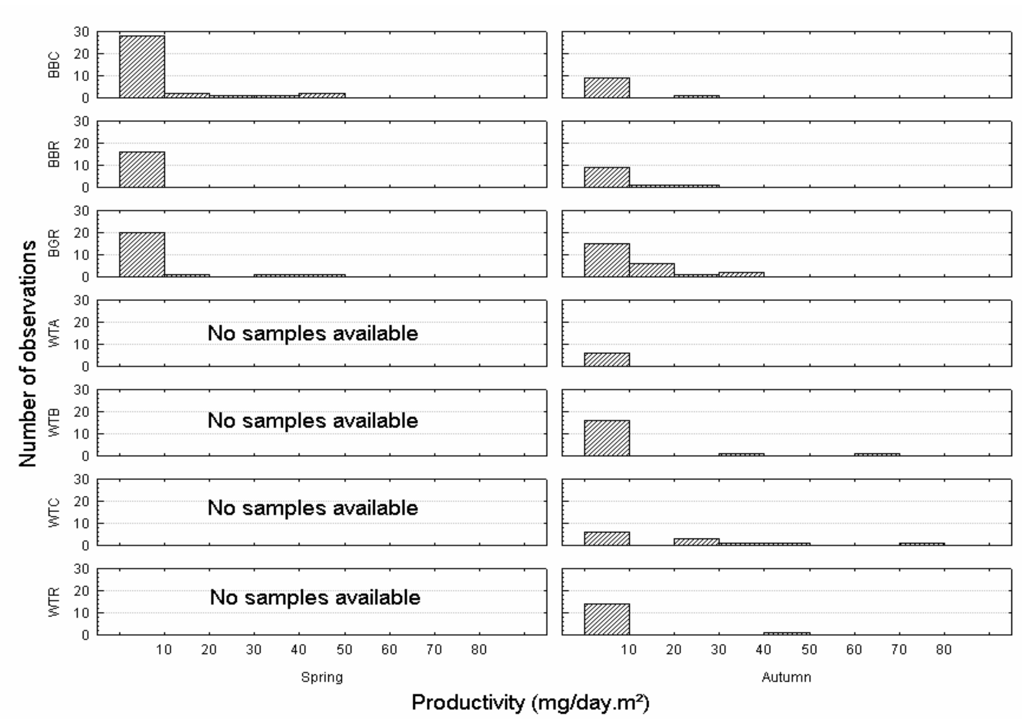

Figure 12. Distribution of productivity (mg/day.m^2) at the different locations

6.3.2.3. Species analysis

Dominant species were determined as species with a mean contribution of more than 15 % to the mean total density.

6.3.2.3.1. Belwind

In Table 26, the seasonal variability of the dominant species for the Bligh Bank and the Goote Bank is shown. *Nephtys cirrosa* is clearly the dominant species in all sample locations on the Bligh Bank during spring and autumn. Looking at the Goote Bank, *Nephtys cirrosa* is the dominant species during spring while during autumn, it is *Spiophanes bombyx*.

Table 26
Dominant species in the sample locations BBC, BBR and BGR and their mean contribution to the mean total density in terms of percentage

Spring			Autumn		
Sample location	Species	Mean contribution of a species in terms of percentage (%)	Sample location	Species	Mean contribution of a species in terms of percentage (%)
BBC	*Nephtys cirrosa*	83.30	BBC	*Nephtys cirrosa*	45.56
BBR	*Nephtys cirrosa*	77.91	BBR	*Nephtys cirrosa*	44.49
BGR	*Nephtys cirrosa*	64.87	BGR	*Spiophanes bombyx*	52.06
				Nephtys cirrosa	19.69

6.3.2.3.2. C-Power

The seasonal variability of the dominant species for the Goote Bank is shown in 3.3.3.1 Belwind. Since no samples were taken on the Thorntonbank during spring, *Nephtys cirrosa* was again the dominant species of this season. During autumn, the same trend can be seen on the Thorntonbank, though less prominent, since *Nephtys cirrosa* is joined by two other dominant species: *Spiophanes bombyx* (WTB, WTC, WTR) and *Nephtys caeca* (WTC).

Table 27
Dominant species in the sample locations WTA, WTB, WTC, WTR and BGR and their mean contribution to the mean total density in terms of percentage

Autumn			Autumn		
Sample location	Species	Mean contribution of a species in terms of percentage	Sample location	Species	Mean contribution of a species in terms of percentage
WTA	*Nephtys cirrosa*	69.06	WTC	*Nephtys cirrosa*	28.97
WTB	*Nephtys cirrosa*	55.44		*Nephtys caeca*	20.51
	Spiophanes bombyx	19.12		*Spiophanes bombyx*	16.68
WTR	*Nephtys cirrosa*	49.26			
	Spiophanes bombyx	17.49			

6.3.2.4. Multivariate community analysis

Some multivariate analyses have been done, using Bray-Curtis similarity matrices to build up non-metric multidimensional scaling plots (MDS). MDS plots give reliable information on relations between data points in a visual way. It might be important for future monitoring and research to know how the different locations and samples are related to one another based on grain size and community composition. The results of the Simper analyses can be found in Annex 4 – SIMPER analysis.

6.3.2.4.1. Belwind

In Figure 13, grain size partition, given as volume percentages for each fraction (see 6.2.2.1), was set out for each sample station on the Bligh Bank (BBC and BBR) and the Goote Bank (BGR). This takes into account some more information for each sample than the median grain size as the percentages of all fractions present in a sample are incorporated. In this MDS plot, sample station BGR9 (in autumn), with aberrant high fractions of clay and silt, was removed from the analysis to prevent hyperclustering of the other data points. It can be seen that there is no distinction in grain size between spring and autumn for each sample location. This result is confirmed by the Simper analysis, which indicates that the different sample locations have low dissimilarities between spring and autumn. Besides, no clear distinction can be made between the sample locations, although BBC and BGR show some more separation than BBR. In general, it can be said that the variation in grain size partition within and between sample locations is comparable.

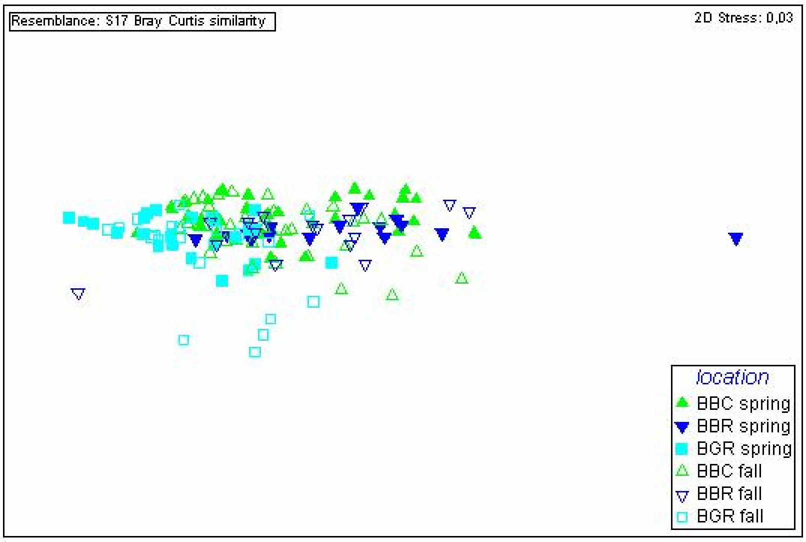

Figure 13. MDS based on grain size partitioning for the Bligh Bank and Goote Bank in spring and autumn

In Figure 14, community composition based on densities is set out for each sample station at BBC, BBR and BGR in spring. No clear trends are visible and no distinction can be made between the sample locations. This result is confirmed by the Simper analysis which indicates that similarities/dissimilarities in community composition within and between sample locations are of the same magnitude.

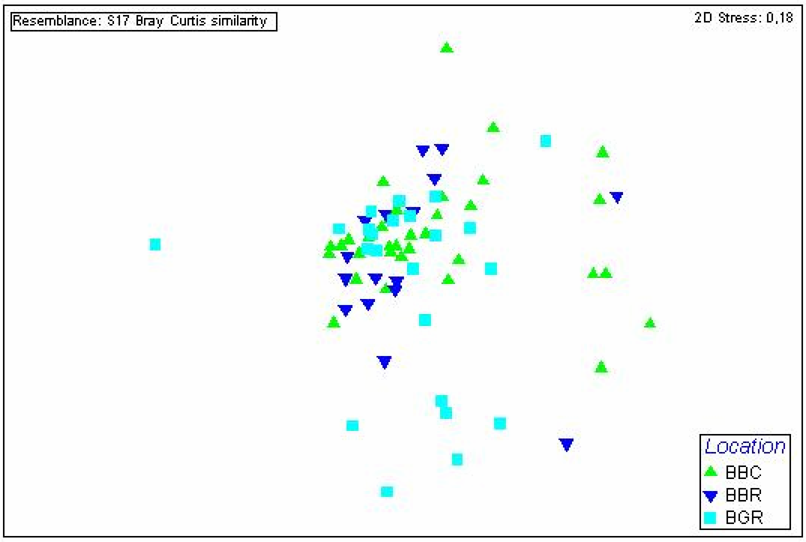

Figure 14. MDS based on community composition (densities) for BBC, BBR and BGR in spring 2008

In Figure 15, the same analysis as in Figure 14 can be seen but for autumn instead of spring. Sample stations BGR4 and BGR7, with an aberrant community composition, were removed to prevent hyperclustering of the other data points. BGR4 and BGR7 have a much higher number of *S. bombyx* present in comparison with the other samples. No clear clustering is observed after removal. However, the dissimilarity in community composition between BGR and either BBC or BBR is larger than the dissimilarity between BBC and BBR. In general similarities/dissimilarities in community composition within and between sample locations are of the same magnitude, which is confirmed by the Simper analysis (Annex 4 – Simper analysis).

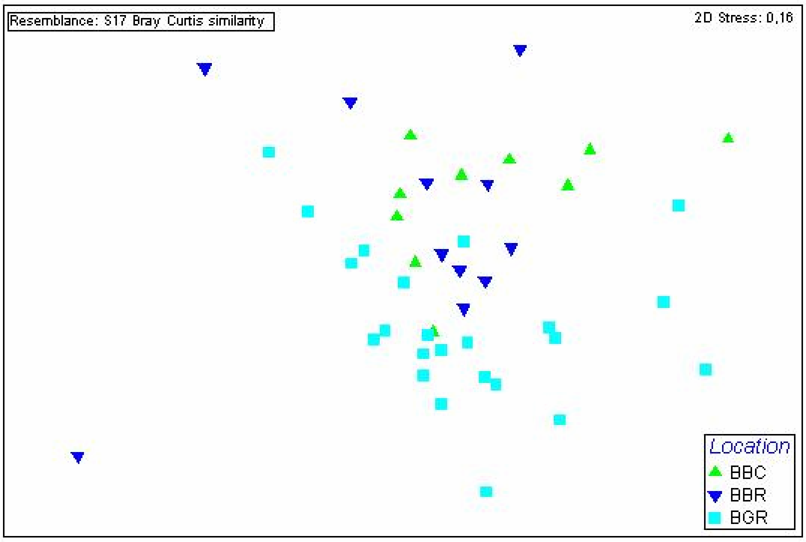

Figure 15. MDS based on community composition (densities) for BBC, BBR and BGR in autumn 2008. BGR 4 & BGR 7 are excluded

6.3.2.4.2. C-Power

In Figure 16, grain size partition, given as volume percentages for each fraction (see 6.2.2.1) was set out for each sample station. In this MDS plot, sample stations BGR9 and WTR14, with aberrant high fractions of clay and silt, were removed from the analysis to prevent hyperclustering of the other data points. No distinction in grain size can be made between the different sample locations. The Simper analysis confirms that the similarity/dissimilarity percentages are of the same order of magnitude both within and between the sample locations (Annex 4 – Simper analysis).

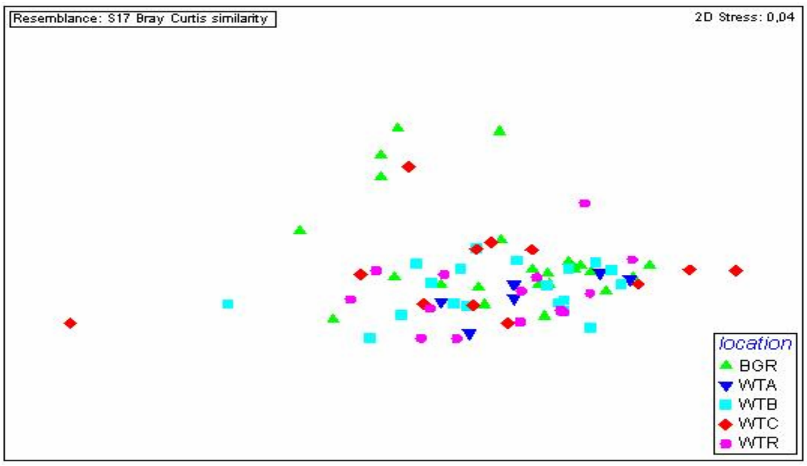

Figure 16. MDS based on grain size partitioning for the Thorntonbank and Goote Bank in autumn 2008. BGR9 and WTR14 are excluded

In the MDS plot of Figure 17, community composition based on densities is set out for each sample station at BGR, WTA, WTB, WTC and WTR. No clear distinction in community composition can be seen. As confirmed by the Simper analysis, the variance within and between the sample locations are of the same order of magnitude (Annex 4 – Simper analysis).

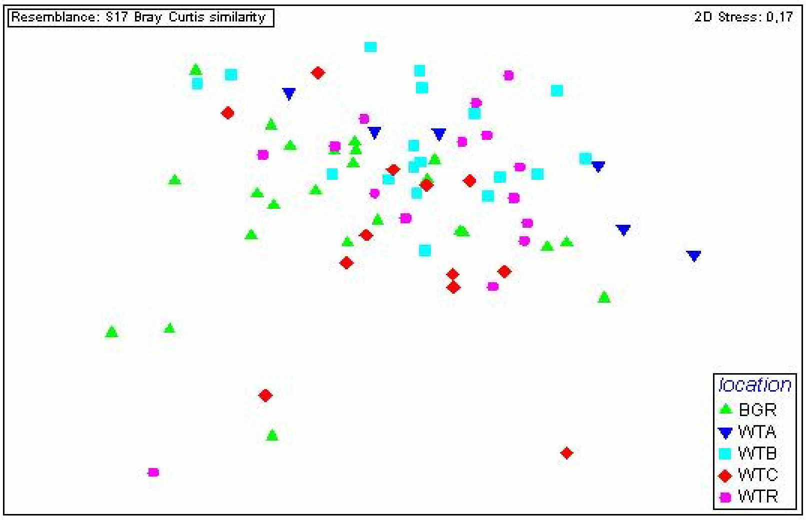

Figure 17. MDS based on community composition (densities) for the Thorntonbank and Goote Bank in autumn 2008

In the MDS plot of Figure 18, community composition based on densities is set out for each sample station at BGR, WTA, WTB, WTC and WTR sampled in 2005 and 2008. The samples of 2005 and 2008 were analyzed by different scientists. The identification up to species level of certain genera depends upon minor differences in characteristics which makes the error variance due to scientist-specific handling rather large. Therefore an analysis on a higher level than species level is advisable for some genera although information on species level was available. For this analysis, *Nephtys sp*., Spionida, *Bathyporeia sp.* and *Urothoe sp.* were used instead of the exact species.

A clear separation in community composition is visible between 2005 (red circle) and 2008 (black circle). Within each cluster no further distinctions can be made between the different sample locations. Simper analysis confirms that within each cluster the dissimilarity is in most cases smaller than between the two clusters. In each cluster the similarities/dissimilarities in community composition are of a comparable order of magnitude within and between sample locations (Annex 4 – Simper analysis).

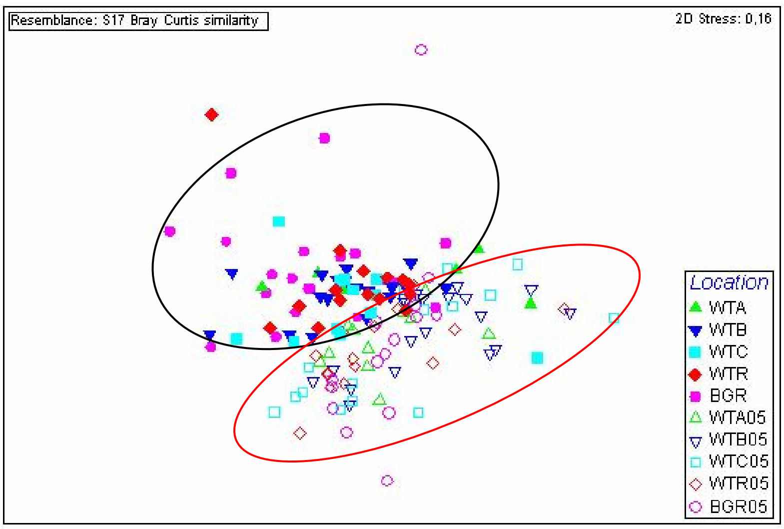

Figure 18: MDS based on community composition (densities) for the Thorntonbank and Goote Bank in autumn 2005 and 2008

6.4. Discussion

This research has been done to quantify possible impacts of wind turbines on the endobenthos of soft sediments. A BACI (Before and After Control Impact) concept was used. In this way information is available on the ecological situation before and after the impact on the habitat. Biotic and abiotic data were gathered both in the impact area as in an indicated reference site.

6.4.1. Sediment characteristics

Most samples at the Bligh Bank and Goote Bank were characterized by medium sand, with low mud content and low percentages of organic material, both in spring and autumn. In spring no mud is present at all at these locations. In autumn only one sample has a very high mud content. The median grain size is somewhat higher in spring compared to autumn. Based on the MDS plot of Figure 13 no distinction can be made between the different sample locations for grain size partitioning. Based on all information given in the results, it can be concluded that the concession area BBC as well as the border zone BBR and the reference site BGR have comparable sediment characteristics.

Most samples at the Thorntonbank and Goote Bank are characterized by medium sand, with low mud content. Low percentages of organic material are present in the samples. There is no mud present in any of the samples at WTA and WTB. Only two samples have a very high mud content. The MDS plot of Figure 16 shows that no separation can be made based on grain size partitioning. All information given in the results indicates that all sample locations have comparable sediment characteristics.

The sediment characteristics of the Thorntonbank and Goote Bank in this study are comparable to the ones found in the study performed in 2005 by De Maersschalck *et al*. (2006). Most sample stations in the latter were characterized by medium sand, low mud content and low percentages of organic material. This indicates that the sediment characteristics did not change significantly, even not in WTA, between 2005 and 2008.

6.4.2. Macrobenthos

6.4.2.1. Belwind

Maximum densities vary between 600 and 900 ind./m² in spring and 800 and 3500 ind./m² in autumn at the Bligh Bank and Goote Bank. Species richness is rather low at all sample locations: between 1 and 18 species/0.1 m² in spring and between 1 and 26 species per sample in autumn. A broad range in biomass is present both in spring and autumn and low productivity is found at all sample locations.

In spring significant differences are found in density, N_0 and N_1 between the concession area BBC and the other areas BBR and BGR. In autumn, significant differences in N_2 are present between BBC and BGR. As the sediment characteristics are comparable between the different locations and no human impact has taken place before, differences should be due to an unmeasured (a)biotic parameter or environmental variability.

If a comparison is made between spring and autumn, quite some significant differences are present. BBC and BGR significantly differ in density, species richness and N_1 between seasons. Between spring and autumn, BBC shows significant differences in N_2, while BGR shows significant differences for biomass and productivity. These results indicate that seasonality may play an important role on the ecosystem and could have an important influence on density, species richness, biomass and productivity.

The dominant species over all the stations on the Bligh Bank is *Nephtys cirrosa*, both in spring and autumn. Looking at the Goote Bank, *Nephtys cirrosa* is the dominant species in spring while in autumn, it is *Spiophanes bombyx*. According to Degraer *et al*. (2006) both species have a wide distribution across the Belgian part of the North Sea and can reach a high frequency of occurrence. They reach high relative occurrence in medium sand sediments, although they can be found in almost all sediment types. *N. cirrosa* and *S. bombyx* are also dominant species on the Thorntonbank, which is dominated by medium sand (De Maersschalk *et al*. 2006).

MDS plots of figure 14 and 15 show that, based on community composition, no differences can be found between the different locations at the Bligh Bank and Goote Bank. This indicates that the variation in community composition within and between sample locations is of the same magnitude.

The spatial distribution of macrobenthos of the Belgian part of the North Sea depends upon the particular physico-chemical environment, with its specific species composition (Van Hoey *et al.* 2004). Based on the sediment characteristics and Van Hoey *et al*. (2004), it was expected to find an *Ophelia limacina*-*Glycera lapidum* community and the transitional community between the *Nephtys cirrosa* community and *Ophelia limacina*-*Glycera lapidum* community (further called the transitional community). Both communities are characterized by medium sand with low mud content, low species richness and rather low densities of species. Based on species composition and species analysis (see 6.3.2.3) of the current study, the samples appear to belong to the *Ophelia limacina*-*Glycera lapidum* community in spring, while in autumn they appear to belong to the transitional community. Based on the biological dataset the samples show a gradual transition from the *N. cirrosa* community to the *O.limacina* - *G. lapidum* community. Within these community compositions, physical as well as biological characteristics are present which belong both to the *N. cirrosa* and *O.limacina – G. lapidum* community (Van Hoey et al. 2004).

6.4.2.2. C-Power

Maximum densities vary between 1500 and 3500 ind./m² at the Thorntonbank and the Goote Bank. Species richness is rather low: between 1 and 24 species per sample at the Thorntonbank and between 1 and 26 species per sample at the Goote Bank. A broad range in biomass is present and a low productivity, less than 10 mg/day.m^2, is found at most sample points, though some sample points have a much higher productivity (between 70 and 80 mg/day.m²).

If the results of 2008 (current study) and 2005 (De Maersschalck *et al*.2006) are compared, higher densities and species richness are found in some samples of 2008. In 2005 the maximum density and species richness are 1300 ind/m² and 16 species respectively. In 2008 maximum density is 3500 ind/m², while maximum species richness in a sample is 26. This result may be influenced by the scientist doing the identification. Most sample points at WTA, WTB and WTC had low densities in 2005, while in 2008 densities are more evenly distributed among the range from low to high. Biomass has a comparable range in distribution in both studies. In 2008, as found in 2005, productivity is very low. However in 2005 much higher productivity was present in some samples at BGR. The differences in density, diversity, biomass and productivity between 2008 and 2005 are not restricted to the concession area WTA.

In 2008, no significant differences in densities are present between the different sample locations. For the diversity indices of Hill, significant differences are present between the different locations. For N_0, WTA shows significant differences with WTC, WTR and BGR. For N_1, WTA differs significantly from all other locations. For N_2 and N_{inf}, significant differences between WTA and WTC, WTR and BGR are present. WTC differs from WTB and BGR as well. Significant differences in biomass and productivity are found between WTR and BGR. However, in 2005, also quite some significant differences were present in density, diversity, biomass and productivity between the different sample locations, although no human impact had taken places before and sediment characteristics are comparable.

The dominant species on the Thorntonbank are *Nephtys cirrosa*, *Nephtys caeca* and *Spiophanes bombyx*. The dominant species on the Goote Bank is *N. cirrosa*. *S. bombyx* and *N. cirrosa* were also found as dominant species in the study performed by De Maersschalck *et al*. (2006) although some more species as *Urothoe brevicornis* and *Bathyporeia guilliamsoniana* had a mean contribution of more than 15% to the mean total density. As mentioned before, both *N. cirrosa* and *S. bombyx* have a wide distribution across the Belgian part of the North Sea and can reach a high frequency of occurrence. They reach high relative occurrence in sediments with a median grain size, however they can be found in almost all sediment types (Degraer *et al*. 2006).

The MDS plot of Figure 17 shows that based on community composition no distinction can be made between the different sample locations. As confirmed by the Simper analysis (Annex 4), the variance within and between the sample locations are of the same magnitude. However, between 2005 and 2008, large differences in community composition can be seen (MDS plot Figure 18). To reduce the impact of scientist-specific handling, higher taxonomic levels were used for some species. However, the samples of 2005 and 2008 are still clearly separated. Within each year, no further distinction can be made between the sample locations. As WTA in Year-1 is not separated from the other locations, the differences in community composition are not caused by the presence of six wind turbines. This result indicates that next to seasonal variation (as seen for the Bligh Bank), large annual variation in community composition is possible although sediment characteristics do not change significantly.

Based on the sediment characteristics a transitional community between the *N. cirrosa* community and *O. limacina – G. lapidum* community is expected (Van Hoey *et al*. 2004). The communities found do tend towards this transitional community. However, the mean densities and species richness of the sample locations is somewhat higher than those of this transitional community. Based on the biological dataset, the samples show a gradual transition from the *N. cirrosa* community to the *O.limacina - G. lapidum* community. Within these community compositions, physical as well as biological characteristics are present which belong both to the *N. cirrosa* and *O. limacina – G. lapidum* community (Van Hoey et al. 2004).

6.5. Conclusion and recommendations

6.5.1. Belwind

All the information available for the Bligh Bank and Goote Bank for Year-0 indicates that significant differences in density, diversity, biomass, productivity and community composition are limited between the concession area BBC and the border zone BBR and reference site BGR. Besides, the sediment characteristics of all three sample locations are comparable. The variation in abiotic parameters has a comparable order of magnitude both within and between the sample locations. These results show that BBR and BGR are good sites to quantify the possible impacts of the wind turbines which will be built on BBC in the future. It has to be brought into account for future research that once turbines are present, some sampling points will be difficult to reach. Other sampling strategies and techniques should be used at these points (see below for suggestions).

6.5.2. C-Power

The results of this study indicate that the impact of six wind turbines on the endobenthos of soft sediments in the first year after implementation is rather low. Seasonal and annual variations in densities, species richness, biomass, productivity and community composition seem to be more important. However, it has to be taken into account that only few samples could be taken at the concession area WTA, the area where the expected possible impacts were highest. Few samples were taken due to the fact that the research vessel ‘Belgica’ has low maneuverability. This makes that, due to logistic limitations, the sample stations close to the wind turbines were excluded from the analysis, although these are the most interesting stations. It is plausible that close to the turbines the impact on the macrobenthos is more pronounced than further away. As can be seen on Figure 1, the closest stations sampled are located more than 100 m away from the wind turbines. To monitor sampling points closer to the turbines, a small research vessel or other sampling strategies and techniques will be necessary in the future. In the future, more wind turbines will be present in the concession area so more sample points will become difficult to reach. The protocol for underwater soft sediment sampling used by Mallefet *et al*. (2008) is one possible technique which can be used in close vicinity of the turbines. However, it has to be brought into account that only a limited number of samples can be collected by divers, while there is the need for a large number of samples to retrieve a representative part of the benthic community structure (Mallefet *et al*. 2008).

It would be interesting to have (more) sampling points in-between WTC and WTB as possible sand shifts and sedimentation patterns are expected (if present) to go, forced by the currents, in northeast direction.

Although no significant impact of the wind turbines on the endobenthos is detected in the first year after implementation, further monitoring is suggested to quantify possible impacts on the long term. A quantification of the possible cumulative impacts of more and more wind turbines which will be present in the future is necessary as well. It would be interesting to know the distribution range of the impact and the possible edge effects of the colonized hard substrates on the surrounding soft sediments. Therefore samples should be taken close to the wind turbines with a small interval. Further off, the interval can be enlarged.

When it comes to general recommendations, we advise to monitor the impact of wind turbine parks on the soft sediment benthos both during and after the installation of the parks themselves. This allows for a monitoring of the recovery of the soft sediment benthos after the installation is completed.

Since wind turbine parks are closed areas for bottom trawling fishery, the importance of this impact on the succession can be surveyed, next to the possible edge effect around the parks, mainly caused by a possible concentration of the fishery activities along the borders of the parks.

The third objective of this study (to incorporate the complex functional-ecological part of the macrofauna and demersal fish by integrating the results of the synchronous studies of the benthic epifauna and demersal fish fauna) will be completed in an integration workshop between MarBiol and ILVO. This allows for a preliminary data analysis and the discussion of the results of both institutes. It might lead to interesting conclusions about the macrobenthos and demersal fish ecosystem around wind turbine parks.

6.6. References

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Chapter 7. Monitoring of the effects of the Thorntonbank and Bligh Bank windmill parks on the epifauna and demersal fish fauna of soft-bottom sediments:
Thorntonbank: status during construction (T1)
Bligh Bank: reference condition (T0)

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Abstract

The consortia C-Power NV and Belwind NV obtained an environmental permit to build and exploit a wind farm in the Belgian part of the North Sea. The wind turbines for C-Power will be/are placed on the Thorntonbank (60 wind turbines, 300 MW). The ones for Belwind will be placed on the Bligh Bank (110 wind turbines, 330 MW). A research design has been drafted to monitor the environmental effects of the construction and exploitation of these wind farms in time. Stations on the Goote Bank, Bligh Bank, Hinderbanken and Thorntonbank were selected as reference sites (no impact site). To scientifically evaluate the ecological effects of a human disturbance on the environment, a BACI (Before After Control Impact) strategy is used, based on repeated samplings (spring and autumn, before and after impact) in impact areas (concession zones) and reference areas. The baseline study (Year-0) of the Thorntonbank has been completed in 2005 (De Maersschalck *et al.*, 2006). In 2008, six wind turbines have been placed on the Thorntonbank. This monitoring project aims at evaluating the Year-0 situation of the Bligh Bank and the Year-1 situation of the Thorntonbank concerning the benthic invertebrates and demersal fish during the construction phase of the wind farms. For both the Thorntonbank and the Bligh Bank monitoring areas, variations in biotic characteristics (density, diversity, biomass, length-frequency) concerning demersal fish were linked to seasonal, interannual and spatial variation (sandbank tops versus gullies). Densities were higher (>200%) in autumn than in spring and overall densities were substantially lower in 2008 compared to 2005 (reduction of 65%). In the Thorntonbank monitoring area, differences between tops and gullies were most outspoken in spring, with higher densities (on average 22%) in the gullies. Perciforms and flatfish were important species groups throughout the years, supplemented by locally and seasonally high densities of clupeids (spring 2005) and gadoids (autumn 2008). In the Bligh Bank monitoring area, differences between tops and gullies were equally important, with higher densities on the tops in autumn (due to high abundance of lesser weever) and comparable densities in spring. The species composition was again mainly determined by perciforms and flatfish, with locally high densities of

gadoids. The species number was higher on the Bligh Bank than on the Hinderbanken. For epibenthos, all analyses concerning community composition, density, biomass, diversity and length showed a difference between sandbank top samples and gully samples, with generally higher (up to six times) values in the gullies. This indicated that gullies are more diverse and richer than the sandbanks themselves. Gully samples, however, displayed more variation in their species compositions than sandbank tops. Nevertheless, seasonal, interannual and spatial variations were mainly due to changing in densities of a few common species such as brown shrimp, two species of brittle stars, hermit crab, flying crab, lesser bobtail and squid. For both ecosystem components, no changes were detected in the patterns in and around the concession zones, and, as such, they remain largely comparable with the reference areas. The selected reference areas (Thorntonbank, Goote Bank, Bligh Bank and Hinderbanken) are considered to be suitable; only limited differences were found concerning biotic variables between the concession zones and their respective reference zones. For future monitoring, adaptations to the sampling design will be implemented, since cables and other structures on the seafloor prevent the completion of the beam trawl tracks in the vicinity of the turbines. These adaptations will include a shortening of the tracks and an increase in track numbers in the vicinity of the turbines.

Samenvatting

De consortia n.v. C-Power en n.v. Belwind verkregen een milieuvergunning voor de bouw en exploitatie van een windmolenpark op het Belgisch deel van de Noordzee. De windturbines voor C-Power worden geplaatst op de Thorntonbank (60 molens, vermogen van 300 MW). De turbines voor Belwind zullen geplaatst worden op de Bligh Bank (110 molen, vermogen van 330 MW). Een monitoringsplan werd uitgetekend om de impact van de bouw en exploitatie van deze windmolens op het milieu na te gaan in de tijd. Er werden referentiegebieden aangeduid op de Goote Bank, Bligh Bank, Hinderbanken en Thorntonbank. Om op wetenschappelijke basis de ecologische gevolgen van een menselijke verstoring op het habitat na te gaan werd een BACI (Before After Control Impact) strategie gekozen. Deze is gebaseerd op herhaalde staalnames (lente en herfst, voor en na impact) in impactgebieden (concessiezones) en referentiegebieden. De baseline studie van de Thorntonbank werd uitgevoerd in 2005 (De Maersschalck *et al.* 2006); in 2008 werden de eerste 6 windmolens geïnstalleerd. Dit monitoringsproject werd uitgeschreven ter uitvoering van de baseline studie (jaar-0) van de Bligh Bank en de jaar-1 studie van de Thorntonbank om de situatie te evalueren tijdens de constructie- en exploitatiefase van de windmolenparken voor de epifauna en demersale vissen. Voor zowel de Thorntonbank als de Bligh Bank monitoringsgebieden waren de variaties in biotische variabelen (densititeit, diversiteit, biomassa, lengte frequentie) betreffende demersale vissen vooral toe te schrijven aan seizoenale, interannuele en ruimtelijke (geulen versus banken) verschillen. Visdensiteiten waren algemeen hoger (>200%) in de herfst dan in de lente, en waren substantieel lager in 2008 dan in 2005 (65% reductie). In het Thorntonbank monitoringsgebied waren de verschillen tussen geulen en banken het meest uitgesproken in de lente, waarbij hogere (gemiddeld 22%) densiteiten werden waargenomen in de geulen. De groepen van de baarsachtigen en de platvissen waren het jaar rond abundant aanwezig. Daarnaast werden lokaal hoge densiteiten waargenomen van haringachtigen (lente 2005) en kabeljauwachtigen (herfst 2008). In het Bligh Bank monitoringsgebied waren de verschillen tussen geulen en banken van even groot belang, en werden hogere densiteiten aangetroffen op de banken in de herfst (vooral door abundantie van kleine pieterman) en vergelijkbare densiteiten tussen geulen en banken in de lente. De soortensamenstelling werd opnieuw grotendeels bepaald door baarsachtigen en platvissen, aangevuld met lokaal hoge densiteiten van kabeljauwachtigen. Het aantal soorten was hoger op de Bligh Bank en aanpalende geulen dan op de top en in de geulen van de Oosthinder. Alle analyses betreffende de soortensamenstelling, densiteit, biomassa, diversiteit en lengte frequentie van het epibenthos toonden een duidelijk verschil aan tussen de zandbankstations en de geulstations, waarbij hogere (tot zes keer hoger) densiteiten werden genoteerd in de geulen. Dit toont aan dat aanpalende geulen diverser en rijker zijn de zandbanken zelf. Stalen uit geulen vertoonden echter wel een grotere onderlinge variatie dan zandbankstalen. De aangetoonde seizoenale, interannuele en ruimtelijke variatie was vooral het gevolg van wisselende proporties van een aantal algemene epibenthische soorten zoals de grijze

garnaal, twee soorten slangsterren, heremietkreeft, zwemkrab, sepiola en dwergpijlinktvis. Voor geen enkel van deze ecosysteemcomponenten werden veranderingen waargenomen in de patronen in en rond de concessiezones, waardoor deze nog steeds vergelijkbaar zijn met de referentiezones. Aangezien slechts kleine verschillen werden waargenomen betreffende de biotische variabelen tussen de concessiezones en hun respectievelijke referentiezones, blijken de geselecteerde referentiegebieden (Thorntonbank, Goote Bank, Bligh Bank and Hinderbanken) als dusdanig geschikt. De constructie van turbines in de concessiegebieden heeft echter wel een invloed op de uitvoering van boomkorslepen, aangezien de aanwezigheid van kabels en andere objecten op de zeebodem de voltooiing van een sleep verhindert. Bijgevolg zal de staalnamestrategie bij volgende campagnes moeten worden aangepast, voornamelijk door het verkorten van de slepen en een verhoging van het aantal slepen in de buurt van de turbines.

7.1. Introduction

The assemblage of macro-epibenthic and macro-endobenthic organisms constitutes an important source of prey items for demersal fish species. Hence, any change within the benthic community resulting from the construction, exploitation and dismantlement of a windmill park may give rise to changes within the demersal fish community. In order to observe and understand changes in this community during the proceedings of several windmill projects from an ecological perspective (i.e. functional approach), it is imperative to gather data on both the demersal fish communities and on the availability and use of prey items.

The distribution of benthic macro-invertebrates strongly depends on seafloor conditions. Differences in sedimentology and seafloor morphology are major factors determining the presence and abundance of the encountered species. Consequently, the benthic macro-invertebrate community structure is expected to be influenced by geomorphological changes (e.g. construction of windmills, creation of a new habitat, change of the original habitat) in windmill concession zones.

Next to undergoing direct effects of the existence of windmill parks, benthic macro-invertebrate and demersal fish communities may also react to a reduction of beam trawling activities in the windmill concession zones. Additionally, an increase in fisheries pressure along the borders of a closed area (ref. plaice box in the Netherlands) is expected to impact the benthic ecosystem (= fringe-effect). Finally, the introduction of hard substrates in the windmill concession zones implies the introduction of an associated fauna, both macro-invertebrates and fish, which can play a structuring role (e.g. predation) within the benthic ecosystem of soft substrates.

Given the expected effects of windmill park construction and exploitation on benthic macro-invertebrates and demersal fish, and the ecological and socio-economical importance of these species groups, they merit ample attention in the ecological evaluation of windmill park projects.

At present, there is one windmill park under construction, more precisely the one of the company C-power on the Thorntonbank. Concerning this particular park, a detailed pilot study (T0) has already been carried out in 2005, during which the reference condition of the demersal fish fauna, and the macro-epibenthic and macro-endobenthic fauna of the present soft substrates on the Thorntonbank and the Goote Bank were described (De Maersschalck et al., 2006). In accordance with the general monitoring plan of MUMM, this study was followed by the assessment of the condition of the different ecosystem components during year 1 (construction; T1). A second concession has been granted to n.v. Belwind for the construction and exploitation of a windmill park on the Bligh Bank. A detailed description of the reference conditions (T0) in the Bligh Bank area was also included in the general monitoring plan of MUMM.

7.2. Aims

This report investigates the condition of demersal fish and macro-epibenthos in the concession zones and reference zones of the Thorntonbank windmill park at year 1 and of the Bligh Bank windmill park at year 0. These results form the basis of the impact assessment concerning the construction and exploitation of the windmill parks under investigation (including the effects of the closure of the concession zones for beam trawling and sand extraction);

The aims of the monitoring activities were:

- Assessing the condition of the demersal fish fauna and the macro-epibenthic fauna of the soft substrates in the concession zones and reference zones of the Thorntonbank windmill park during year 1 (2008). The results were compared with the reference conditions observed in 2005.
- Assessing the condition of the demersal fish fauna and the macro-epibenthic fauna of the soft substrates in the concession zones and reference zones of the Bligh Bank windmill park during year 0 (reference condition 2008). Furthermore, the suitability of potential reference zones was evaluated.

- The results of ecosystem components macro-epibenthos and demersal fish were compared and integrated with the results about ecosystem component macro-endobenthos

7.3. Sampling strategy and methods

In order to maximize the (statistical) sensitivity of the survey strategy and analyses to changes due to the ecological impact of the construction and exploitation of windmill parks, a considerable coverage is required. Consequently, a high sampling intensity (such as the one used in the Thorntonbank baseline study) was maintained for the evaluation of the Thorntonbank construction impact (T1), and was duplicated for the Bligh Bank baseline study (T0). Due to this high sampling intensity in and around the windmill park concession zones, the spatial variability in density, biomass and diversity is representatively mapped. Sampling was repeated in spring and autumn, since numerous national and international research projects indicate that sampling in these seasons is adequate for analyzing the presence and density of most species.

The used strategy and techniques correspond well with the ones used in other studies concerning the macro-epibenthos and demersal fish from Belgian maritime waters. This way, existing data can be optimally used in the ecological evaluation of the current status. Detailed information about the sampling campaigns can be found in the campaign reports and the interim project report (Hostens *et al*. 2008a,b,c; Vandendriessche *et al*. 2008).

7.3.1. T_1 - Thorntonbank/Goote Bank area

For the monitoring of the macro-epibenthos and demersal fish, a similar level of detail was maintained as in the pilot study (T0). In the Goote Bank reference zone, however, only the fish track on the sandbank top (WG2) was repeated, since the composition of the resident fauna in the gullies differed too strongly from the composition observed in the Thorntonbank gullies (De Maersschalck *et al*., 2006). Furthermore, construction works at one of the six windmills in the western concession zone and the vulnerability of their wiring on the seafloor necessitated the repositioning of fish tracks WT4 and WT5 with 500m to the SE during the autumn campaign (Figure 1).

During the 2008 monitoring campaigns, one fish track was done in every concession area, 4 fish tracks each were done in the adjoining gullies and the reference areas (3 in the Thorntonbank reference area and 1 in the Goote Bank reference area) from which both demersal fish and macro-epibenthic assemblages were analysed (Table 1, Figure 1).

The preservation of the level of detail, bar the described adjustments, allows a straightforward assessment of the direct impact of the recent windmill construction works (habitat loss, changes in community structure, effects of reduced fisheries pressure, etc.) and a comparison with the reference condition of 2005 (T_0).

Table 1
The Thorntonbank sampling stations in the concession zones, in the adjoining gullies and the reference zones, per ecosystem component.

	Concession zones	Fringe effects	Reference zones
Epibenthos	2	4	4
Demersal fish	2	4	4

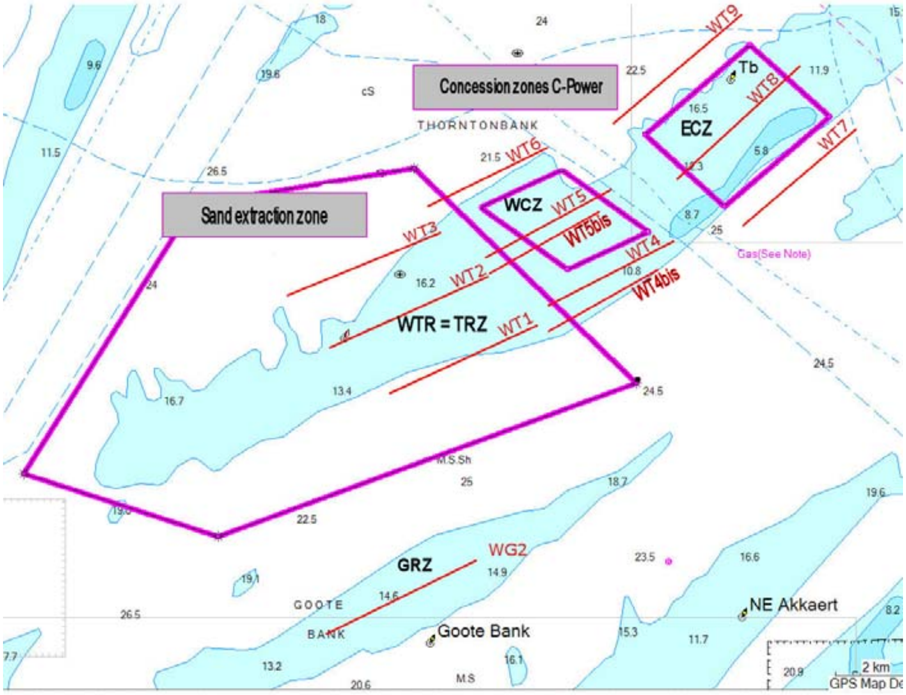


Figure 1. Position of the fish tracks (epibenthos and demersal fish) in the Thorntonbank concession zones, in the adjoining gullies and in the reference zones of the Thorntonbank and the Goote Bank, with indication of the sample codes.

7.3.2. T_0 - Bligh Bank/Hinderbanken area

Given the size of the Bligh Bank concession zone (35.6 km²; 49.1 km² including the safety zone) and the variable bathymetry of the area, it was decided to do three fish tracks within the concession zone (according to bathymetry) and two fish tracks along its borders to monitor the fringe effects (Table 2, Figure 2). Two reference zones were selected, i.e. the Bligh Bank reference zone and the Hinderbanken (Oosthinder) reference zone, in which three fish tracks were done to evaluate their suitability as references areas for the Bligh Bank concession zone. From each fish track, the demersal fish fauna and the macro-epibenthic fauna were sorted and analysed.

Table 2
The Bligh Bank sampling stations in the concession zone, along its borders and in the reference zones, per ecosystem component.

	Concession zone	Fringe effects	Reference zones
Epibenthos	3	2	6
Demersal fish	3	2	6

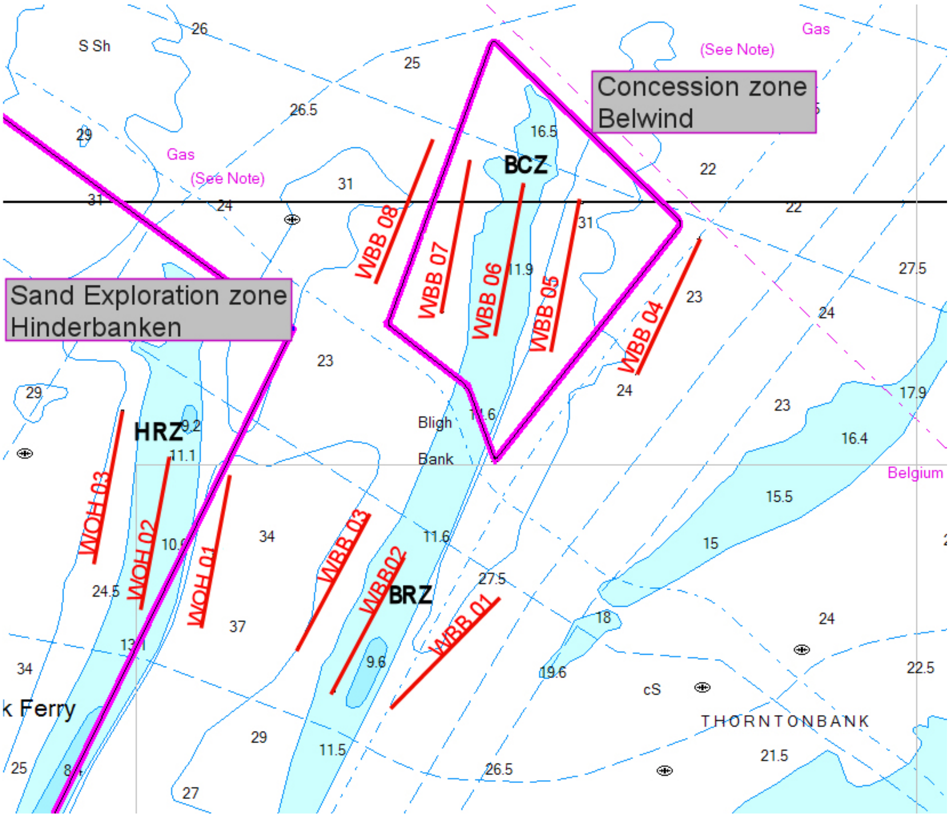


Figure 2. Position of the fish tracks (epibenthos and demersal fish) in the Bligh Bank concession zone, in the adjoining gullies and in the reference zones of the Bligh Bank and the Oosthinder, with indication of the sample codes.

Demersal fish fauna and macro-epibenthos can be defined as the organisms that live on or in close association with the seafloor, and that are caught representatively and efficiently with a beam trawl. Both ecosystem components were sampled onboard the research vessel Belgica with an 8-meter beam trawl with a fine-meshed shrimp net (stretched mesh width 22 mm in the codend) and a bolder-chain but no tickler chains (to minimize the environmental damage). The net was dragged during 30 minutes at an average speed of 4 knots over the bottom. As such, a mean distance of 3500m was covered. Data were recorded on time, start and stop coordinates, trajectory and sampling depth in order to enable a correct conversion towards sampled surface units. The fish tracks were positioned following depth contours that run parallel to the coastline, thereby minimizing the depth variation within a single track. After each fish track, a photograph was taken of the net content prior to the processing of the catch (see Annex 5).

Since the catch sizes from the 2008 campaigns were generally rather modest, the net contents were processed without the use of a rincing and sieving machine. All fish, except gobies, were identified, measured and/or counted or wet weighed on board. For a number of tows, the epibenthos (including gobies) was processed on board as well; for other tows, a subsample of 6 liters was frozen for further laboratory analyses. Rare or peculiar species/individuals were stored for further reference or investigation.

Continuous CTD recordings of a number of environmental variables on the sampling locations were used in the analysis of the spatial distribution of the encountered species. General weather conditions were recorded and were also provided by the concession holder.

The net contents were divided into 'demersal fish' and 'epifauna'. These ecosystem components were dealt with separately concerning density, biomass (epibenthos only), diversity, length frequency distribution and community structure. The number of individuals per sample and per species was converted to number of individuals per 1000m² (abundance). Biomass was expressed as grams of wet weight (WW) per 1000m² and diversity was evaluated based on Hill's diversity indices (Hill, 1973). The values of statistical variables were calculated with the programs Statistica 8 (Kruskall-Wallis ANOVA and Mann-Whitney U tests). The community structure of epifauna and demersal fish were analysed using the multivariate techniques non-metric multidimensional scaling (MDS), ANOSIM (analysis of similarities) and SIMPER (similarity percentages procedure) available in Primer v5 (Plymouth Routines in Multivariate Ecological Research; Clarke & Gorley, 2001). These analyses were based on 4th root transformed and reduced datasets[1] of frequency of occurrence and density. For the most important species of demersal fish and epibenthos, the length frequency distributions were analysed and visualized. Maps were generated with ArcView 9.3.

All acquired data will be available within the BMDC database of MUMM at the following web site (http://www.mumm.ac.be/datacentre).

7.4. Results

7.4.1. Demersal fish: density

7.4.1.1. Thorntonbank (C-Power concession): condition in 2008

In 2008, the total densities of demersal fish were generally higher (> twice) in autumn compared to spring, with outlier values at the gullies of the Eastern Concession Zone (ECZ) in autumn (Table 3). While densities were comparable between the WCZ and its gulies, the values from the gullies at the ECZ were considerably higher than the values observed within the ECZ.
In spring, the dominant species groups were perciforms (45%), pleuronectiforms (12%) and clupeiforms (32%) for the WCZ, and perciforms (73%) and pleuronectiforms (22%) for the ECZ (Table 4, Figure 3). In the gullies of both zones, perciforms and pleuronectiforms made up the bulk of the density, with a dominance of perciforms (72-85%) along the WCZ and of pleuronectiforms (65-69%) at the ECZ. In autumn, clupeids were absent and perciforms dominated both the concession zones as their neighboring gullies (64-74% in WCZ; 19-78% in ECZ). Pleuronectiforms were of less importance, and a high percentage of gadiforms (64%) was observed at the SE gully of the ECZ (Table 5, Figure 3).

Table 3. Overview of the mean density of demersal fish fauna per taxonomic group for the examined years and seasons – monitoring stations Thorntonbank.

Season	year	density	density per taxonomic group (#/1000m^2)						
		#/1000m^2	Clupeiformes	Gadiformes	Gobiidae	other	Perciformes	Pleuronectiformes	Scorpaeniformes
spring	2005	34	21,6	0,4	0,5	0,1	5,6	4,7	1,0
	2008	12	0,6	0,3	0,3	<0,1	4,8	5,6	0,2
autumn	2005	30	<0,1	1,7	3,0	<0,1	18,8	6,2	0,2
	2008	37	0,1	17,6	2,2	0,1	18,1	9,6	0,2

In the Thorntonbank reference zone (TRZ), densities were comparable between the top and the gullies of the bank in both seasons. At the tops of both reference zones (Thorntonbank and Goote Bank) perciforms and pleuronectiforms were the dominant species groups, complemented in spring in with a high number of clupeiforms (18-22%). The gullies of the Thorntonbank reference zone were characterized by high numbers of perciforms (32-76%) and pleuronectiforms(12-64%).

No significant differences were found concerning density between the different zones in both seasons for 2008. Densities in the TRZ were quite similar to those observed in the WCZ, for both the tops and gullies. In both seasons, the differences between tops and gullies were more pronounced in the ECZ, with low densities on the top, especially in spring, and high densities in the gullies. Density values on top of the Goote Bank were the lowest observed (2 ind/1000m^2 in spring, 11 ind/1000m^2 in autumn).

In spring, the Thorntonbank stations were dominated in terms of density by dab *Limanda limanda* and solenette *Buglossidium luteum* for the pleuronectiforms and by two dragonet species

[1] The datasets were reduced to all species observed in more than two fish tracks and occurring with a mean density of more than 0,01 individuals per 1000m^2.

Callionymus lyra and *C. reticulatus*, and the lesser weever *Echiichtys vipera* for the perciforms. At the Goote Bank, the same species were observed in high abundance, with the addition of the presence of sprat *Sprattus sprattus* for the clupeiforms. In autumn, the Goote Bank station was populated by mainly lesser weevers, dragonets and the sand goby *Pomatoschistus minutus* as representatives of the perciforms, and by dab as representative for the pleuronectiforms. At the Thorntonbank stations, poor cod *Trisopterus minutus* was very abundant (gadiforms), together with lesser weevers, dragonets, dab and solenette.

7.4.1.2. Thorntonbank (C-power concession): comparison 2005 - 2008

The general trends between and within the different zones of the Thorntonbank monitoring area (Thorntonbank references zone, eastern and western concession zone and Goote Bank reference zone) remain quite similar in both years:

- In the ECZ and the TRZ, the densities were lower on the top than in the neighboring gullies, while densities from top and gullies were comparable within the WCZ
- In the Goote Bank reference zone (GRZ), densities were higher on the top compared to the gullies. In 2008, only a top sample was taken, however with low values in both seasons.

When comparing the total fish densities between the years 2005 and 2008, it is quite obvious that spring densities were significantly lower in 2008: an average density of 34 ind/1000m² was recorded in 2005, while this number was reduced to 12 ind/1000m² in 2008. This is a reduction of 65% of the average density, when pooling all stations. Statistical verification showed this observation to be significant (Mann-Whitney U test, $p=0.004$) and most outspoken in the western concession zone, where densities were on average 80% lower in 2008. There were no significant differences between years for the autumn samples (overall $p=0.8$).

When analyzing the differences found between spring data of the two years on the level of species groups, it became obvious that the differences were largely due to a reduction of clupeiforms, being predominantly sprat (*Sprattus sprattus*) and herring (*Clupea harengus*). In the spring of 2005, these fish species were observed with an average density of 22 ind/1000m², while in the same period of 2008, an average density of only 1 ind/1000m² was registered. The reduction of the densities in herring and sprat was visible in all stations and zones, implying that this observation is due to interannual variation in the distribution and/or demography of these species.

The average densities of the other species groups (gobies, perciforms, pleuronectiforms and gadiforms) showed no marked differences between the years; only scorpaeniforms were more abundant in the spring of 2005 (1 ind/1000m², in comparison with 0.2 ind/1000m² in 2008). This difference was predominantly due to variations in the abundance of hooknose (*Agonus cataphractus*).

For both years and seasons, the following species returned as highly important in terms of density: dragonets, dab, solenette, lesser weever and sand goby. The horse mackerel (*Trachurus trachurus*) was a dominant species in autumn of 2005, but was also frequently found in autumn 2008, albeit in very modest abundance. Poor cod (*Trisopterus minutus*), on the other hand, showed a peak density in autumn 2008 (station WT7), but was also found spring and autumn of 2005 (especially at stations WG3 and WT7).

Table 4
Overview of the mean density of demersal fish fauna per station and per taxonomic group – monitoring stations Thorntonbank, spring 2005 & 2008.

Thornton 2005 spring

Area		Zone	Station	spring density	spring density per taxonomic group (#/1000m²)						
				#/1000m²	Clupeiformes	Gadiformes	Gobiidae	other	Perciformes	Pleuronectiformes	Scorpaeniformes
Ref Th	TRZ	SE gully	WT1	59	54,1	0,6	0,1	-	2,7	1,4	0,3
	TRZ	top	WT2	15	9,9	0,1	0,1	-	4,0	1,1	0,1
	TRZ	NW gully	WT3	47	9,5	1,1	0,2	-	19,2	16,0	1,0
West Conc	WCZ	SE gully	WT4	66	60,4	<0,1	1,1	-	3,0	1,8	0,1
	WCZ	top	WT5	38	31,6	0,3	-	-	4,8	1,1	0,2
	WCZ	NW gully	WT6	34	7,4	0,4	-	-	14,2	10,3	1,6
East Conc	ECZ	SE gully	WT7	39	15,5	0,6	1,8	0,2	3,5	11,4	5,7
	ECZ	top	WT8	9	7,5	<0,1	-	-	1,0	0,7	<0,1
	ECZ	NW gully	WT9	18	6,8	0,4	<0,1	-	4,2	5,5	1,3
Ref Gb	GRZ	SE gully	WG1	10	5,4	0,4	0,1	-	0,6	2,7	0,9
	GRZ	top	WG2	51	48,7	<0,1	0,1	<0,1	0,5	1,2	0,4
	GRZ	NW gully	WG3	17	2,4	0,8	0,8	-	9,9	2,7	0,4

Thornton 2008 spring

Area		Zone	Station	spring density	spring density per taxonomic group (#/1000m²)						
				#/1000m²	Clupeiformes	Gadiformes	Gobiidae	other	Perciformes	Pleuronectiformes	Scorpaeniformes
Ref Th	TRZ	SE gully	WT1	11	0,0	0,4	0,3	-	5,9	4,4	<0,1
	TRZ	top	WT2	8	1,4	0,3	0,3	-	5,2	0,7	<0,1
	TRZ	NW gully	WT3	18	0,2	0,5	<0,1	-	5,7	11,5	<0,1
West Conc	WCZ	SE gully	WT4	6	0,0	-	<0,1	-	5,2	0,8	-
	WCZ	top	WT5	7	2,4	0,2	0,5	-	3,3	0,9	-
	WCZ	NW gully	WT6	10	-	0,1	<0,1	-	7,1	2,5	<0,1
East Conc	ECZ	SE gully	WT7	32	<0,1	1,3	1,1	<0,1	6,5	22,1	1,0
	ECZ	top	WT8	3	-	<0,1	0,1	-	1,9	0,6	-
	ECZ	NW gully	WT9	19	-	0,1	-	-	6,4	12,1	-
Ref Gb	GRZ	top	WG2	2	0,4	0,1	<0,1	<0,1	1,0	0,3	-

Table 5
Overview of the mean density of demersal fish fauna per station and per taxonomic group – monitoring stations Thorntonbank, autumn 2005 & 2008.

Thornton 2005 autumn

Area		Zone	Station	autumn density	autumn density per taxonomic group (#/1000m²)						
				#/1000m²	Clupeiformes	Gadiformes	Gobiidae	other	Perciformes	Pleuronectiformes	Scorpaeniformes
Ref Th	TRZ	SE gully	WT1	29	-	2,1	1,4	-	18,8	6,7	<0,1
	TRZ	top	WT2	19	-	0,1	2,1	-	11,8	4,6	0,1
	TRZ	NW gully	WT3	35	-	1,6	-	-	21,8	11,9	0,2
West Conc	WCZ	SE gully	WT4	20	<0,1	-	3,5	-	15,2	1,0	-
	WCZ	top	WT5	24	-	0,4	4,2	-	13,9	5,6	<0,1
	WCZ	NW gully	WT6	26	<0,1	0,7	2,3	-	18,3	4,9	0,2
East Conc	ECZ	SE gully	WT7	37	-	5,1	4,1	-	9,9	17,4	0,8
	ECZ	top	WT8	9	-	0,2	1,3	-	5,9	1,0	0,1
	ECZ	NW gully	WT9	35	-	1,3	7,4	-	17,2	8,5	0,8
Ref Gb	GRZ	SE gully	WG1	19	-	3,6	3,2	-	8,8	3,5	0,1
	GRZ	top	WG2	84	-	0,2	3,3	-	78,2	2,4	<0,1
	GRZ	NW gully	WG3	16	-	3,7	0,5	-	5,7	6,5	<0,1

Thornton 2008 autumn

Area		Zone	Station	autumn density	autumn density per taxonomic group (#/1000m²)						
				#/1000m²	Clupeiformes	Gadiformes	Gobiidae	other	Perciformes	Pleuronectiformes	Scorpaeniformes
Ref Th	TRZ	SE gully	WT1	22	-	-	1,7	0,1	15,3	5,0	<0,1
	TRZ	top	WT2	20	-	-	2,3	-	15,4	2,5	-
	TRZ	NW gully	WT3	31	-	0,1	2,7	-	22,0	6,6	0,1
West Conc	WCZ	SE gully	WT4	15	<0,1	-	2,1	-	10,8	1,7	-
	WCZ	top	WT5	24	-	-	3,6	-	15,5	5,0	-
	WCZ	NW gully	WT6	21	<0,1	<0,1	2,1	-	14,3	4,7	-
East Conc	ECZ	SE gully	WT7	109	-	69,5	1,7	<0,1	20,8	16,8	0,1
	ECZ	top	WT8	18	-	-	1,1	-	14,3	2,9	-
	ECZ	NW gully	WT9	98	-	0,6	3,1	-	45,3	48,8	0,7
Ref Gb	GRZ	top	WG2	11	0,1	-	1,4	-	7,0	2,1	-

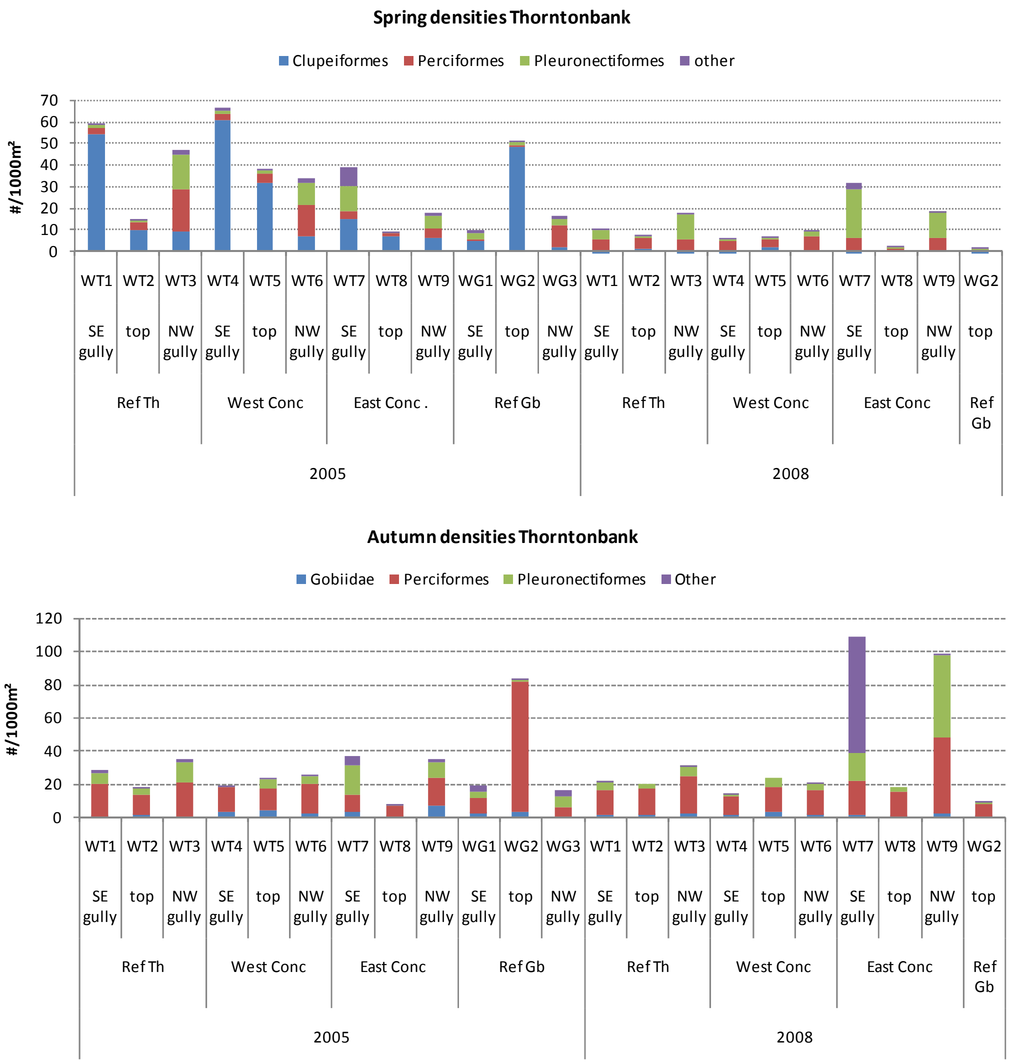


Figure 3. Column chart of densities of demersal fish per taxonomic group for all stations and zones - monitoring stations Thorntonbank, spring (upper) and autumn (lower) 2005 & 2008.

7.4.2. Bligh Bank (Belwind concession): condition in 2008

In autumn, densities from the tops of the concession zone and the Bligh Bank reference zone (BRZ) were about double of the spring values (Table 6, Figure 4). Values from the neighboring areas were similar in both seasons. In the Hinderbanken reference zone (HRZ), values from all stations were about three times higher in autumn compared to spring.

In both seasons, perciforms were highly dominant at the top of the concession zone (>90% of the total density per station; mainly lesser weever). In the gullies from the concession zone and at the Bligh Bank borders (BBB), both perciforms and pleuronectiforms were observed most abundantly. Only in spring, at the SE part of the gully and the NW border of the concession zone, gadiforms showed high relative abundances (69% and 45%, respectively).

The patterns in density and taxonomic composition in both reference zones reflected those from the concession zone, with densities from the tops that were 1.3 to 2 times higher in autumn compared to spring, while densities from the gullies remained similar. The tops were dominated (>90%) by perciforms, while pleuronectiforms were of similar importance as perciforms in the gullies. In spring, the mean density was higher in the Bligh Bank reference zone compared to the Hinderbanken reference zone (x2), but in autumn the density values were quite similar. No significant differences were found concerning density between the different zones in both seasons for 2008.

Table 6
Overview of the mean density of demersal fish fauna per station and per taxonomic group – monitoring stations Bligh Bank, spring and autumn 2008.

Bligh 2008 spring

Area	Zone	Station	spring density	spring density per taxonomic group (#/1000m²)						
			#/1000m²	Clupeiformes	Gadiformes	Gobiidae	other	Perciformes	Pleuronectiformes	Scorpaeniformes
	SE gully	WBB01	33	-	6,9	-	-	11,0	14,6	0,2
Ref BB	Top	WBB02	30	0,2	-	0,2	-	28,4	1,0	-
	NW gully	WBB03	18	-	0,8	<0,1	<0,1	6,6	10,7	0,1
BBB	ZO border	WBB04	11	-	1,1	<0,1	-	6,0	3,5	-
	SE gully	WBB05	32	<0,1	22,2	-	-	4,7	5,1	-
Conc	Top	WBB06	20	0,2	0,3	<0,1	-	18,8	1,1	-
	NW gully	WBB07	24	0,3	0,6	-	-	16,9	5,8	-
BBB	NW border	WBB08	44	<0,1	19,7	-	-	12,5	11,3	0,2
	SE gully	WOH01	13	-	1,1	-	-	3,0	9,1	<0,1
Ref HB	top	WOH02	15	-	-	0,1	-	14,5	0,8	-
	NW gully	WOH03	11	-	0,1	<0,1	-	9,0	2,2	<0,1

Bligh 2008 autumn

Area	Zone	Station	autumn density	autumn density per taxonomic group (#/1000m²)						
			#/1000m²	Clupeiformes	Gadiformes	Gobiidae	other	Perciformes	Pleuronectiformes	Scorpaeniformes
	SE gully	WBB01	30	-	0,1	6,5	-	18,9	4,7	0,1
Ref BB	Top	WBB02	71	-	-	0,5	-	68,7	1,6	-
	NW gully	WBB03	18	-	0,1	0,8	-	14,0	3,0	0,1
BBB	ZO border	WBB04	31	-	5,8	2,4	<0,1	14,9	7,6	0,1
	SE gully	WBB05	20	-	2,1	3,2	<0,1	9,8	5,0	0,2
Conc.	Top	WBB06	61	-	-	1,5	-	57,4	2,3	0,1
	NW gully	WBB07	35	-	0,1	2,6	<0,1	26,1	6,2	0,4
BBB	NW border	WBB08	29	-	1,4	0,8	-	18,5	8,2	0,1
	SE gully	WOH01	40	-	8,3	3,6	-	18,5	9,7	0,4
Ref HB	Top	WOH02	51	-	-	0,7	-	49,6	1,0	-
	NW gully	WOH03	31	-	0,1	1,3	-	24,3	4,7	0,3

The most important species in spring for the Bligh Bank area were the lesser weever *Echiichtys vipera* for the perciforms, whiting *Merlangius merlangus* for the gadiforms and dab (*Limanda limanda*), solenette (*Buglossidium luteum*) and plaice (*Pleuronectes platessa*) for the pleuronectiforms. Since gadiforms were far less abundant in the Hinderbanken reference zone, dab and the dragonet *Callionymus lyra* showed higher relative abundances than in the Bligh Bank area.

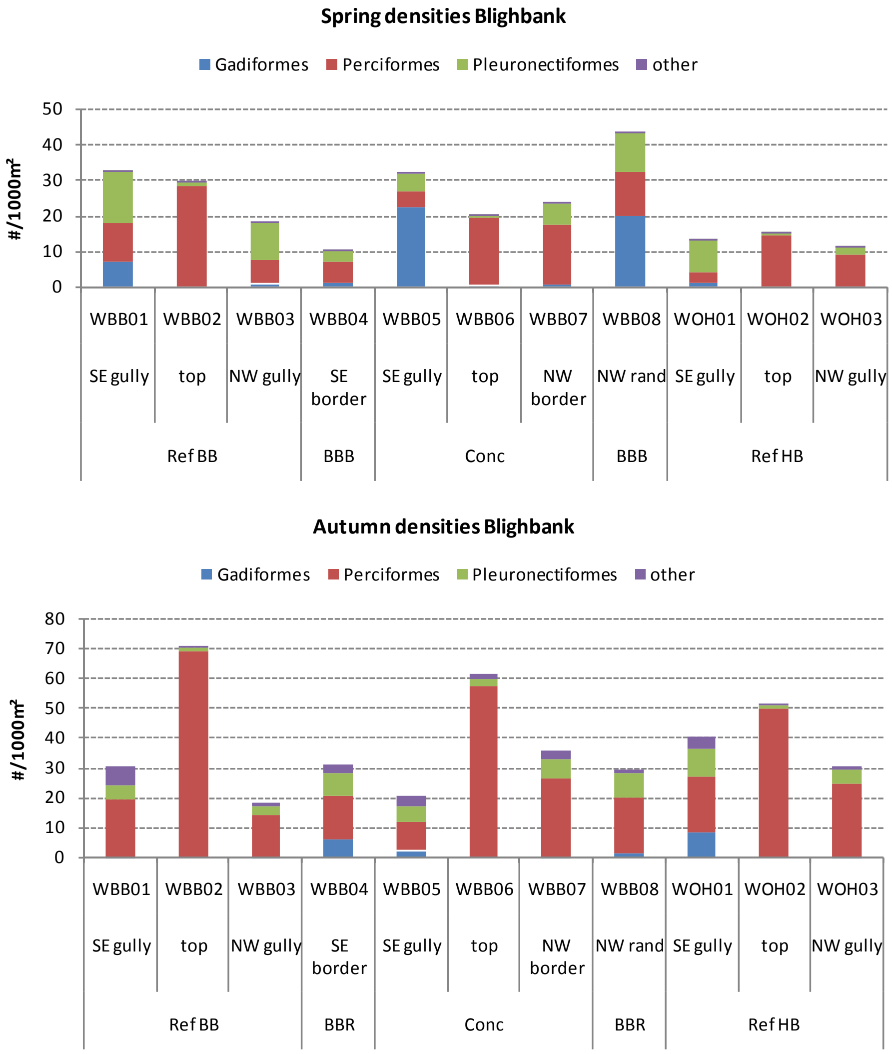


Figure 4. Column chart of densities of demersal fish per taxonomic group for all stations and zones - monitoring stations Bligh Bank, spring (upper) and autumn (lower) 2008.

7.4.3. Demersal fish: diversity

7.4.3.1. Thorntonbank (C-power concession): condition in 2008

In total, 37 fish species were identified (see Annex 6), of which 25 were encountered in spring and 30 in autumn. Twelve species were only found in autumn, while 8 other species were recorded only in spring. An average of 13 species per fish track was found in spring, and an average of 15 species in autumn (Table 9, Figure 5). A minimum value of 9 species was observed at the NW gully of the ECZ in spring; maximum values of 19 species were observed in spring at the SE gully of the ECZ and in autumn at the NW gully of the ECZ.

In spring, the species richness (N0) was quite similar between the concession zones and the reference zones. There were no straightforward trends in the differences between gullies and sandbank tops. In autumn, the average species number per fish track increased, but this increase was not consistent. Only in the TRZ and ECZ, the values from the tops of the sandbanks were lower than in the neighboring gullies.

In spring, only three species were found in all fish tracks: dab *Limanda limanda*, lesser weever *Echiichthys vipera* and the dragonet *Callionymus reticulatus*. Four species were found in 75-90% of the tracks, 11species in 10-75% of the tracks and 7 species in only one track. In autumn, eight species were observed in all fish tracks: the three species mentioned for the spring samples, plus plaice

Pleuronectes platessa, scaldfish *Arnoglossus laterna*, solenette *Buglossideum luteum*, the sand goby *Pomatoschistus minutus*, and the dragonet species *Callionymus lyra*. Six species were found in 75-90% of the tracks, 8 species in 10-75% of the tracks, and 8 species in only one fish track.

The trends observed for the diversity numbers of Hill (N_1, N_2, N_{inf}) differed slightly from the ones observed for the species richness N_0: depending on the sensitivity to rare species in the Hill series, the status of bank tops and gullies varied. In the ECZ, for example, the highest H_0 was found in the SE gully in spring, whereas N_{inf} showed a higher value at the sandbank top. In autumn at the same location, the lowest N_0 was found on the top, while N_{inf} showed the highest value in the NW gully. This indicates a high variation in evenness between the different fish tracks.

The average Hill numbers (pooled over all stations) were higher in autumn compared to spring. In spring, minimum values for the Hill numbers were found in the SE gully at the WCZ (N_1=3.0; N_2=1.9; N_{inf} = 1.4) and maximum values in de SE gully of the TRZ (N_1=8.3; N_2=6.1; N_{inf} = 3.6). In autumn, minimum and maximum values were found at different stations for the different Hill numbers:

- N_1: min 3.7 at WT7; max 8.4 at WT1 and WT5
- N_2: min 2.3 at WT4; max 7.0 at WT6
- N_{inf}: min 1.5 at WT4; max 4.6 at WT3

No significant differences were found concerning the four Hill numbers between the different zones (GRZ excluded since only one sample) in both seasons for 2008.

7.4.3.2. Thorntonbank (C-power concession): comparison 2005 - 2008

Although a similar number of species was observed in both years (40 species in 2005; 37 species in 2008), there were quite a lot of species that were only observed in one of the years: 7 species were only observed in 2005, 6 species were only observed in 2008 (Table 8, Figure 5). These species, however, were usually rare (e.g. twaite shad *Allosa fallax*, Ballan wrasse *Labrus bergylta*, pipefish *Syngnathus acus* and *S. rostellatus*). As for the more dominant species, clear differences were observed between years, with the variation in densities of clupeiforms as main feature (see density section). Generally, the data from 2005 showed a higher degree of dominance than the data from 2008, due to the high relative abundances of sprat (39%) in spring and of horse mackerel (27%) in autumn. When comparing the seasons, dominance was highest in spring of both years (average N_{inf}: 2.7 in spring of both years; 3.4 in autumn 2005 and 2.9 in autumn 2008).

The species number N0 in spring 2005 was 1.5 times higher in the gullies compared to the sandbank tops, while in spring 2008, tops and gullies showed similar values and the trend seen in 2005 was not recognizable. In autumn 2005, the tops from the TRZ and the WCZ showed higher or similar values compared to the gullies, while in 2008, the tops from the TRZ and the ECZ showed lower species numbers than the gullies.

In spring 2005, overall low values for the diversity numbers were found at the top of the WCZ and the SE gully of the TRZ; high values were found at the NW gully of the TRZ and the NW gully of the ECZ. In 2008, low and high values were found at other sites (low: NW gully of the ECZ and SE gully of the WCZ; high: SE gully of the TRZ and the top of the GRZ). In autumn of both years the position of the highest and lowest values for the diversity numbers was similarly inconsistent (see table).

When comparing the values of the diversity numbers between the years 2005 and 2008 (overview of averaged values in table), one can conclude that the values were generally higher in 2005, especially in autumn. Statistical analyses, however, found these differences to be insignificant for all Hill numbers, for both spring samples and autumn samples.

Table 7
Overview of the mean diversity numbers concerning demersal fish fauna for the examined years and seasons – monitoring stations Thorntonbank.

Year	Spring				Autumn			
	HillN0	HillN1	HillN2	HillNinf	HillN0	HillN1	HillN2	HillNinf
2005	16,3	5,4	3,9	2,7	17	7,5	5,6	3,4
2008	13,2	5,6	4,1	2,7	15	6,5	4,8	2,9

Table 8
Overview of the diversity numbers concerning demersal fish fauna per station– monitoring stations Thorntonbank, 2005.

Area		Zone	Station	Spring				Autumn			
				HillN0	HillN1	HillN2	HillNinf	HillN0	HillN1	HillN2	HillNinf
Ref Th	TRZ	SE gully	WT1	14	2,6	1,9	1,4	18	9,1	7,0	3,8
	TRZ	top	WT2	14	5,5	4,1	3,0	20	7,5	4,5	2,3
	TRZ	NW gully	WT3	19	7,9	6,3	4,4	16	6,6	5,5	3,9
West Conc	WCZ	SE gully	WT4	13	2,9	2,3	1,8	13	5,0	3,6	2,5
	WCZ	top	WT5	12	2,7	1,9	1,4	18	9,4	8,0	5,7
	WCZ	NW gully	WT6	16	7,0	5,1	2,9	18	7,0	4,9	3,1
East Conc	ECZ	SE gully	WT7	18	7,0	5,2	3,4	17	7,0	4,7	2,7
	ECZ	top	WT8	11	3,9	2,9	2,1	15	7,8	5,3	2,8
	ECZ	NW gully	WT9	18	8,6	7,0	5,0	17	8,5	7,0	4,7
Ref Gb	GRZ	SE gully	WG1	19	6,7	4,0	2,3	19	11,7	9,5	4,9
	GRZ	top	WG2	16	2,5	2,2	2,0	13	2,0	1,4	1,2
	GRZ	NW gully	WG3	25	7,0	3,5	2,0	18	8,2	5,5	3,2

Table 9
Overview of the diversity numbers concerning demersal fish fauna per station– monitoring stations Thorntonbank, 2008.

Area		Zone	Station	Spring				Autumn			
				HillN0	HillN1	HillN2	HillNinf	HillN0	HillN1	HillN2	HillNinf
Ref Th	TRZ	SE gully	WT1	17	8,3	6,1	3,6	17	8,4	6,0	3,1
	TRZ	top	WT2	16	6,2	4,4	2,9	13	5,6	3,3	1,9
	TRZ	NW gully	WT3	13	5,9	4,3	2,5	18	8,5	7,2	4,6
West Conc	WCZ	SE gully	WT4	10	3,0	1,9	1,4	13	4,0	2,3	1,5
	WCZ	top	WT5	14	6,3	4,8	3,1	15	8,4	6,9	4,0
	WCZ	NW gully	WT6	13	4,8	3,7	2,8	15	8,3	7,0	4,5
East Conc	ECZ	SE gully	WT7	19	5,6	3,9	2,7	17	3,7	2,5	1,7
	ECZ	top	WT8	10	5,5	4,2	3,0	13	5,4	3,5	2,1
	ECZ	NW gully	WT9	9	3,2	2,3	1,6	19	6,3	4,8	3,2
Ref Gb	GRZ	top	WG2	11	7,1	5,5	3,2	14	6,2	4,3	2,5

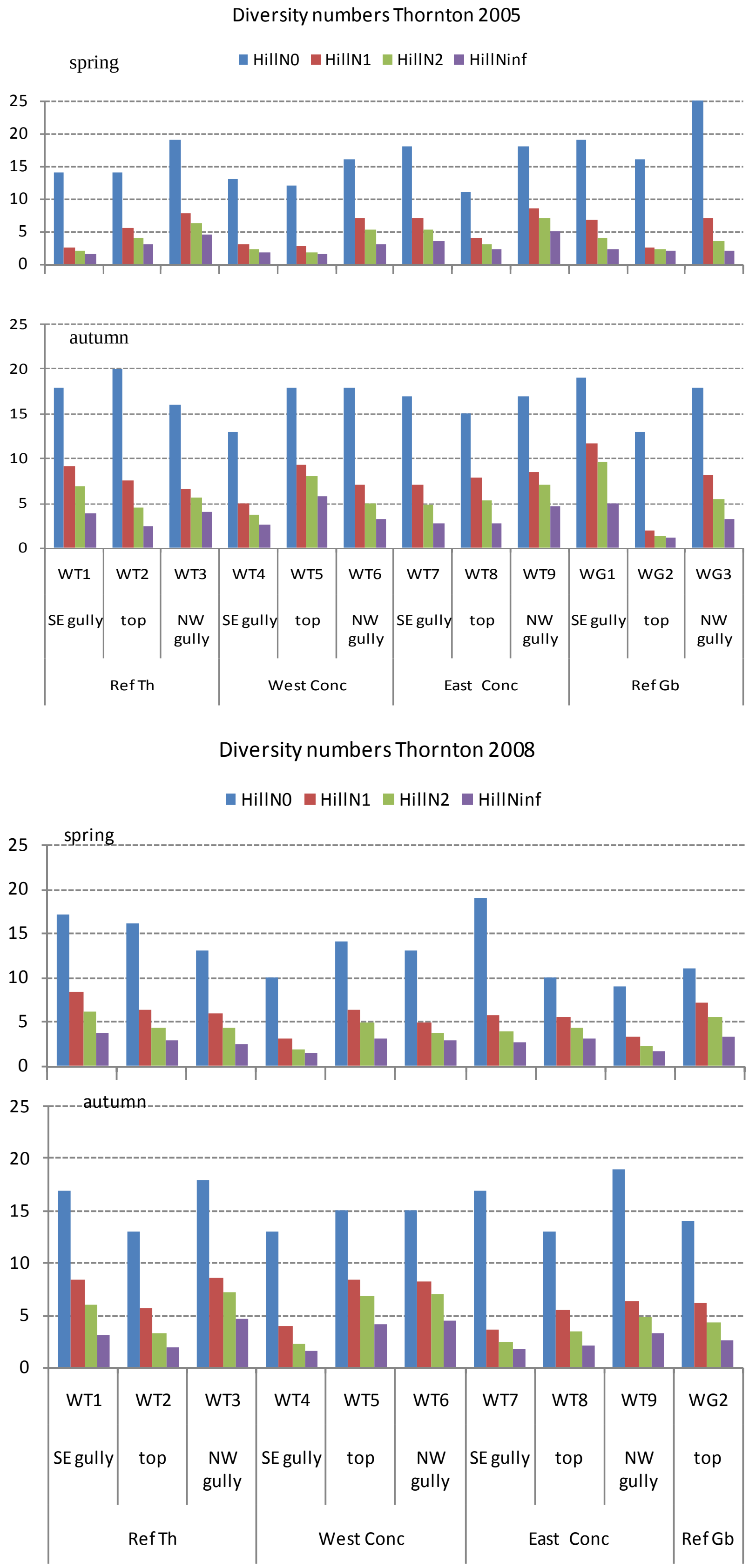


Figure 5. Column chart of diversity numbers concerning demersal fish for all stations and zones - monitoring stations Thorntonbank, 2005 (upper) 2008 (lower).

7.4.3.3. Bligh Bank (Belwind concession): condition in 2008

A total of 30 demersal fish species were recorded in the research area in autumn, all of which were caught in the Bligh Bank region, while only 24 species were encountered in the Hinderbanken region. In spring, a total of 27 species was recorded, of which 25 species were observed in the Bligh Bank region and 17 in the Hinderbanken region. Ten species were only found in autumn, while 6 other species were recorded only in spring. An average of 13 species per fish track was found in spring, and an average of 18 species in autumn. A minimum value of 8 species was observed at the top of the Hinderbanken reference zone in spring; maximum values of 22 species were observed in autumn at the SE gully and SE border of the concession zone.

In spring, the species richness (N0) was quite similar between the concession zone and the reference zones (Table 10, Figure 6). The values from the concession border however, were higher than the values from within the concession zone, especially in the NW (18 species). Additionally, the values from the tops of the sandbanks in the three investigated zones were lower than in the neighboring gullies. This trend was most outspoken in the HRZ (8 species on the sandbank, 13 species in both the gullies). In autumn, the same trends were observed concerning variations between and within the different zones, but the species richness was consistently higher than in spring for all stations.

In spring, only four species were found in all fish tracks: plaice, dab, lesser weever and the sandeel *Hyperoplus lanceolatus*. Five species were found in 75-90% of the tracks, 10 species in 10-75% of the tracks and 8 species in only one track. In autumn, eleven species were observed in all fish tracks: the four species mentioned for the spring samples, plus the sandeel *Ammodytes tobianus*, scaldfish *Arnoglossus laterna*, solenette, two goby species *Pomatoschistus lozanoi* and *P. minutus*, and the two dragonet species *Callionymus lyra* and *C. reticulatus*. Three species were found in 75-90% of the tracks, 13 species in 10-75% of the tracks, and 3 species in only one fish track.

The diversity numbers of Hill (N_1, N_2, N_{inf}) reflect the same trends as observed for the species richness N_0: the values from the tops of the sandbanks in the three investigated zones were lower than in the neighboring gullies and borders. These differences diminish as the sensitivity to rare species decreases in the Hill series from N_0 to N_{inf}. Between seasons, the diversity values of the sandbank tops remained similar, whereas the values from the gullies and the concession border consistently increased. In spring, minimum values for the Hill numbers were found at the top of the BRZ and maximum values in de SE gully of this zone. In autumn, minimum values were found again at the top of the BRZ, but maximum values were observed in the SE gully and border of the concession zone.

No significant differences were found concerning the four Hill numbers between the different zones in both seasons for 2008.

Table 10
Overview of the diversity numbers concerning demersal fish fauna per station– monitoring stations Bligh Bank, 2008.

Area	Zone	Station	Spring				Autumn			
			HillN0	HillN1	HillN2	HillNinf	HillN0	HillN1	HillN2	HillNinf
	SE gully	WBB01	15	6,0	4,7	3,5	16	7,5	4,8	2,5
Ref BB	top	WBB02	11	1,5	1,2	1,1	12	1,3	1,1	1,0
	NW gully	WBB03	16	5,1	3,3	2,1	18	6,1	3,8	2,3
BBB	SE border	WBB04	13	4,7	3,1	2,0	22	9,7	7,3	4,5
	SE gully	WBB05	12	3,1	2,1	1,5	22	9,9	7,3	4,0
Conc	top	WBB06	11	1,9	1,3	1,1	16	1,7	1,2	1,1
	NW gully	WBB07	12	4,1	2,7	1,8	20	5,7	3,1	1,8
BBB	NW border	WBB08	18	5,2	3,7	2,4	18	7,1	4,9	2,9
	SE gully	WOH01	13	4,5	2,7	1,7	19	8,6	6,4	4,2
Ref HB	top	WOH02	8	1,7	1,3	1,1	13	1,7	1,2	1,1
	NW gully	WOH03	13	3,3	2,0	1,5	20	5,2	3,0	1,9

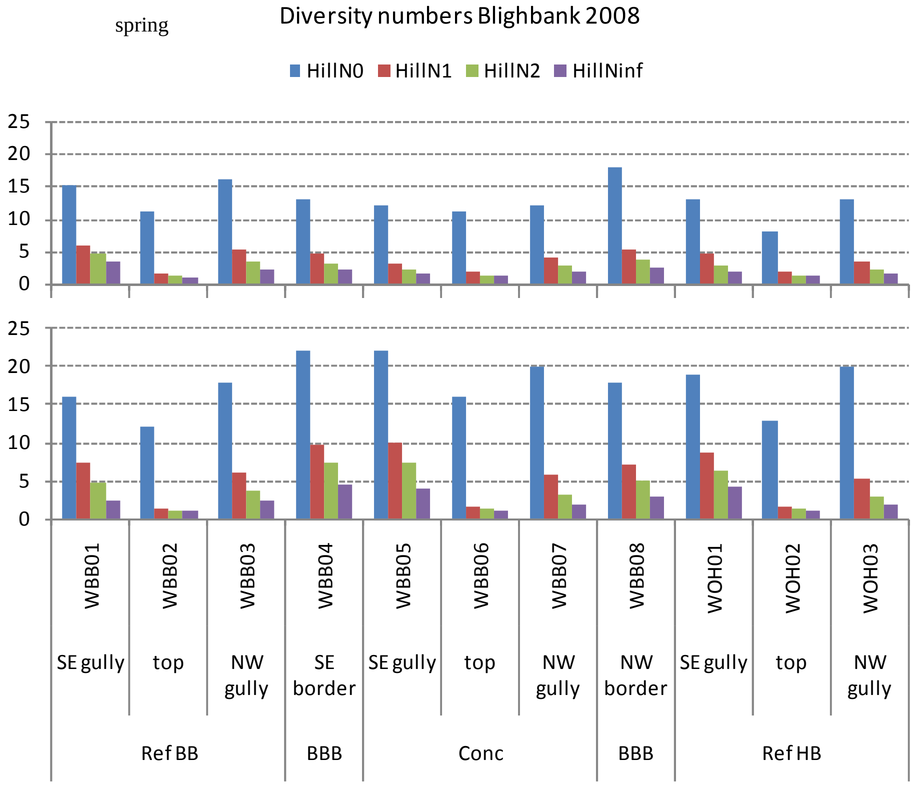


Figure 6. Column chart of diversity numbers concerning demersal fish for all stations and zones - monitoring stations Bligh Bank, 2008.

7.4.4. Demersal fish: community analysis

7.4.4.1. Thorntonbank (C-power concession): condition in 2008

After the reduction of the database based on densities and frequencies of occurrences, 18 species were taken into account for spring and 23 species for autumn.

The MDS plot of the spring samples showed a clear distinction between the fish tracks taken on the sandbank tops (WT 2-5-8 and WG2) and slopes (WT4), and the sandbank gullies (WT1, WT3, WT6, WT7, WT9) (Figure 7). ANOSIM analysis based on the differences between these two groups resulted in an R-value of 0.54 (p=0.008), which indicates significant differences between the groups. The similarities within these groups were 70% and 72% for the group of top samples and the group of gully samples, respectively. The SIMPER procedure indicated that mainly varying densities of lesser weever, the two dragonet species and dab were responsible for the similarities within groups and the differences between groups: dab and dragonet were found in higher densities in the gully samples, while lesser weever was more dominant in the top samples. Additionally, sprat was found abundantly in the top samples WT5, WT2 and WG2. The isolated position of the top sample WG2 was due to the presence of Ballan wrasse at that location.

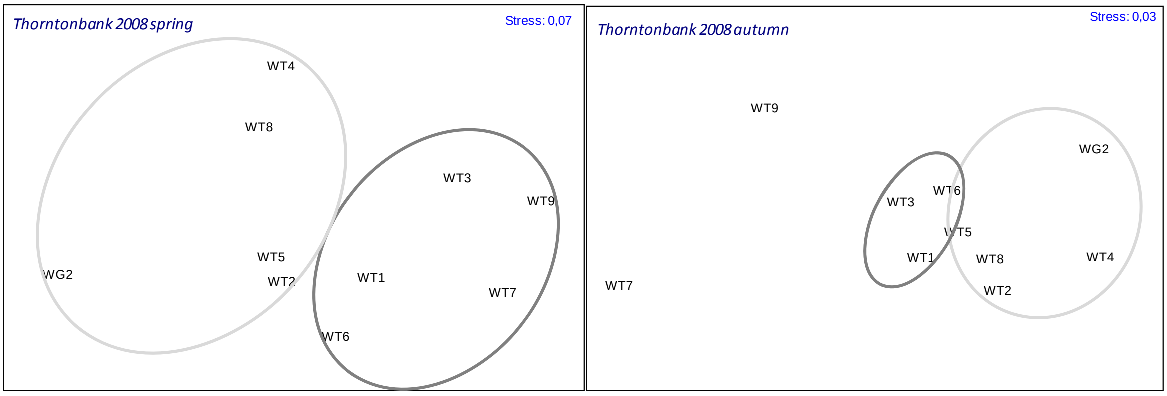


Figure 7. MDS plots of spring and autumn samples, indicating groupings based on position in a gully (dark grey contour) or on a sandbank top (light grey contour)- monitoring stations Thorntonbank, 2008.

The MDS plot of the autumn samples showed a grouping of the fish tracks taken on the sandbank tops (WT 2-5-8 and WG2) and slopes (WT4) (Figure 7). The species composition of the top samples of the Thorntonbank differed slightly from the gully samples of the TRZ (WT1, WT3) and the WCZ (WT6). The gully samples from the ECZ (WT7, WT9) were positioned at a larger multivariate distance in the plot. ANOSIM analysis based on the differences between the observed groups (1 = tops, 3 = gullies of ECZ, 2 = gullies of WCZ and TRZ) resulted in an R-value of 0.54 (p=0.01), which indicates significant differences between the groups. The similarities within these groups were rather high (group 1: 82%, group 2: 87%, group 3: 70%). The species responsible for the differences between groups and the similarities within groups were identified using the SIMPER procedure. The group consisting of top samples was characterized by high densities of lesser weever, sand goby and dab. The gully samples of the TRZ and the WCZ were mostly populated by lesser weever, horse mackerel (however also present at station WT9) and dragonet. The gullies of the ECZ were characterized by dragonet, dab and solenette. The still considerable distance between samples WT7 and WT9 in this group was the result of high densities of hooknose and whiting at WT9 and of bib, poor cod and dab at WT7.

7.4.4.2. Thorntonbank (C-power concession): comparison 2005 - 2008

For a comparison between years, the data of 2005 and 2008 were analyzed together per season (Figure 8). The multivariate analysis based on spring data showed a straightforward primary separation of fish tracks based on sampling year (average dissimilarity between years = 46%, similarity within years slightly higher in 2005 (65% vs. 68%)), mainly based on varying densities of herring, sprat and hooknose (mostly 2005) and lesser weever (2008). Within years, the earlier described grouping of fish tracks taken on sandbank tops (and slopes) and in sandbank gullies remains a fact. A two-way ANOSIM revealed significant differences between years and sampling positions (tops vs gullies): R= 0.78 for the difference between year groups (p=0.001), and R=0.62 for the difference between sampling position groups (p=0.001). Hence, interannual differences should be considered dominant to differences between sandbank tops/slopes and gullies considering spring samples. The four groups discerned in the MDS (tops 2005, gullies 2005, tops 2008, gullies 2008) were characterized by average similarities of 68-73%. Gullies and sandbanks tops in 2005 were both dominated by sprat, herring and dab, but the groups were distinguishable based on differing densities of dragonet (gullies), solenette (gullies) and herring (tops). In 2008, gully and top samples both supported the presence of lesser weever, dragonet and dab, but groups were still separated based on density variations in dab, dragonet and solenette.

The clear grouping of samples according to sampling year and position observed in spring was not duplicated in autumn. Two-Way ANOSIM R-values for differences between years and sampling positions were significant, but were both much lower than in spring (years groups R= 0.26, p=0.007; sampling position groups R= 0.32, p=0.002). Apparently, the effect of sampling year was less outspoken in autumn compared to spring. The effect of sampling position was still important, but with a higher degree of overlap between groups than in spring, especially concerning stations from the Thorntonbank reference zone and the WCZ (stations WT1-6). The differences between both years were mainly due to the local abundance of horse mackerel and whiting in 2005 and of poor cod in 2008. The highest degree of coherence (82% similarity) was observed in the group of top samples from 2008, which was characterized by the species lesser weever, sand goby and dab. Lesser weever and sand goby were also abundant in the top samples from 2005, but these samples also harbored large numbers of horse mackerel. Gully samples from both years showed the highest contribution percentages from the species dab, dragonets and solenette.

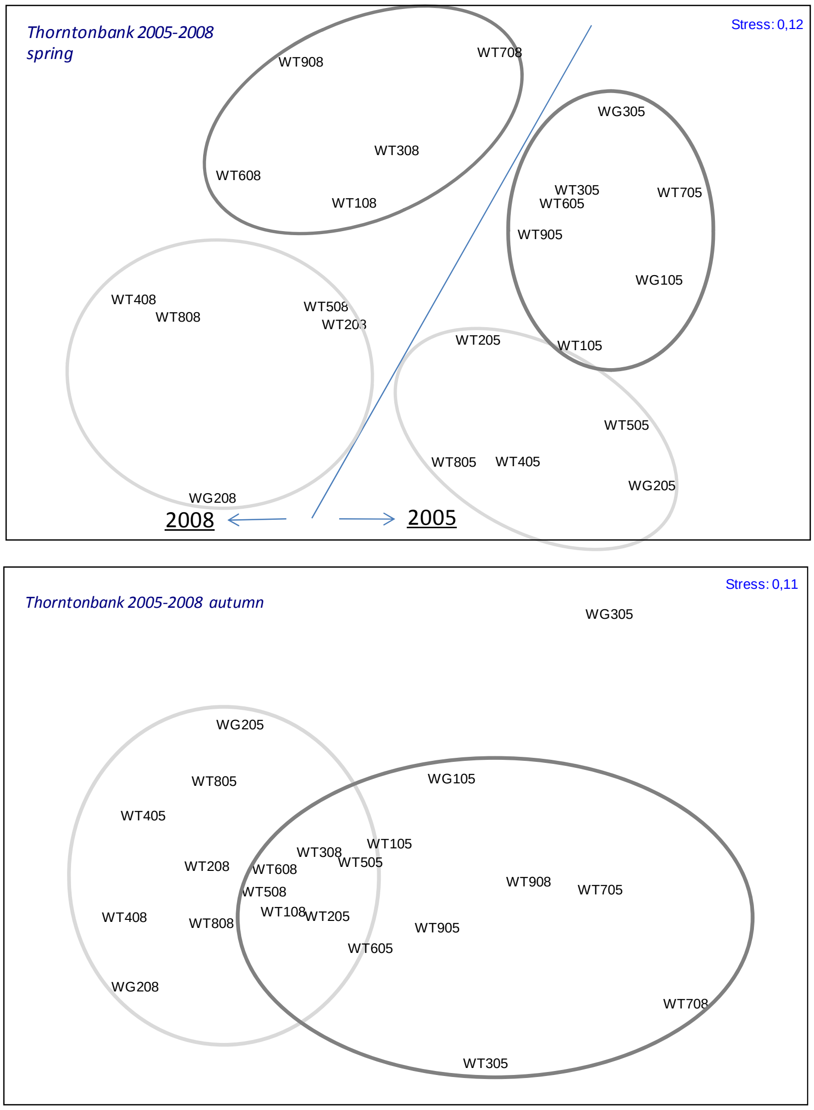


Figure 8. MDS plot of spring (upper) and autumn (lower) samples, indicating groupings based on position in a gully (dark grey contour) or on a sandbank top (light grey contour)- monitoring stations Thorntonbank, 2005 & 2008.

7.4.4.3. Bligh Bank (Belwind concession): condition in 2008

After the reduction of the database based on densities and frequencies of occurrences, 19 species were taken into account for spring and 27 species for autumn.

The MDS plot of the spring samples showed a clear distinction between the fish tracks taken on the sandbank tops (WBB02, WBB06, WOH02), and the sandbank gullies (rest of the samples) (Figure 9). ANOSIM analysis based on the differences between these two groups resulted in a very high R-value of 0.88 (p=0.006), which indicates that most of the variation in species composition is explained by the position of the sample on a sandbank top or in a sandbank gully. The similarities within these groups were 77% and 81% for the group of gully samples and the group of top samples, respectively. The SIMPER procedure indicated that mainly varying densities of lesser weever, plaice and dab were responsible for the similarities within groups; the differences between groups (39% dissimilarity) was mainly caused by the species whiting, cod and and dragonet that were especially abundant in the gully samples (the dragonet *C. lyra* was only found in gullies, the reticulated dragonet *C. reticulatus* was found in both sample types).

The subdivision based on sampling position was equally clear from the MDS based on autumn samples, with a similar ANOSIM R (R= 0.83, p=0.006). The similarity within the groups was a bit larger than in spring (79% for gully samples, 87% for top samples). Lesser weever was found in all samples, but with highest densities in the top samples; top samples also typically contained plaice and sand gobies. Gully samples mainly yielded lesser weever, dragonet and dab and some of the gully stations showed local concentrations of whiting (stations WBB08, WBB05 and WOH1) and poor cod (stations WOH1 and WBB04).

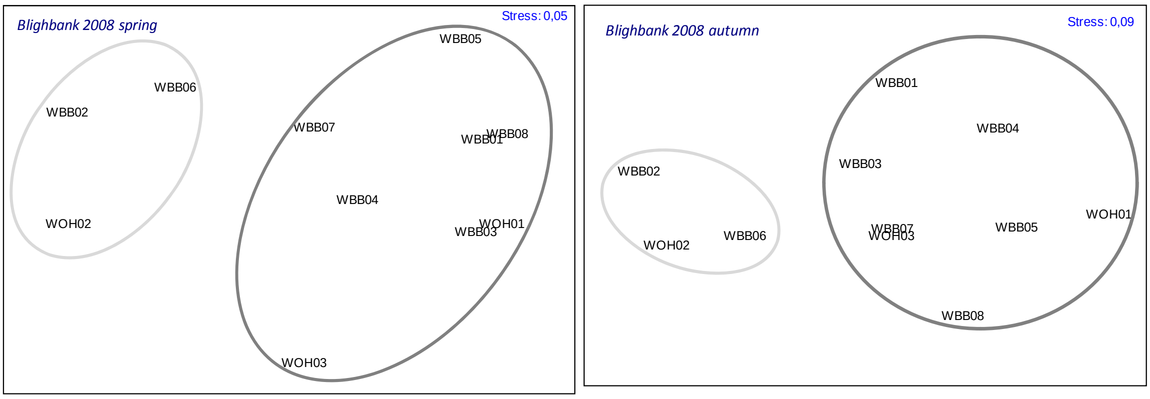


Figure 9. MDS plots of spring and autumn samples, indicating groupings based on position in a gully (dark grey contour) or on a sandbank top (light grey contour)- monitoring stations Bligh Bank, 2008.

7.4.5. Demersal fish: length-frequency

7.4.5.1. Thorntonbank (C-Power concession): condition in 2008 and comparison 2005 - 2008

For all fish species, the mean total length was determined. Additionally, the average length-frequency distribution was determined and visualized (Figure 12) for most of the species of which the distribution was already analyzed in 2005 (De Maersschalck et al, 2006). Sole and herring were seldomly found in 2008 and were no longer considered; two species of sandeel (*Ammodytes tobianus* and *Hyperoplus lanceolatus*) on the other hand were found abundantly in 2008 and were incorporated in the analyses.

Plaice *Pleuronectes platessa*

In 2008, the length of plaice ranged from 80-380mm. In autumn, individuals were considerably larger than in spring (mean 218mm versus 180mm). The 0 and 1+ year classes were of equal importance in spring, but the 1+ year class was more abundant in autumn. Significant differences between top samples and gully samples were observed in autumn (p=0.008), with the highest mean total length observed in the gullies (226mm vs 210mm on the tops). No differences were observed considering mean total length as a result of sampling zone in either of the seasons.

The length-frequency distributions of 2005 and 2008 show similar patterns, but there were higher densities of individuals of year class 1+ in autumn 2008 (length classes between 190 and 240mm). The increase of individuals of this particular size was visible in all stations (Figure 10), but was quite spectacular at station WT9. The differences between gullies and tops are consistent over the years.

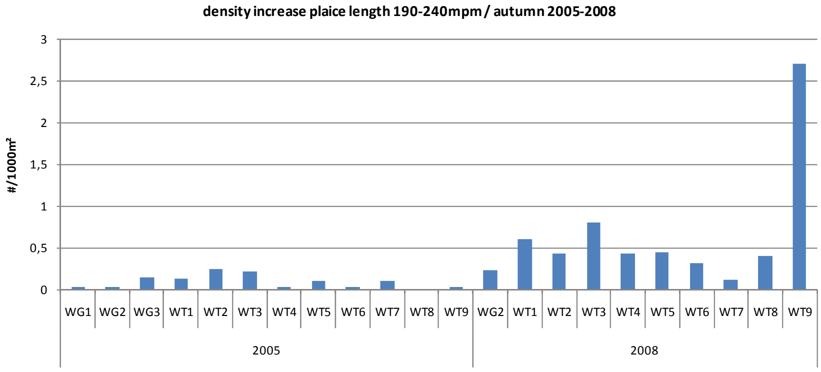


Figure 10. Column chart showing the density of plaice (length 190-240mm) at all stations between years - monitoring stations Thorntonbank, 2005 & 2008.

Sprat *Sprattus sprattus*

In 2008, sprat was only caught in spring at lengths ranging between 80 and 13mm (mean 108mm – Dominant Size Class (=DSC) 90-100mm). No differences were observed considering mean total length as a result of sampling zone or position on a sandbank top or in a gully.

The length-frequency distributions of 2005 and 2008 show similar patterns, but there were higher densities of all size classes in spring 2005. The decrease in 2008 was visible in all stations, resulting in a virtual absence at the gully stations and very low densities at the top stations WG2, WT2 and WT5.

Dab *Limanda limanda*

The individuals of dab caught in 2008 had lengths of 40-350mm (1 extreme of 70cm in spring 2005 at WT3), with averages in spring and autumn of 141 and 118mm. The length-frequency distribution in spring showed 1 density peak at 130-140mm, while the distribution of autumn had a bimodal shape representing year class 0 (DSC 70-80mm) and year class 1+ (DSC 170-180mm). No differences were observed considering mean total length as a result of sampling zone or position on a sandbank top or in a gully.

The length-frequency distributions of 2005 and 2008 showed some differences:

- Whereas the year classes in 2005 were clearly separated in 2005, they formed one single curve in 2008 showing higher densities of larger individuals. This might be the result of the difference in sampling dates (end of February in 2005, half of March in 2008).
- In autumn 2008, the year class 0 was much more important than in 2005, with densities per size class that were up to five times higher. Within the length range of 50-110mm (Figure 11), this increase in densities was mainly due to changes at stations WT7 and WT9 (gully stations of the ECZ).

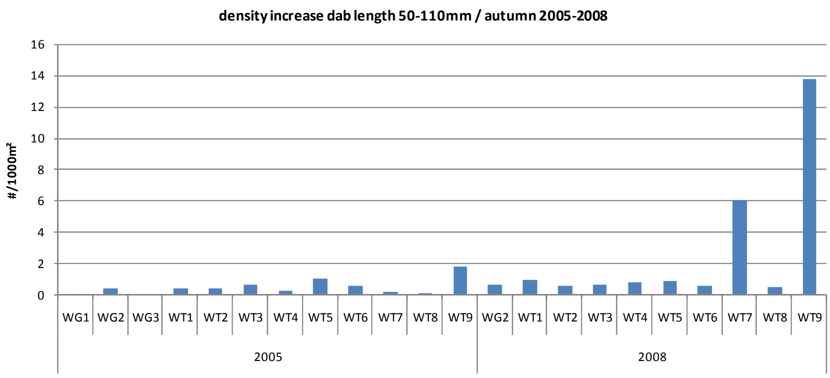


Figure 11. Column chart showing the density of dab (length 50-110mm) at all stations between years - monitoring stations Thorntonbank, 2005 & 2008.

Solenette *Buglossidium luteum*

In 2008, very little variation was observed in length (range 600-130mm), with average lengths of 103mm in spring and 102mm in autumn. The length-frequency distributions of both seasons are very similar in shape, with higher densities per size class in autumn. The dominant size class was the one of 100-110mm for both seasons. No differences were observed considering mean total length between the zones and between tops and gullies.

In spring samples of 2005 and 2008, similar densities of solenette were observed, but the DSC shifted from 80-90mm in 2005 to 100-110mm in 2008. In autumn, the DSC stayed the same, but densities ware considerably higher per size class in 2008 (mainly station WT9).

Reticulated dragonet *Callionymus reticulatus*

The mean lengths of the reticulated dragonet were very similar in both seasons (92mm in spring, 96mm in autumn. The length-frequency curve showed the same shape, with a DSC of 90-100mm in both seasons. No differences were observed considering mean total length as a result of sampling position or zone.

While the shape of the length-frequency distribution remained, the densities per size class were reduced by half in 2008 compared to 2005. This reduction was most pronounced in the NE gully samples WT3, WT6 and WT9, while top samples showed similar densities per size class.

Scaldfish *Arnoglossus laterna*

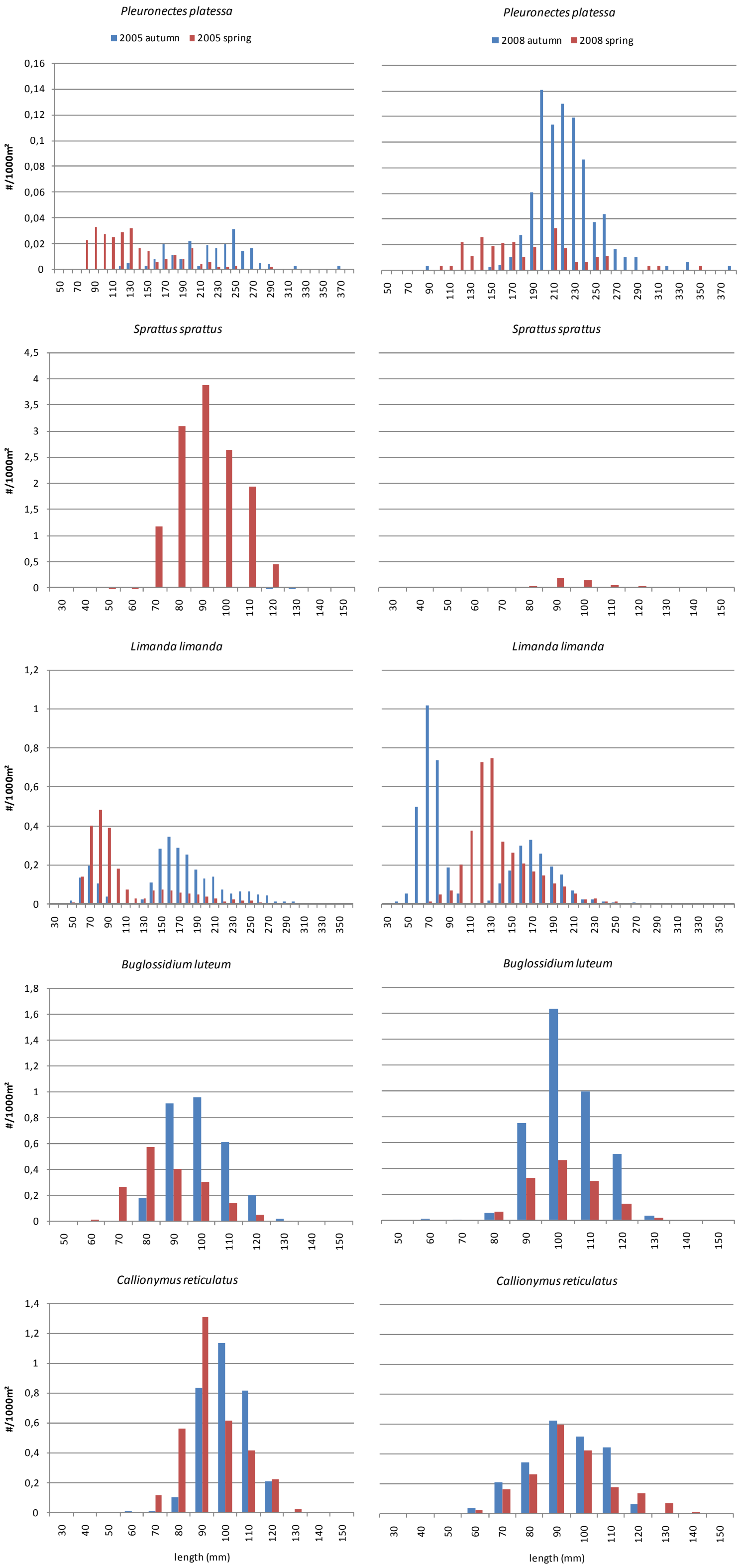
The length of scaldfish in 2008 ranged from 40 to 150mm, with averages of 110mm in spring and 108mm in autumn. In both seasons, two year classes could be distinguished based on the length-frequency data, with dominant size classes of 70-80mm and 120-130mm. In both seasons, the year class 1+ showed the highest densities per length class. No differences were observed considering mean total length as a result of sampling position or zone.

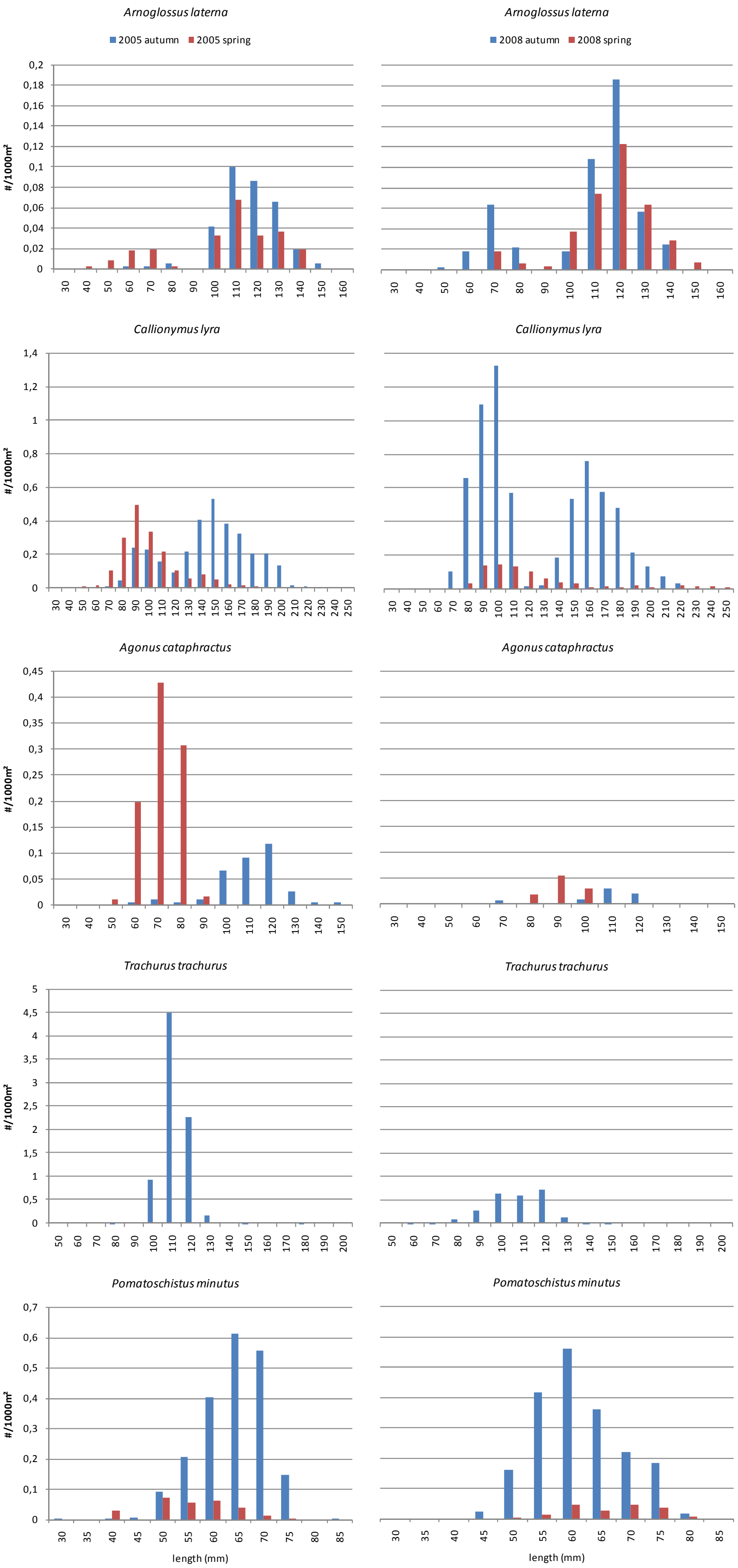
The same two year classes were also observed in both seasons of 2005. The year class 0, however, was more pronounced in autumn 2008 than in 2005. Generally, the densities per year class were higher in autumn 2008. For the length interval 60-90mm, increases were observed in all stations. For length class 120-130mm, however, increases could be attributed to observed changes at stations WT3 and WT9 (NE gully stations of the TRZ and the ECZ).

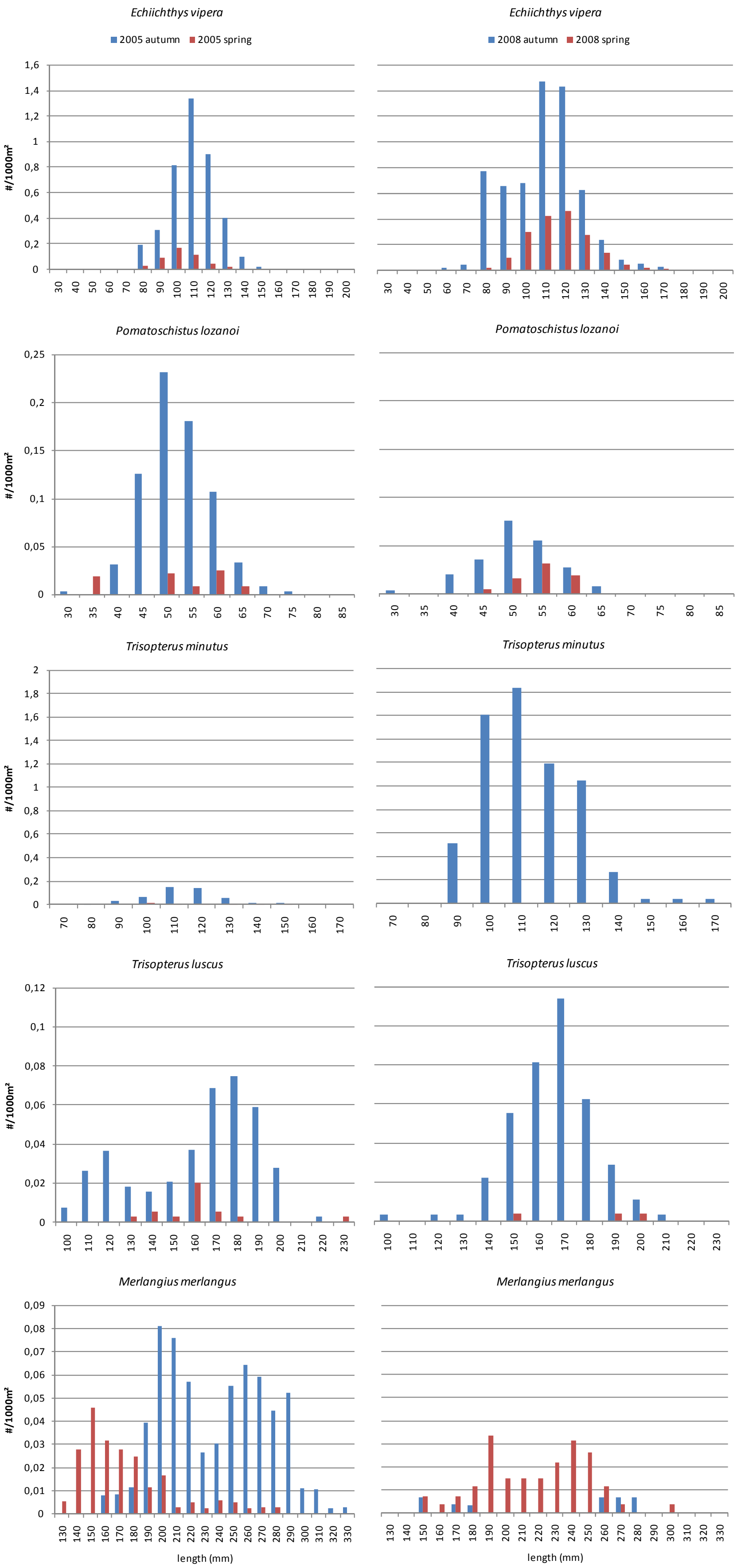
Dragonet *Callionymus lyra*

The length of dragonet in 2008 ranged from 70 to 250mm, with averages of 148mm in spring and 129mm in autumn. One density peak of small juveniles (DSC 100-110mm) was observed in spring; the curve from autumn was bimodal with density peaks at the length classes of 100-110mm and 160-170mm. No differences were observed considering mean total length as a result of sampling position or zone.

While the patterns of the length-frequency distribution and the position of the DSC's remained, the densities per size class were reduced in spring 2008 and were higher in autumn 2007 (especially concerning the youngest year class). These changes were seen at all stations with a similar intensity.


Pleuronectes platessa
2005 autumn
2005 spring
Pleuronectes platessa
2008 autumn
2008 spring
Sprattus sprattus
Sprattus sprattus
Limanda limanda
Limanda limanda
Buglossidium luteum
Buglossidium luteum
Callionymus reticulatus
Callionymus reticulatus
#/1000m²
length (mm)
length (mm)


Arnoglossus laterna
2005 autumn
2005 spring
Arnoglossus laterna
2008 autumn
2008 spring
#/1000m²
Callionymus lyra
Callionymus lyra
#/1000m²
Agonus cataphractus
Agonus cataphractus
#/1000m²
Trachurus trachurus
Trachurus trachurus
#/1000m²
Pomatoschistus minutus
Pomatoschistus minutus
#/1000m²
length (mm)
length (mm)


Echiichthys vipera
2005 autumn
2005 spring
Echiichthys vipera
2008 autumn
2008 spring
Pomatoschistus lozanoi
Pomatoschistus lozanoi
Trisopterus minutus
Trisopterus minutus
Trisopterus luscus
Trisopterus luscus
Merlangius merlangus
Merlangius merlangus
#/1000m²
length (mm)
length (mm)

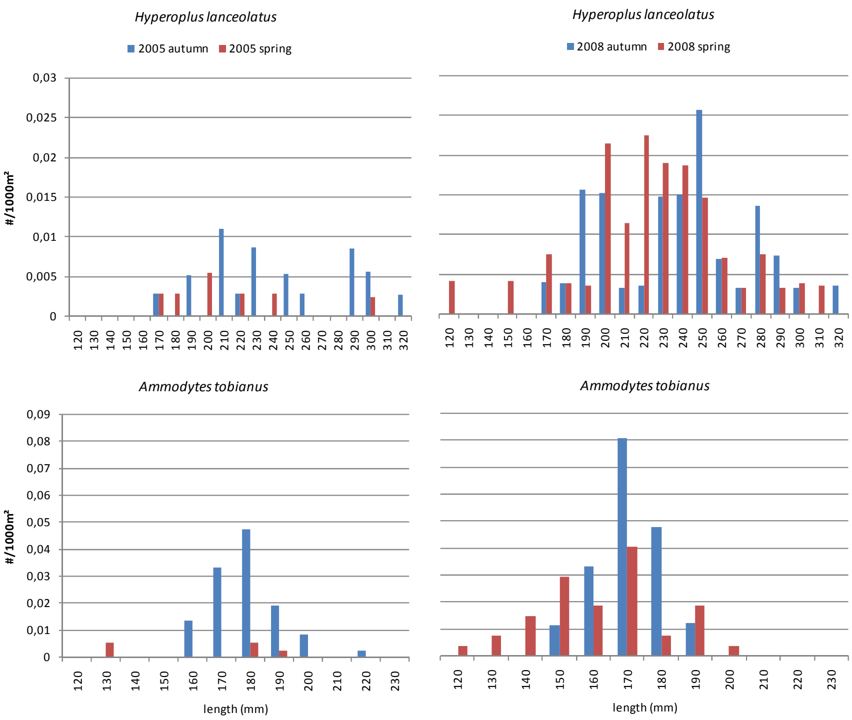


Figure 12. Averaged length-frequency distributions (all fish tracks) of 17 fish species - monitoring stations Thorntonbank, 2005 & 2008.

Hooknose *Agonus cataphractus*

The lengths of hooknose in 2008 varied between 70 and 120mm, with mean lengths of 90 and 112mm in spring and autumn. Very low densities were observed per size class (max 0.05 Ind/1000m²); the dominant size classes were the one of 90-100mm in spring and 110-120mm in autumn.

The observed densities in 2008 were considerably lower than in 2005, especially in spring. Additionally, the individuals were generally larger (DSC 70-80mm in 2005; 90-100mm in 2008). This reduction was visible at all stations, resulting in low density values in gully samples and a virtual absence of this species in the top samples.

Horse mackerel *Trachurus trachurus*

Horse mackerel was only found in fish tracks in autumn, with a length range of 60-150mm (average 107mm). No differences were observed considering mean total length as a result of sampling position or zone. When comparing 2005 and 2008, the length range and the pattern in length-frequency are quite similar, except for the lower densities per size class observed in 2008 (up to 10 times lower). This reduction in density was most pronounced at stations WT1, WT4 and especially WG2 (Figure 13).

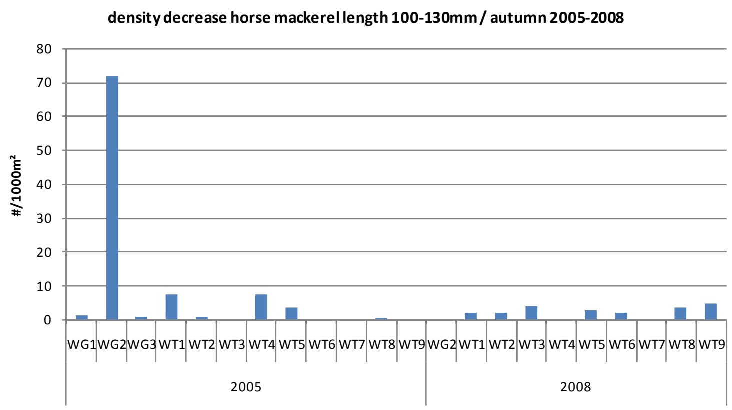


Figure 13. Column chart showing the density of horse mackerel (length 100-130mm) at all stations between years - monitoring stations Thorntonbank, 2005 & 2008.

Sand goby *Pomatoschistus minutus*

The sand goby Pomatoschistus minutus showed a length rage of 45-80mm in 2008, with an average of 66mm in spring and 61mm in autumn. The DSC was 70-75mm in autumn and 60-65mm in spring. No differences were observed considering mean total length as a result of sampling position or zone. The observed patterns showed very little changes over de years, except for a small decrease in length towards 2008 (average 61mm compared to 65mm in 2005).

Lesser weever *Echiichthys vipera*

The total length of the lesser weever varied between 60 and 180mm in 2008, with a mean length of 118mm in spring and 111mm in autumn. The dominant size class evolved from 120-130mm in spring to 110-120mm in autumn. The densities per size class were two to three times higher in autumn than in spring. There were no obvious differences between the investigated zones. However, differences between top samples and gully samples appeared significant in autumn (p:0.03): the mean total length was 12mm higher in gully samples (mean 117mm) compared to top samples (mean 105mm).

The length-frequency distributions from 2005 and 2008 showed similar shapes, but the spring densities per size class doubled in 2008. This density increase (especially at 100-140mm length) was most pronounced in the TRZ (WT1-3) and the WCZ (WT4-6) (Figure 14).

Lozano's goby *Pomatoschistus lozanoi*

This species showed a length rage of 30-65mm in 2008, with an average of 55mm in spring and 50mm in autumn. The DSC was 50-55mm in autumn and 55-60mm in spring. No differences were observed considering mean total length as a result of sampling position or zone. The observed patterns showed very little changes over de years, except for a density decrease in the length classes between 45 and 65mm in autumn. While Lozano's goby was quite abundant in the ECZ in 2005 (51-60 Ind/1000m²), and especially in the gullies, almost no individuals were found in this zone in 2008 (0-45 Ind/m²).

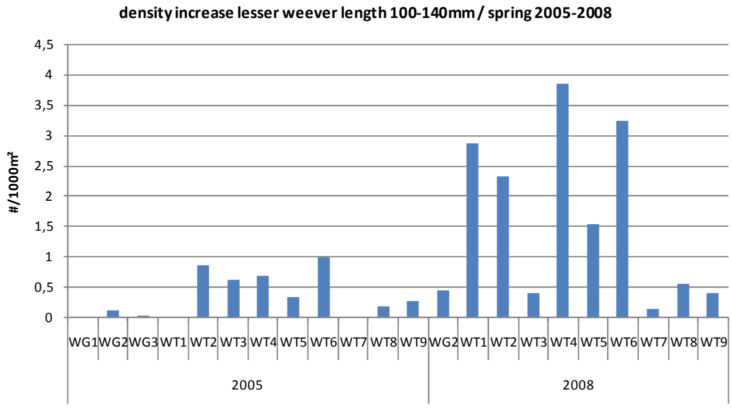


Figure 14. Column chart showing the density of lesser weever (length 100-140mm) at all stations between years - monitoring stations Thorntonbank, 2005 & 2008.

Poor cod *Trisopterus minutus* and bib *Trisopterus luscus*

Poor cod was almost exclusively found in autumn of both years. Length in 2008 ranged from 90-170mm, with an average length of 105mm in autumn and a DSC of 110-120mm. The DSC's of both years were identical, but densities per size class were about 10 times higher in 2008. This is solely the result of extremely high numbers observed at station WT7 in autumn 2008 (64 Ind/1000m² for individuals of 90-150mm in length).

In 2008, bib was caught at length of 100-210mm, with a DSC of 170-180mm in autumn. In 2005, two year classes could be distinguished (DSC: 120-130mm and 170-180mm) from catches at stations WG1, WG3 and WT7. In 2008, bib was only caught at station WT7 and these individuals mainly belonged to year class 1+.

Whiting *Merlangius merlangus*

The total length of whiting varied between 150 and 300mm, with a mean length of 217mm in spring and 220mm in autumn. In spring, larger juveniles were caught (DSC 190-200mm & 240-250mm). In autumn, the densities of whiting were much lower and the individuals were either small (140-190mm) or rather large (270-290mm). This is a totally different picture than the one observed in 2005, in which whiting was most abundant in autumn and the fraction of smaller individuals (140-180mm) was more important in spring. In autumn 2008, whiting was caught in low densities at only 3 stations (WT3-6-9), while this species was abundantly found in all gully stations in 2005. The changes in year class strengths between years were best observed at stations WT1-2-3-5-6-7-9.

Sandeels *Hyperoplus lanceolatus* and *Ammodytes tobianus*

The great sandeel *H. lanceolatus* showed a length range of 12-320mm. Mean length was slightly higher in autumn compared to spring (232 vs. 227mm). The length frequency distribution was rather discontinuous but three density peaks can roughly be distinguished in both seasons (at the size classes of 160-170mm, 220-230mm and 280-290mm in spring; at 190-200mm, 250-260mm and 280-290mm in autumn). No differences were observed considering mean total length as a result of sampling zone or position. Since the length-frequency distribution showed no distinguishable patterns in 2005 due to low densities (half of the ones observed in 2008) and low frequency of occurrence, no straightforward comparison between the years could be made.

The sandeel *A. tobianus* was caught at lengths ranging from 120 to 200mm, with average lengths of 162 and 173mm in spring and autumn of 2008. The DSC for both seasons was the one of 170-180mm, which is 10mm larger than the DSC observed in 2005. Autumn densities per size class were higher in 2008, but the most striking difference between the years is the abundance of sandeels in spring 2008 compared to their scarcity in spring 2005. In spring 2005, sandeels were found at 2 stations only (WG3 and WT7). In 2008, seven stations harbored sandeels, with highest densities in the TRZ and the WCZ.

7.4.5.2. Bligh Bank (Belwind concession): condition in 2008

For all fish species, the mean total length was determined. Additionally, the average length-frequency distribution was determined and visualized for the ten species with the overall highest densities and frequencies of occurrences (Figure 15).

The total length of the lesser weever *Echiichtys vipera* varied between 40 and 170mm, with a mean length of 111mm in spring and 107mm in autumn. Two length groups were distinguishable in both spring and autumn (spring: 40-60mm & 80-160mm; autumn: 60-80mm & 90-170mm). There were no obvious differences between the concession zone and the reference zones. However, differences between top samples and gully samples appeared significant in both spring and autumn (p:0.02 & 0.01, respectively): the mean total length was generally higher in gully samples (mean 114mm in spring, 112mm in autumn) compared to top samples (mean 105mm in spring, 92mm in autumn).

The total length of dab *Limanda limanda* varied between 50 and 320mm, with a mean length of 139mm in spring and 146mm in autumn. In spring, individuals from year class 0 were rare and most individuals belonged to year class 1 (DSC 120-130mm). Older fish reached a maximum size of 310mm. In autumn, year class 0 was more important than in spring (DSC 70-80mm), and the DSC of year class 1 was 120-130mm. Older fish reached a maximum size of 320mm. No differences were observed considering mean total length as a result of sampling position or zone.

The total length of whiting *Merlangius merlangus* varied between 140 and 320mm, with a mean length of 184mm in spring and 190mm in autumn. In spring, larger juveniles were caught (DSC 210-22mm & 230-240mm). In autumn, the densities of whiting were much lower but the individuals were about 60mm larger than in spring (DSC 270-280mm). The maximum encountered length increased from 300mm in spring to 320mm in autumn. No differences were observed considering mean total length as a result of sampling zone. Whiting was almost exclusively found in gully samples.

Dragonets *Callionymus lyra* were caught at sizes ranging from 60-250mm, with average values of 97mm in spring and 88mm in autumn. The first and second year classes were present in both seasons, but the bimodal pattern was best discerned in autumn due to higher densities. The dominant size classes for both size groups were identical in spring and autumn (year class 0: 90-100mm; year class 1: 160-170mm). This species was only found in gully samples of the investigated zones; no differences were observed considering mean total length between the zones.

Solenette *Buglossidium luteum* caught in the Bligh Bank monitoring area showed very little variation in length (range 70-130mm), with average lengths of 65mm in spring and 77mm in autumn. The length-frequency distributions of both seasons are very similar in shape, with higher densities per size class in autumn. The dominant size class was the one of 100-110mm for both seasons. Solenette was only found in gully samples of the investigated zones; no differences were observed considering mean total length between the zones.

In autumn, individuals of the species plaice *Pleuronectes platessa* were considerably larger compared to individuals observed in spring (mean 238mm versus 179mm). In spring, mainly juveniles at the end of their first year were caught (DSC 150-160mm). Older individuals reached lengths of max. 330mm. In autumn, the length-frequency-distribution shifted about 80mm to the right (DSC 130-240mm), with higher densities per size class than in spring. Larger individuals attained lengths of about 300mm, with some outliers of up to 440mm. No differences were observed considering mean total length as a result of sampling position or zone.

The mean lengths of the reticulated dragonet *C. reticulatus* (92mm in spring, 85mm in autumn) were very similar to the ones found for *C. lyra*, but the reticulated dragonet showed maximum values of only 120-140mm compared to 230-250mm for *C. lyra*. In autumn, higher densities of small individuals were recorded (DSC 70-80mm) than in spring (DSC 90-100mm). No differences were observed considering mean total length as a result of sampling position or zone.

The sand goby *Pomatoschistus minutus* showed a length rage of 45-75mm, with an average of 66mm in spring and 58mm in autumn. Total densities per fish track were similar in spring and autumn, but the frequency of occurrence was higher in autumn (all autumn samples , only in 5 spring samples). The DSC was 55-60mm in autumn, which is slightly lower than the DSC in spring (60-65mm). No differences were observed considering mean total length as a result of sampling position or zone.

Poor cod *Trisopterus minutus* was only found in fish tracks from gully stations, with the highest frequency of occurrence in autumn. The dominant size classes were 100-110mm and 140-150mm for autumn and spring, respectively. Only in autumn, a clear unimodal curve could be distinguished.

The great sandeel *Hyperoplus lanceolatus* was found in all samples, with a length range of 90-380mm. Mean length was higher in autumn compared to spring (267 vs. 234mm). In spring, three density peaks could be distinguished at the size classes of 160-170mm, 210-220mm and 290-300mm. The length-frequency distribution from autumn samples was rather discontinuous, with 3 density peaks at 200-210mm, 230-240mm and 310-320mm. No differences were observed considering mean total length as a result of sampling zone. In autumn, there was a significant difference concerning length between top samples and gully samples ($p = 0.01$; mean length gullies 277mm, mean length tops 239mm).

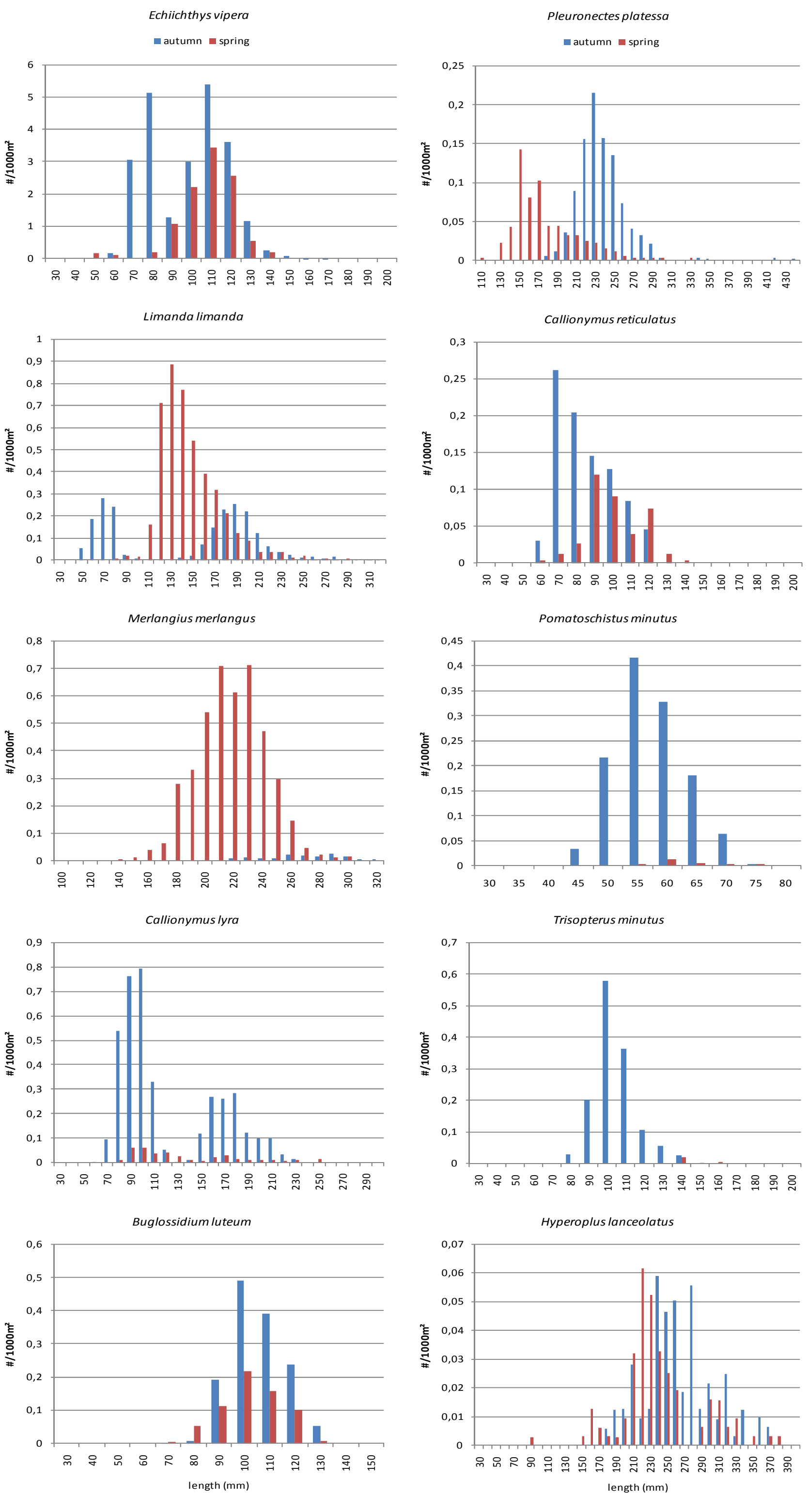


Figure 15. Averaged length-frequency distributions (all fish tracks) of 10 fish species - monitoring stations Bligh Bank, 2008.

7.4.6. Epibenthos: density

7.4.6.1. Thortonbank (C-power) and Bligh Bank (Belwind concession): condition in 2008

In 2008, the total epibenthos densities were generally higher (> twice) in autumn than in spring in most zones on the Thorntonbank (Table 11). The seasonal difference was even more pronounced on the Bligh Bank, with very low densities in spring in all zones (on average only 4 ind/1000m² in spring vs. 24 ind/1000m² in autumn).

Per season, the densities were comparable between both the Western Concession Zone (WCZ) and Eastern Concession Zone (ECZ) on the Thorntonbank (Figure 16). While densities were comparable between the WCZ and its gullies per season, the values from the gullies at the ECZ were on average five times higher than the values observed within (i.e. on top of) the ECZ. In the Thorntonbank reference zone (TRZ), densities were comparable between the top and the gullies of the bank in spring (like in the WCZ), but three times higher in the gullies than the top in autumn (like in the ECZ). For the Bligh Bank, the density values were on average six times higher in the border and gullies than on the top of both concession zone (BCZ) and reference zones on the Bligh Bank (BRZ) and Hinderbanken (HRZ) in both seasons (Table 14).

In spring 2008, the dominant taxonomic groups were shrimps (Caridea, 75%) and echinoderms (Echinodermata, 15%) for both WCZ and ECZ (Table 12, Figure 16). This was also the case in the gullies of both zones, except for the NW gully of ECZ where shrimps were almost completely replaced by hermit crabs (Anomura, 80%). In the gullies around the TRZ, shrimps, echinoderms and hermit crabs were equally abundant.

In autumn 2008, shrimps were less dominant (on average 10%) and comparable with the presence of brachyuran crabs (9%), while the dominant species groups were echinoderms (40%) and hermit crabs (30%) in both concession zones, their neighboring gullies and the reference zones on the Thorntonbank (Table 13, Figure 16). A higher percentage of other species (mainly cephalopods and bivalve mollusks) were noted in autumn in almost all subzones.

On the top of the Goote Bank reference zone (GRZ), echinoderms dominated the epibenthos in both seasons, which is (at least for spring) quite different from the TRZ or the concession zones.

For the Bligh Bank and Hinderbanken, there was a clear dominance of echinoderms (on average 40%) and hermit crabs (40%) in all subzones in both seasons, although it should be stressed again that the tops of these zones were almost void of epibenthic life in spring 2008 (Table 14, Figure 16). Brachyuran crabs (10%), bivalves and cephalopods (the latter mainly in autumn) followed as important groups in most subzones, while caridean shrimps were virtually absent in 2008 in any subzone of the Bligh Bank.

Only few species contributed to the overall density values, i.e. *Crangon crangon* (mainly in spring in all locations) for the Caridea; *Ophiura albida* and to a lesser extent *Ophiura ophiura* (both at higher densities in autumn) for the Echinodermata; *Pagurus bernhardus* (higher densities in autumn, with exceptionally high densities in spring in the NW gully of the eastern concession zone) for the Anomura; *Liocarcinus holsatus* (mainly in autumn) for the Brachyura; *Alloteuthis subulata* (only in autumn in all samples) for Cephalopoda; and several *Spisula* species (mainly in autumn in the NW gullies) for the Bivalvia.

7.4.6.2. Thorntonbank (C-power concession): comparison 2005 - 2008

Some general trends for the epibenthos remained quite similar in both years when comparing the different zones of the Thorntonbank monitoring area (Thorntonbank references zone, eastern and western concession zone and Goote Bank reference zone) per season:

- The densities in de WCZ were only a little higher than in the ECZ
- The densities were generally much higher in the gullies than on the tops in all zones, with the exception of the SE gully of the WCZ.
- The densities were generally higher in the NW gullies in all zones and seasons
- The main species composition and the most abundant species remained the same, although in different proportions.

In 2005 the epibenthos densities decreased from spring towards autumn, while in 2008 the opposite was true in almost all subzones (Figure 16). When comparing the total epibenthos densities per season between the years 2005 and 2008, the spring densities were significantly higher in 2005 (40 ind/1000m^2) vs. 2008 (15 ind/1000m^2). The densities were 2 to 5 times lower in 2008, which was most outspoken in the TRZ and in the gullies, and to a lesser extent on the top in the western concession zone. The reduction was not necessarily due to one group, but was seen in almost all taxonomic groups, with the common crab species *Liocarcinus holsatus* almost absent in the spring 2008 hauls.

In contrast to the spring situation, the total autumn densities were significantly higher in 2008 (34 ind/1000m^2) vs. 2005 (12 ind/1000m^2). The densities were 2 to 5 times higher in 2008, both in the gullies as on the tops of both concession and reference zones. This difference was mostly due to higher densities of hermit crabs and echinoderms in autumn 2008; caridean shrimps and brachyuran crabs were only present in low numbers in autumn of both years.

Table 11
Overview of the mean density of the epibenthos per taxonomic group for the examined years and seasons – monitoring stations Thorntonbank and Bligh Bank.

Season	Zone	mean density	mean density per taxonomic group (#/1000m^2)							
		#/1000m^2	Anomura	Brachyura	Caridea	Echinodermata	Bivalvia	Cephalopoda	Gastropoda	other
spring	thornton 2005	40	4.6	6.2	18.0	11.3	<0.1	<0.1	<0.1	<0.1
	thornton 2008	15	5.9	0.6	5.5	2.5	<0.1	<0.1	<0.1	<0.1
	Bligh Bank2008	4	1.3	0.5	0.1	1.4	0.6	<0.1	<0.1	<0.1
autumn	thornton 2005	13	0.7	3.8	1.5	5.2	0.3	1.1	0.4	<0.1
	thornton 2008	35	8.7	2.4	1.9	17.2	1.5	1.3	1.8	<0.1
	Bligh Bank2008	24	8.9	2.9	<0.1	9.9	1.5	0.7	0.1	<0.1

Table 12
Overview of the density of the epibenthos per station and per taxonomic group – monitoring stations Thorntonbank, spring 2005 & 2008.

Thorntonbank/Goote Bank Spring 2005

Area	Zone	Station	spring density	spring density per taxonomic group (#/1000m^2)							
			#/1000m^2	Anomura	Brachyura	Caridea	Echinodermata	Bivalvia	Cephalopoda	Gastropoda	other
Ref Th	SE gully	WT1	24	5.3	0.3	4.2	12.5	0.3	-	1.5	-
	top	WT2	18	3.3	0.4	3.7	10.3	-	-	-	-
	NW gully	WT3	69	8.9	7.6	28.0	23.7	0.3	-	-	0.2
West Conc	SE gully	WT4	6	1.7	0.8	2.8	0.9	-	<0.1	-	-
	top	WT5	15	2.3	0.6	4.1	7.8	-	-	-	-
	NW gully	WT6	66	5.7	21.4	31.1	7.6	0.1	-	-	-
East Conc	SE gully	WT7	90	8.3	20.4	48.7	12.2	0.2	0.1	-	0.1
	top	WT8	5	1.9	0.5	1.5	1.1	-	-	-	-
	NW gully	WT9	72	3.5	4.3	37.7	26.0	0.1	<0.1	0.1	-
Ref Gb	top	WG2	33	2.0	0.5	11.5	19.4	-	-	<0.1	-
	SE gully	WG1	79	7.2	1.3	30.9	38.1	0.7	-	0.2	0.3
	NW gully	WG3	382	2.8	1.6	17.5	359.4	-	-	-	0.9

Thorntonbank/Goote Bank Spring 2008

Area	Zone	Station	spring density	spring density per taxonomic group (#/1000m^2)							
			#/1000m^2	Anomura	Brachyura	Caridea	Echinodermata	Bivalvia	Cephalopoda	Gastropoda	other
Ref Th	SE gully	WT1	6	1.3	0.6	1.8	1.8	0.2	-	-	-
	top	WT2	5	0.6	0.1	3.9	0.9	-	-	-	-
	NW gully	WT3	13	6.1	0.5	2.5	2.6	0.9	-	0.1	-
West Conc	SE gully	WT4	5	0.6	<0.1	3.2	0.9	-	0.1	-	-
	top	WT5	9	0.8	0.1	6.9	1.0	0.1	-	-	-
	NW gully	WT6	13	1.4	0.2	9.2	1.5	0.3	<0.1	0.1	<0.1
East Conc	SE gully	WT7	28	3.3	2.0	16.0	6.5	0.5	-	-	-
	top	WT8	7	0.3	0.1	4.9	1.3	<0.1	-	0.1	-
	NW gully	WT9	48	38.6	1.4	0.7	6.1	0.6	<0.1	0.4	<0.1
Ref Gb	top	WG2	18	0.5	0.3	1.9	15.2	0.1	-	-	-

Table 13
Overview of the density of the epibenthos per station and per taxonomic group – monitoring stations Thorntonbank, autumn 2005 & 2008.

Thorntonbank/Goote Bank Autumn 2005

Area	Zone	Station	autumn density	autumn density per taxonomic group (#/1000m^2)							
			#/1000m^2	Anomura	Brachyura	Caridea	Echinodermata	Bivalvia	Cephalopoda	Gastropoda	other
Ref Th	SE gully	WT1	14	0.9	1.3	0.5	6.6	0.5	1.4	2.8	<0.1
	top	WT2	8	0.5	2.2	0.8	3.1	0.1	0.7	0.1	-
	NW gully	WT3	23	1.5	2.8	1.2	16.2	0.6	0.9	0.1	-
West Conc	SE gully	WT4	4	0.1	1.2	1.3	-	-	1.1	-	-
	top	WT5	8	0.3	3.6	2.3	0.8	0.1	1.1	-	-
	NW gully	WT6	13	1.1	3.7	0.7	6.0	0.5	0.8	-	<0.1
East Conc	SE gully	WT7	11	0.5	2.5	2.8	3.8	<0.1	1.4	0.2	0.3
	top	WT8	6	0.6	1.9	0.1	0.8	0.1	1.9	<0.1	-
	NW gully	WT9	30	0.5	15.0	4.0	9.4	0.5	0.9	-	<0.1
Ref Gb	top	WG2	5	0.4	0.8	0.1	1.8	<0.1	2.1	<0.1	-
	SE gully	WG1	15	1.9	0.7	0.5	8.7	0.1	1.7	0.6	0.4
	NW gully	WG3	20	0.5	0.8	<0.1	16.4	<0.1	1.7	0.1	0.3

Thorntonbank/Goote Bank Autumn 2008

Area	Zone	Station	autumn density	autumn density per taxonomic group (#/1000m^2)							
			#/1000m^2	Anomura	Brachyura	Caridea	Echinodermata	Bivalvia	Cephalopoda	Gastropoda	other
Ref Th	SE gully	WT1	31	8.9	1.3	0.2	15.8	0.2	3.6	0.6	<0.1
	top	WT2	10	2.1	1.1	1.2	4.8	0.2	0.8	-	-
	NW gully	WT3	40	8.3	2.5	0.8	21.0	6.7	0.8	-	-
West Conc	SE gully	WT4	9	2.9	1.2	0.9	2.5	0.1	1.9	-	-
	top	WT5	14	4.2	1.2	2.3	5.0	0.3	1.2	-	-
	NW gully	WT6	21	8.5	1.5	1.9	6.6	0.8	1.0	0.4	-
East Conc	SE gully	WT7	49	16.8	4.4	1.6	25.0	0.2	0.9	0.4	-
	top	WT8	19	5.6	1.7	2.7	7.6	-	0.9	0.1	-
	NW gully	WT9	120	21.1	6.4	5.8	66.3	5.2	0.5	15.0	-
Ref Gb	top	WG2	25	3.5	0.8	0.9	15.6	0.2	3.2	0.2	-

Table 14
Overview of the density of the epibenthos per station and per taxonomic group – monitoring stations Bligh Bank, spring and autumn 2008.

Bligh Bank/Hinderbanken Spring 2008

Area	Zone	Station	spring density	spring density per taxonomic group (#/1000m^2)							
			#/1000m^2	Anomura	Brachyura	Caridea	Echinodermata	Bivalvia	Cephalopoda	Gastropoda	other
Ref BB	SE gully	WBB01	3	1.4	1.1	0.2	0.3	0.3	0.0	0.1	-
	top	WBB02	1	0.3	<0.1	0.3	0.1	-	-	-	-
	NW gully	WBB03	9	1.1	1.3	0.1	1.9	3.6	0.2	-	0.4
BBR	SE border	WBB04	6	4.2	0.5	<0.1	1.0	0.4	<0.1	0.1	-
	SE gully	WBB05	3	2.1	<0.1	-	1.1	0.1	-	0.1	-
BCZ	top	WBB06	1	0.2	-	0.2	0.3	-	-	-	-
	NW gully	WBB07	5	0.6	0.6	-	3.9	0.2	-	-	0.1
BBR	NW border	WBB08	4	0.9	0.3	-	2.4	0.6	<0.1	-	0.1
Ref HB	SE gully	WOH01	15	2.8	0.7	<0.1	9.7	1.3	0.1	-	0.2
	top	WOH02	<1	0.2	<0.1	0.1	0.1	-	-	-	-
	NW gully	WOH03	3	0.8	0.1	-	1.9	-	-	-	-

Bligh Bank/Hinderbanken Autumn 2008

Area	Zone	Station	autumn density	autumn density per taxonomic group (#/1000m^2)							
			#/1000m^2	Anomura	Brachyura	Caridea	Echinodermata	Bivalvia	Cephalopoda	Gastropoda	other
Ref BB	SE gully	WBB01	34	7.1	10.3	0.1	12.5	2.8	0.8	0.1	0.1
	top	WBB02	4	1.9	0.7	-	0.3	<0.1	0.8	0.1	<0.1
	NW gully	WBB03	34	7.1	1.9	<0.1	21.0	2.2	1.1	0.6	0.1
BBR	SE border	WBB04	37	18.7	4.7	0.2	9.8	2.7	0.8	0.1	0.1
	SE gully	WBB05	23	9.3	1.0	-	10.4	1.0	0.8	0.2	<0.1
BCZ	top	WBB06	4	1.9	0.5	0.1	1.0	0.1	0.2	-	-
	NW gully	WBB07	30	14.0	2.1	-	11.7	1.6	0.3	-	-
BBR	NW border	WBB08	28	11.0	1.8	-	12.9	1.6	0.7	0.1	0.1
Ref HB	SE gully	WOH01	62	15.4	3.8	0.2	38.9	2.7	0.6	0.3	0.1
	top	WOH02	7	3.6	1.0	-	1.6	0.7	0.3	0.1	0.1
	NW gully	WOH03	28	13.3	1.7	-	10.7	1.5	0.4	0.4	-

Figure 16. Column chart of densities of epibenthos per taxonomic group for all stations and zones - monitoring stations Thorntonbank and Bligh Bank, spring (left) and autumn (right) 2005 & 2008.

7.4.7. Epibenthos: biomass

7.4.7.1. Thortonbank (C-Power) and Bligh Bank (Belwind concession): condition in 2008

The patterns in biomass were largely comparable with the patterns found in terms of density. The biomass values were higher in autumn 2008 (on average twice as high) compared to the spring values in almost all zones in and around the Thornton and Bligh Bank concession zones (Table 15). The biomass was usually higher (on average 3 times) in the gullies surrounding the concession zones than on top of (i.e. within) the concession zones. This difference was even more pronounced in spring 2008 as a very low epibenthos biomass was recorded on top of the BCZ, while in autumn 2008 the difference between top and gully was less clear for the WCZ on the Thornton bank. The biomass patterns in the reference zones are quite similar with the concession zones, with higher values in autumn, higher values in the gullies and very low values on top of the BRZ and HRZ in spring 2008 (as in BCZ).

In spring 2008, the dominant taxonomic groups were shrimps (80%) followed by echinoderms (10%) for both WCZ and ECZ (Table 16, Figure 17). This was also the case for the top of the TRZ and in the gullies around both concession zones, except for the NW gully of ECZ where shrimps were almost completely replaced by hermit crabs (Anomura, 60%). In the gullies around the TRZ, shrimps, echinoderms and hermit crabs showed almost the same biomass. On top of the GRZ, the importance of shrimps and echinoderms was completely reversed when compared to the other top locations in spring.

For the Bligh Bank (including Hinderbanken locations), the image in spring 2008 was rather different from the one in the Thorntonbank and more comparable with the assemblage composition in autumn (Table 18, Figure 17). There was a clear dominance of echinoderms (on average 40%) followed by hermit crabs (20%) and brachyuran crabs (10%) in all subzones, and of bivalves (20%) in the gullies.

In autumn 2008, shrimps were almost absent on the Thorntonbank and completely absent from the Bligh Bank (Table 17, Figure 17). In terms of biomass, the most important groups were echinoderms (on average 30%), brachyuran crabs (25%) and hermit crabs (15%) in the concession zones, their neighboring gullies and the reference zones for the Thorntonbank and Bligh Bank. Also higher biomasses of bivalves and cephalopods (both 10 %) were registered in autumn for almost all deeper subzones.

7.4.7.2. Thorntonbank (C-Power concession): comparison 2005 - 2008

Some general trends in biomass were similar in both years. Per year and season, the biomass on the tops of the different zones (WCZ, ECZ, TRZ and GRZ) was quite comparable. In most cases, the biomass in the gullies was higher than on the tops of the different zones (Figure 17). The dominance of caridean shrimps in spring and the low biomass of this species in autumn was registered in both years.

In spring the overall epibenthos biomass was 3 times higher in 2005 (120 gWW/1000m²) vs. 2008 (40 gWW/1000m²), except for the SE gully of the WCZ where a much higher biomass value was noted for caridean shrimps in spring 2008. The main species composition largely remained the same. The lower biomass values in spring 2008 were noted for all species groups, but were most visible for the brachyuran crabs in almost all sampling locations.

In autumn the overall biomass was comparable between both years (65 gWW/1000m²), although for most locations in the gullies and on the tops of both concession and reference zones, a little lower biomass was noted in 2008. Differences in the assemblage composition were noted, with lower biomass values in autumn 2008 (vs. autumn 2005) for brachyuran crabs and bivalves, and higher biomasses for hermit crabs and echinoderms in almost all zones.

Table 15
Overview of the mean biomass of the epibenthos per taxonomic group for the examined years and seasons – monitoring stations Thorntonbank and Bligh Bank.

Season	Zone	mean biomass	mean biomass per taxonomic group (gWW/1000m²)							
		gWW/1000m²	Anomura	Brachyura	Caridea	Echinodermata	Bivalvia	Cephalopoda	Gastropoda	other
spring	thornton 2005	123	7.6	57.8	40.5	16.2	0.2	<0.1	0.2	<0.1
	thornton 2008	39	6.4	3.5	20.7	7.0	1.2	0.1	<0.1	<0.1
	Bligh Bank2008	22	2.4	2.7	0.2	6.0	9.3	0.8	<0.1	0.2
autumn	thornton 2005	64	1.2	35.4	2.4	6.3	1.2	16.9	0.7	0.1
	thornton 2008	65	9.5	20.3	2.7	19.6	6.5	3.9	2.4	<0.1
	Bligh Bank2008	48	8.6	9.7	<0.1	16.9	8.3	4.6	0.1	0.1

Table 16
Overview of the biomass of the epibenthos per station and per taxonomic group – monitoring stations Thorntonbank, spring 2005 & 2008.

Thorntonbank/Goote Bank Spring 2005

Area	Zone	Station	spring biomass	spring biomass per taxonomic group (gWW/1000m^2)							
			gWW/1000m^2	Anomura	Brachyura	Caridea	Echinodermata	Bivalvia	Cephalopoda	Gastropoda	other
Ref Th	SE gully	WT1	45	6.9	2.7	8.1	25.7	0.4	-	1.5	-
	top	WT2	24	5.7	1.8	7.8	8.9	-	-	-	-
	NW gully	WT3	196	16.4	63.9	69.9	45.0	0.4	-	-	0.1
West Conc	SE gully	WT4	23	4.9	8.5	7.2	1.8	-	0.1	-	-
	top	WT5	25	2.3	4.7	10.6	7.9	-	-	-	-
	NW gully	WT6	300	7.2	213.1	68.8	10.3	0.2	-	-	-
East Conc	SE gully	WT7	321	15.6	183.5	99.7	21.3	0.5	0.1	-	0.2
	top	WT8	12	3.6	3.0	4.0	1.5	-	-	-	-
	NW gully	WT9	158	6.0	39.2	88.5	23.2	0.2	0.2	0.3	-
Ref Gb	top	WG2	52	2.9	2.0	28.2	17.9	-	-	1.3	-
	SE gully	WG1	183	9.7	10.0	62.3	98.1	1.0	-	0.7	1.6
	NW gully	WG3	330	2.1	16.5	31.1	278.0	-	-	-	2.1

Thorntonbank/Goote Bank Spring 2008

Area	Zone	Station	spring biomass	spring biomass per taxonomic group (gWW/1000m^2)							
			gWW/1000m^2	Anomura	Brachyura	Caridea	Echinodermata	Bivalvia	Cephalopoda	Gastropoda	other
Ref Th	SE gully	WT1	21	0.8	4.2	4.5	10.5	1.0	-	-	-
	top	WT2	12	0.5	0.7	9.1	1.5	-	-	-	-
	NW gully	WT3	33	6.5	2.7	6.0	12.7	5.2	-	<0.1	-
West Conc	SE gully	WT4	81	0.8	0.2	76.0	3.8	-	0.4	-	-
	top	WT5	18	0.6	0.9	14.6	1.4	0.1	-	-	-
	NW gully	WT6	30	1.7	1.2	23.9	1.7	0.7	0.5	<0.1	<0.1
East Conc	SE gully	WT7	71	2.9	13.1	38.1	15.4	1.3	-	-	-
	top	WT8	15	0.2	0.5	11.9	2.7	0.1	-	<0.1	-
	NW gully	WT9	70	43.4	8.2	2.2	13.6	2.6	0.1	0.2	<0.1
Ref Gb	top	WG2	30	0.6	0.6	3.7	24.6	0.3	-	-	-

Table 17
Overview of the biomass of the epibenthos per station and per taxonomic group – monitoring stations Thorntonbank, Autumn 2005 & 2008.

Thorntonbank/Goote Bank Autumn 2005

Area	Zone	Station	autumn biomass	Autumn biomass per taxonomic group (gWW/1000m^2)							
			gWW/1000m^2	Anomura	Brachyura	Caridea	Echinodermata	Bivalvia	Cephalopoda	Gastropoda	other
Ref Th	SE gully	WT1	63	1.4	12.6	0.8	6.7	3.0	33.6	4.9	<0.1
	top	WT2	35	0.9	23.3	1.7	5.0	0.7	3.6	0.2	-
	NW gully	WT3	58	2.8	23.9	1.2	14.4	2.6	13.1	0.4	-
West Conc	SE gully	WT4	44	0.1	14.8	2.3	-	-	27.0	-	-
	top	WT5	59	0.7	47.2	4.3	3.0	0.4	3.5	-	-
	NW gully	WT6	57	2.3	40.0	1.0	5.7	1.9	6.0	-	0.2
East Conc	SE gully	WT7	58	0.9	25.1	4.2	8.1	0.2	18.7	0.4	0.5
	top	WT8	55	0.6	22.7	0.4	1.3	0.3	29.4	0.1	-
	NW gully	WT9	148	1.4	109.2	5.6	13.0	2.1	16.9	-	<0.1
Ref Gb	top	WG2	52	0.7	6.5	0.1	8.9	0.2	35.7	0.1	-
	SE gully	WG1	65	2.2	12.4	0.3	26.5	1.6	20.1	1.4	0.3
	NW gully	WG3	88	0.9	22.3	<0.1	23.6	0.0	40.5	0.1	0.7

Thorntonbank/Goote Bank Autumn 2008

Area	Zone	Station	autumn biomass	Autumn biomass per taxonomic group (gWW/1000m^2)							
			gWW/1000m^2	Anomura	Brachyura	Caridea	Echinodermata	Bivalvia	Cephalopoda	Gastropoda	other
Ref Th	SE gully	WT1	60	9.2	9.2	0.2	30.6	2.2	7.2	1.0	<0.1
	top	WT2	24	3.1	8.8	1.7	7.5	2.1	1.2	-	-
	NW gully	WT3	81	8.4	20.4	0.9	17.7	28.9	4.3	-	-
West Conc	SE gully	WT4	24	3.9	8.1	1.5	6.0	0.5	3.9	-	-
	top	WT5	29	4.0	10.4	3.0	7.8	1.7	2.6	-	-
	NW gully	WT6	36	8.8	12.7	2.9	4.4	3.9	3.3	0.3	-
East Conc	SE gully	WT7	113	20.7	40.0	2.4	44.4	0.4	4.6	0.8	-
	top	WT8	37	6.4	16.1	4.7	8.1	-	1.9	0.1	-
	NW gully	WT9	179	20.6	56.9	7.1	49.7	18.9	5.8	19.8	-
Ref Gb	top	WG2	40	3.1	6.1	1.1	19.0	1.3	9.8	0.1	-

Table 18

Overview of the biomass of the epibenthos per station and per taxonomic group – monitoring stations Bligh Bank, Spring and Autumn 2008.

Bligh Bank/Hinderbanken Spring 2008

Area	Zone	Station	spring biomass gWW/1000 m²	Anomura	Brachyura	Caridea	Echinodermata	Bivalvia	Cephalopoda	Gastropoda	other
				spring biomass per taxonomic group (gWW/1000m²)							
Ref BB	SE gully	WBB01	14	2.0	6.7	0.4	2.0	2.9	0.1	<0.1	-
	top	WBB02	2	0.5	0.2	0.6	0.3	-	-	-	-
	NW gully	WBB03	85	1.5	4.2	0.1	16.8	56.0	5.5	-	1.2
BBR	SE border	WBB04	15	6.9	2.6	0.1	3.0	2.6	0.1	<0.1	-
	SE gully	WBB05	15	5.9	0.1	-	7.9	0.6	-	<0.1	-
Conc	top	WBB06	2	0.3	-	0.6	1.0	-	-	-	-
	NW gully	WBB07	24	1.2	5.7	-	9.0	7.6	-	-	0.3
BBR	NW border	WBB08	17	1.2	1.8	-	8.1	4.9	0.3	-	0.4
Ref HB	SE gully	WOH01	58	4.1	4.1	<0.1	34.9	14.0	0.2	-	0.3
	top	WOH02	1	0.4	0.0	0.3	0.1	-	-	-	-
	NW gully	WOH03	7	1.1	0.5	-	5.4	-	-	-	-

Bligh Bank/Hinderbanken Autumn 2008

Area	Zone	Station	autumn biomass gWW/1000 m²	Anomura	Brachyura	Caridea	Echinodermata	Bivalvia	Cephalopoda	Gastropoda	other
				autumn biomass per taxonomic group (gWW/1000m²)							
Ref BB	SE gully	WBB01	84	7.7	19.0	0.1	31.2	19.3	6.9	0.2	0.1
	top	WBB02	12	2.5	4.0	-	2.0	<0.1	2.9	0.2	<0.1
	NW gully	WBB03	74	7.3	12.0	<0.1	25.7	17.4	11.1	0.3	0.1
BBR	SE border	WBB04	72	15.5	18.7	0.1	18.3	12.2	6.6	0.1	0.3
	SE gully	WBB05	50	9.5	4.2	-	27.0	5.1	3.8	0.3	<0.1
Conc.	top	WBB06	12	2.2	3.5	<0.1	3.1	1.3	1.5	-	-
	NW gully	WBB07	35	14.6	6.5	-	9.7	3.2	0.6	-	-
BBR	NW border	WBB08	49	9.3	10.0	-	17.9	7.7	3.8	0.1	0.2
Ref HB	SE gully	WOH01	125	15.0	24.1	0.1	69.9	11.6	2.6	1.8	0.1
	top	WOH02	20	5.1	5.3	-	4.0	4.9	0.7	<0.1	<0.1
	NW gully	WOH03	47	15.3	7.1	-	17.4	5.0	1.9	0.5	-

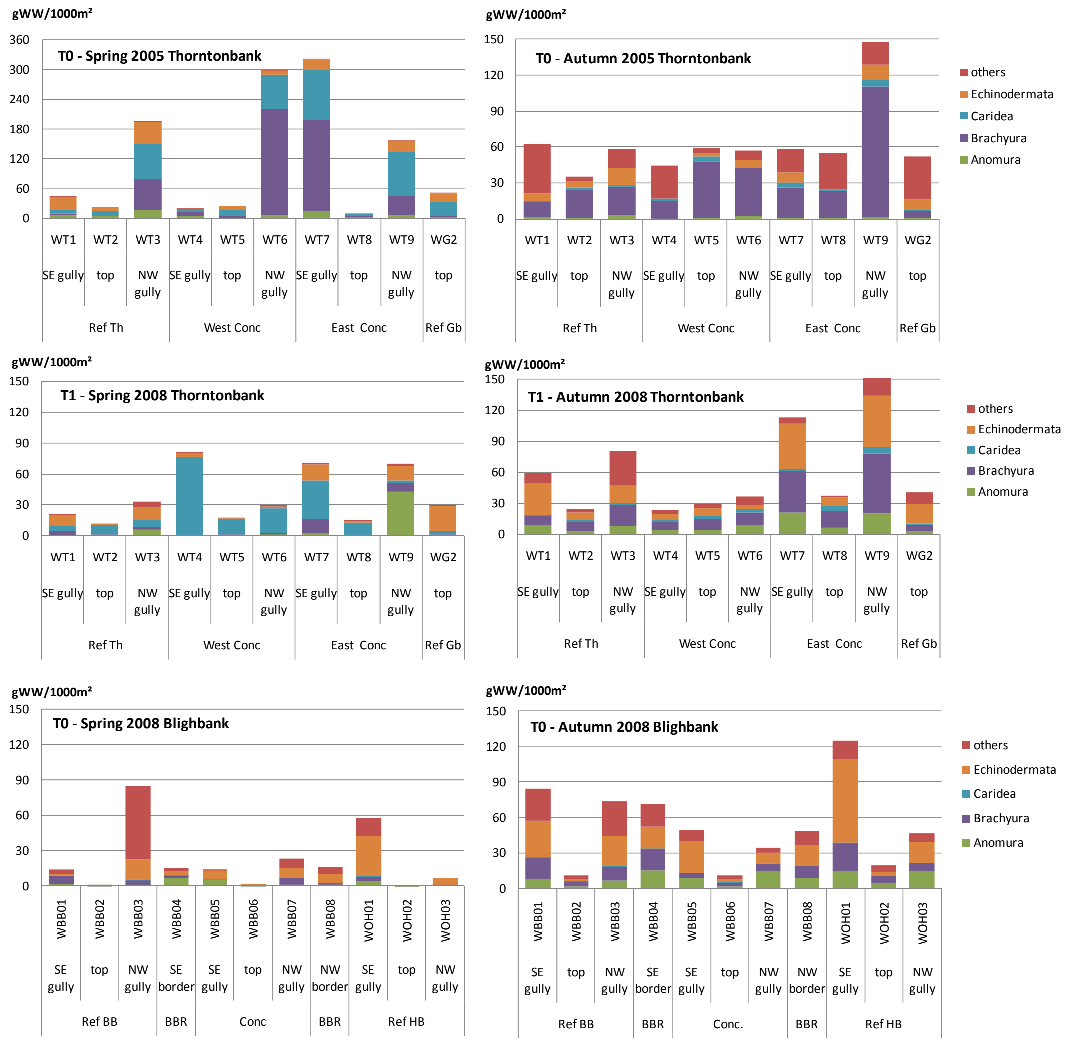


Figure 17. Column chart of biomass of epibenthos per taxonomic group for all stations and zones - monitoring stations Thorntonbank and Bligh Bank, spring (left) and autumn (right) 2005 & 2008.

7.4.8. Epibenthos: diversity

7.4.8.1. Thortonbank (C-Power) and Bligh Bank (Belwind concession): condition in 2008

In total, 37 epibenthic species were identified on and around the Thorntonbank/Goote Bank area in 2008, of which 30 species were observed in spring and 31 in autumn 2008. Only 24 species were found in both seasons, leaving 6 and 7 species which were only found in spring or autumn respectively. On and around the Bligh Bank/Hinderbanken area, a total of 41 epibenthic species were found, with 24 species common in both seasons and a total of 31, respectively 34, species in spring and autumn 2008. On average only 12 and 18 species were recorded per fish track in spring, respectively autumn (Table 19). In and around the windmill concession zones, 48 different epibenthic species were recorded in 2008 (Annex 7), of which 30 species were common to both bank systems, while 7, respectively 11 species were only found in the Thornton and Bligh Bank areas.

The reference zones (TRZ, GRZ, BRZ and HRZ) all showed similar seasonal and depth-related patterns in species richness and diversity, comparable to the concession zones (WCZ, ECZ and BCZ) (Table 20, Table 21, Figure 18). There was a clear difference between the number of species (N0) on top of the banks (and thus in the concession zones) vs. the gullies in the Thorntonbank area, with on average 9 species per location on the tops and 14 species in the gullies in spring 2008 and respectively 15 and 18 species per track in autumn. The difference between tops and gullies qua total number of species is even more pronounced, with 13 vs. 28 species in spring and 22 vs. 31 species in autumn.

All species that were found on the tops were also observed in the gullies, which shows that the gullies are clearly more diversified.

For the Bligh Bank/Hinderbanken area, more or less the same difference between tops and gullies was found in total number of species: 9 vs. 30 species in spring and 20 vs. 32 species in autumn, on tops and gullies respectively (Table 22, Figure 18). Also, most of the species found on the tops were also present in the gullies, while several species were only observed in the gullies. As has been shown, there was a clear increase in total species diversity from spring to autumn for the tops, and a smaller increase for the gullies, although on a per station base the increase was equally substantial for most of the gullies.

For the other diversity indices, the patterns were less pronounced (Figure 18). The values for N1, N2 and Ninf were much lower in spring 2008 in the Thorntonbank area compared to all other zones and seasons, with lower values on the tops compared to the gullies. In autumn 2008 for the Thornton area and in both seasons for the Bligh Bank area, the patterns were quite similar with average values of 5.9, 4.0 and 2.5 for the respective diversity indices (N1, N2 and Ninf) with only small differences between tops and gullies. In contrast to the other locations, slightly higher values were observed on the tops compared to the respective gullies in and around the Thorntonbank area in autumn 2008.

In spring 2008, only 6 epibenthic species occurred in all fish tracks in the Thorntonbank/Goote Bank area: *Crangon crangon*, *Ophiura albida*, *Ophiura ophiura*, *Pagurus bernhardus*, *Liocarcinus holsatus* and *Asterias rubens.* In autumn 2008 the same 6 species together with *Sepiola atlantica* and *Alloteuthis subulata* were recorded in all samples of this area. Nine, respectively 4 species were found in only one location in spring resp. autumn. For the Bligh Bank/Hinderbanken area the same species with the exception of *Crangon crangon* occurred in most of the locations both in spring and autumn 2008.

7.4.8.2. Thorntonbank (C-Power concession): comparison 2005 - 2008

Although a similar total number of species was observed in the Thorntonbank/Goote Bank area in both years (35 species in 2005; 37 species in 2008), only 29 species were found in both years, leaving 14 epibenthic species that were recorded in only one of the sampling years.

For all diversity indices the same patterns were noted in both years with higher values in autumn compared to spring (Figure 18). In spring 2005 almost no difference was noted between tops and gullies, while in spring 2008 the diversity indices were substantially higher in the gullies. Still, unless for number of species (N0), the other indices were lower for most sampling locations compared to 2005. For N1, N2 and Ninf a reduction of 40 % was calculated on the tops of the area, and a reduction of 15% for the gullies. On the other hand, in autumn almost the same values were recorded in 2005 and 2008 and the difference between tops and gullies showed an opposite trend with lower values in the gullies which was clear in autumn 2005 and less pronounced in autumn 2008.

Table 19
Overview of the mean diversity indices of the epibenthos per taxonomic group for the examined years and seasons – monitoring stations Thorntonbank and Bligh Bank.

season	zone	mean diversity			
		S	N1	N2	Ninf
spring	thornton 2005	11	4.5	3.5	2.3
	thornton 2008	12	3.7	2.5	1.7
	Bligh Bank2008	13	6.0	4.1	2.5
autumn	thornton 2005	17	6.8	4.6	2.8
	thornton 2008	17	6.5	4.8	3.0
	Bligh Bank2008	18	5.8	3.8	2.4

Table 20
Overview of the diversity indices of the epibenthos per station and per taxonomic group – monitoring stations Thorntonbank, spring 2005 & 2008.

Thorntonbank/Goote Bank Spring 2005

Area	Zone	Station	spring diversity			
			S	N1	N2	Ninf
Ref Th	SE gully	WT1	14	6.2	5.1	3.3
	top	WT2	9	3.9	3.1	2.1
	NW gully	WT3	14	5.0	3.8	2.6
West Conc	SE gully	WT4	8	4.4	3.5	2.3
	top	WT5	9	4.1	3.2	2.1
	NW gully	WT6	10	4.0	3.1	2.2
East Conc	SE gully	WT7	14	4.3	3.0	1.9
	top	WT8	9	5.0	3.8	2.6
	NW gully	WT9	14	3.6	2.7	2.0
Ref Gb	top	WG2	13	4.7	3.3	2.3
	SE gully	WG1	18	6.4	4.7	2.8
	NW gully	WG3	14	2.0	1.4	1.2

Thorntonbank/Goote Bank Spring 2008

Area	Zone	Station	spring diversity			
			S	N1	N2	Ninf
Ref Th	SE gully	WT1	14	7.4	5.5	3.1
	top	WT2	6	2.7	1.9	1.4
	NW gully	WT3	15	5.2	3.4	2.1
West Conc	SE gully	WT4	8	3.1	2.1	1.5
	top	WT5	7	2.3	1.6	1.3
	NW gully	WT6	12	2.9	1.8	1.4
East Conc	SE gully	WT7	17	4.8	2.9	1.8
	top	WT8	10	2.8	1.8	1.4
	NW gully	WT9	18	2.4	1.5	1.2
Ref Gb	top	WG2	11.0	2.5	1.6	1.3

Table 21
Overview of the diversity indices of the epibenthos per station and per taxonomic group – monitoring stations Thorntonbank, autumn 2005 & 2008.

Thorntonbank/Goote Bank Autumn 2005

Area	Zone	Station	autumn diversity			
			S	N1	N2	Ninf
Ref Th	SE gully	WT1	18	8.1	5.2	2.8
	top	WT2	16	8.0	5.6	3.3
	NW gully	WT3	22	4.6	2.4	1.6
West Conc	SE gully	WT4	9	5.6	4.5	3.1
	top	WT5	15	6.1	4.1	2.4
	NW gully	WT6	17	6.2	4.1	2.5
East Conc	SE gully	WT7	20	9.0	6.4	4.2
	top	WT8	15	8.1	5.8	3.3
	NW gully	WT9	18	5.1	3.3	2.1
Ref Gb	top	WG2	15	9.0	7.4	4.8
	SE gully	WG1	22	11.6	8.5	4.8
	NW gully	WG3	17	6.2	4.0	2.3

Thorntonbank/Goote Bank Autumn 2008

Area	Zone	Station	autumn diversity			
			S	N1	N2	Ninf
Ref Th	SE gully	WT1	24	7.1	5.4	4.1
	top	WT2	15	7.5	5.4	3.0
	NW gully	WT3	16	6.0	4.1	2.4
West Conc	SE gully	WT4	14	7.5	5.8	3.3
	top	WT5	17	7.0	5.4	3.4
	NW gully	WT6	15	5.7	4.0	2.4
East Conc	SE gully	WT7	20	6.1	4.3	3.0
	top	WT8	11	5.7	4.8	3.3
	NW gully	WT9	18	5.6	3.7	2.2
Ref Gb	top	WG2	18.0	6.2	4.4	2.5

Table 22
Overview of the diversity indices of the epibenthos per station and per taxonomic group – monitoring stations Bligh Bank, spring and autumn 2008.

Bligh Bank/Hinderbanken Spring 2008

Area	Zone	Station	spring diversity			
			S	N1	N2	Ninf
Ref BB	SE gully	WBB01	14	6.8	4.3	2.5
	top	WBB02	7	4.4	3.4	2.5
	NW gully	WBB03	20	11.4	8.4	4.0
BBR	SE border	WBB04	17	4.6	2.4	1.6
	SE gully	WBB05	9	3.7	2.4	1.6
Conc	top	WBB06	6	5.0	4.5	3.0
	NW gully	WBB07	12	4.6	2.6	1.7
BBR	NW border	WBB08	16	7.3	4.9	2.8
Ref HB	SE gully	WOH01	16	5.2	3.2	2.0
	top	WOH02	5	3.9	3.3	2.2
	NW gully	WOH03	7	3.7	2.8	1.9

Bligh Bank/Hinderbanken Autumn 2008

Area	Zone	Station	autumn diversity			
			S	N1	N2	Ninf
Ref BB	SE gully	WBB01	24	9.0	6.6	4.2
	top	WBB02	13	5.5	3.4	2.0
	NW gully	WBB03	25	5.2	2.9	1.8
BBR	SE border	WBB04	24	6.1	3.4	2.0
	SE gully	WBB05	16	5.8	3.9	2.4
Conc.	top	WBB06	11	5.4	3.4	2.0
	NW gully	WBB07	11	4.1	2.9	2.2
BBR	NW border	WBB08	20	5.2	3.6	2.5
Ref HB	SE gully	WOH01	20	5.2	3.3	2.1
	top	WOH02	16	6.3	3.6	2.0
	NW gully	WOH03	15	4.6	3.1	2.1

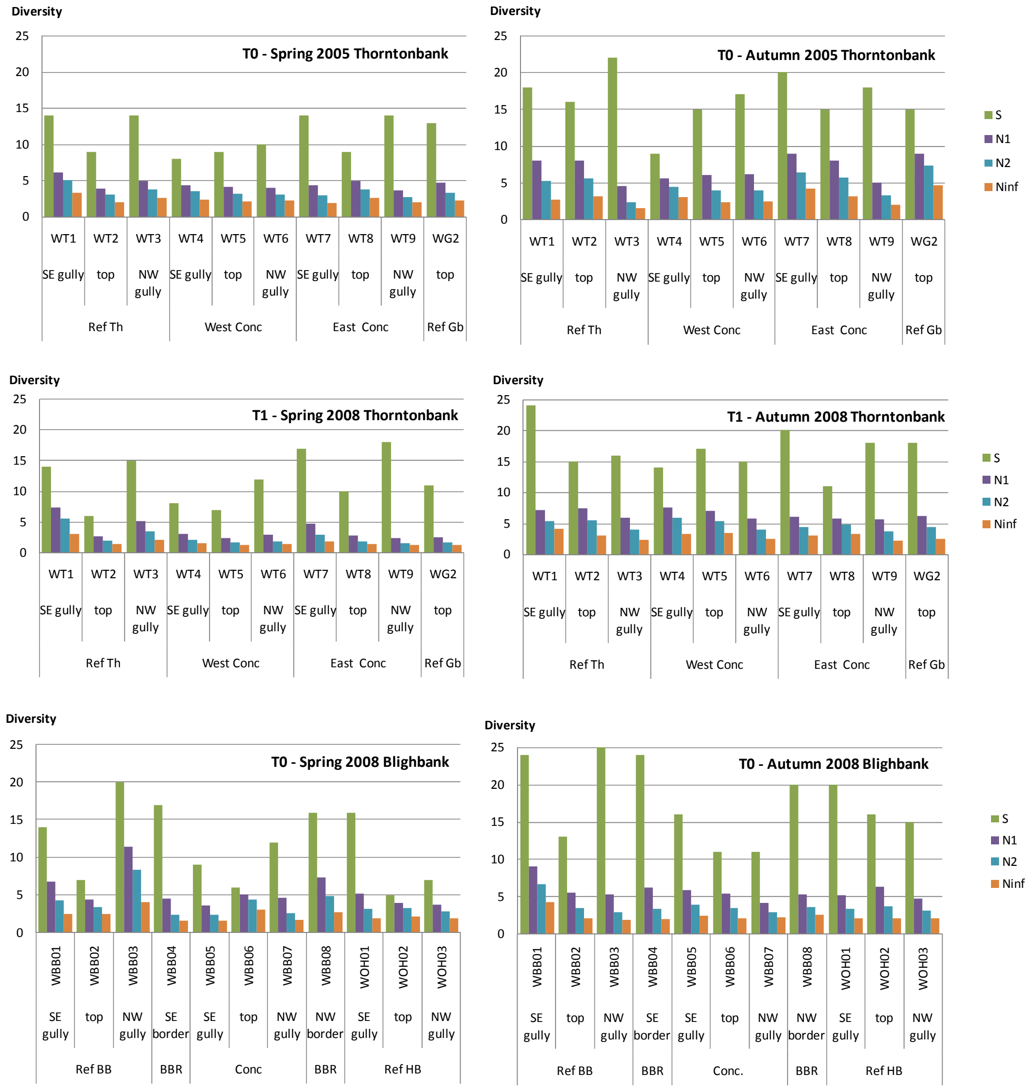


Figure 18. Column chart of diversity of epibenthos per taxonomic group for all stations and zones - monitoring stations Thorntonbank and Bligh Bank, spring (left) and autumn (right) 2005 & 2008.

7.4.9. Epibenthos: community analysis

7.4.9.1. Thortonbank (C-Power) and Bligh Bank (Belwind concession): condition in 2008

After the reduction of the database based on densities and frequencies of occurrences (> 1%), 15 resp. 24 species were taken into account for spring and 17 resp. 21 species for autumn for the Thorntonbank/Goote Bank area, resp. Bligh Bank/Hinderbanken area.

The MDS plot of the spring 2008 samples clearly groups the fish tracks on the sandbank tops of the Thorntonbank and to a lesser extent the top of the Goote Bank (Figure 19). Station WT4, which is located on the SE slope of the WCZ, showed more similarities with the top than with the deeper gullies. Another group that can be delineated consists of the sampling locations in the NW gully. The SW gully samples are scattered around the plot. ANOSIM analysis based on the differences between these two groups resulted in an R-value of 0.56 (p=0.03), which indicates significant differences between the groups. Simper analysis calculated similarities within these groups of 75 % for the top locations and 75% for the NW gully locations. The differences between tops and gullies were mainly due to the higher abundance of hermit crab *Pagurus bernhardus* and lesser brittle star *Ophiura albida* in the gullies and the more common brittle star *Ophiura ophiura* on the tops. Additionally, higher densities of heart urchin *Echinocardium cordatum* and thick trough shell *Spisula solida* were recorded in the gullies and more green urchin *Psammechinus miliaris* in the top locations.

For the autumn 2008 samples of the Thorntonbank/Goote Bank area, a clear aggregation of the top and slope locations is visible in the MDS plot (80 % similarity in ANOSIM), while the gully locations are scattered (Figure 19). However, also the gully locations showed a high similarity of 70%. Only 25% dissimilarity was calculated between both top and gully locations. The differences were mainly due to higher densities in the gullies for the brittle star species *Ophiura albida* and *O. ophiura* and hermit crabs, next to netted dog whelk *Nassarius reticulatus* and several *Spisula* species.

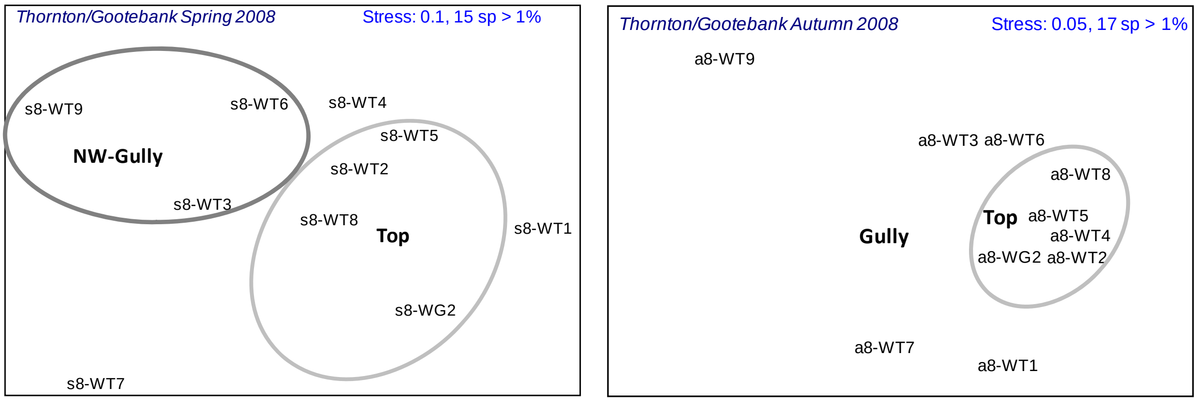


Figure 19. MDS plots of spring (left) and autumn (right) samples, indicating groupings based on position in a gully (dark grey contour) or on a sandbank top (light grey contour)- monitoring stations Thorntonbank, 2008.

The spring 2008 MDS plot of the Bligh Bank/Hinderbanken area clearly shows an aggregation of the top locations, and a difference between the samples in the NW gully and those in the SE gully (pairwise test R = 0.6, p= 0.001) (Figure 20). ANOSIM calculated a similarity of 60 to 70 % within the 3 groups and on average 60% dissimilarity between the tops and gullies. *Pagurus bernhardus* and *Ophiura albida* occurred in much higher densities in the gullies. However, since the top samples in the Bligh Bank/Hinderbanken area were almost void of epibenthic life in spring 2008, the presence of several other species in the gullies also contributed to the difference between the tops and gullies. The difference between the NW gully and the SE gully was mainly due to higher densities of sword razor clam *Ensis arcuatus* and the ophiuroid *Ophiura albida* in the NW gully and higher densities of hermit crab *Pagurus bernhardus* in the SE gully, next to a large list of species that are more abundant in either the NW gullies or the SE gullies.

In the autumn 2008 MDS plot of data from the Bligh Bank/Hinderbanken area, only two groups could be distinguished, with a similarity of 80% for the gullies and 70% for the top locations (Figure 20). Fish track WBB07 is located on the NW slope and showed more affinity with the top locations than with the gullies. The dissimilarity of 35% between the top and gullies (R=0.69, p=0.003) is mainly due to higher densities in the gullies of *Ophiura albida*, *Pagurus bernhardus*, *Ophiura ophiura*, long legged spider crab *Macropodia rostrata*, flying crab *Liocarcinus holsatus*, starfish *Asterias rubens* and several *Spisula* species.

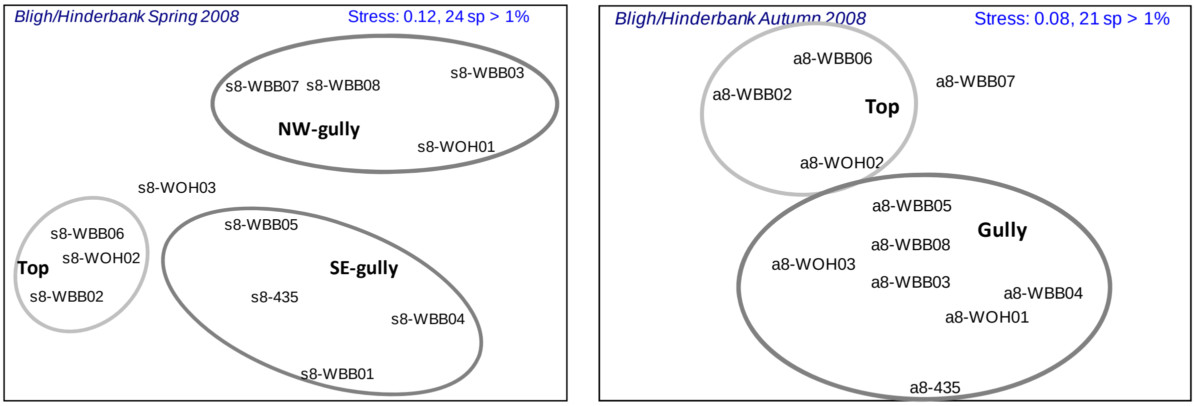


Figure 20. MDS plots of spring (left) and autumn (right) samples, indicating groupings based on position in a gully (dark grey contour) or on a sandbank top (light grey contour)- monitoring stations Bligh Bank, 2008.

7.4.9.2. Thorntonbank (C-Power concession): comparison 2005 - 2008

After the reduction of the database based on densities and frequencies of occurrences (> 1%), 20 species were taken into account for spring and 24 species for autumn when comparing the Thorntonbank/Goote Bank area for 2005 and 2008 per season.

The MDS plot for the spring comparison showed a clear difference between top (75% similarity) and gully locations and a difference between 2005 (78 % similarity) and 2008 (64 % similarity) for the gully locations (Figure 21). The top locations were more or less aggregated per year. ANOSIM calculated a global R-value of 0.60 (p=0.001) and SIMPER calculated a 40% dissimilarity between the 3 groups. *Liocarcinus holsatus*, brown shrimp *Crangon crangon*, *Ophiura albida* and *Pagurus bernhardus* were present in much higher densities in the gullies compared to the tops in spring 2005. These species, together with several others were responsible for the difference between the gullies in 2005 vs. 2008, due to the very low densities in spring 2008. The difference between the top and gullies in 2008 was also due to higher densities of *Pagurus bernhardus* and *Liocarcinus holsatus* in the gullies, but *Ophiura albida* and *Ophiura ophiura* showed higher densities in the top locations.

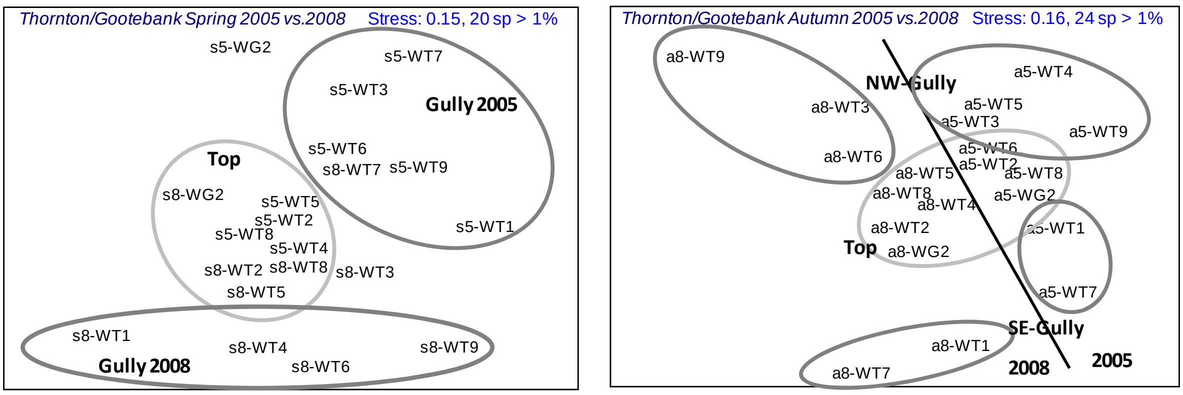


Figure 21. MDS plots of spring (left) and autumn (right) samples, indicating groupings based on position in a gully (dark grey contour) or on a sandbank top (light grey contour)- monitoring stations Thornton, 2005 vs. 2008.

For the comparison of the autumn samples, the MDS plot showed a difference between 2005 and 2008, and a difference between tops vs. NW gully vs. SE gully (Figure 21). The ANOSIM pairwise test calculated a global R-value of 0.66 (p=0.001), while SIMPER calculated a similarity of 70 to 75% within the groups and 25 to 35% dissimilarity between the groups.

- Difference top locations - NW gullies: mainly due to higher densities of *Ophiura albida*, *Pagurus bernhardus*, *Ophiura ophiura*, *Liocarcinus holsatus*, *Crangon crangon* and *Nassarius reticulatus* in the NW gullies.
- Difference tops - SE gullies: mainly higher densities of *Ophiura albida*, *Pagurus bernhardus*, *Ophiura ophiura*, *Asterias rubens* in the SE gullies.

- Difference SE gullies - NW gullies: mainly due to higher abundance of *Nassarius reticulatus*, *Spisula solida*, *Ophiura* species and *Liocarcinus holsatus* in the NW gullies.
- Difference 2005 - 2008 for the SE gullies: mainly due to more *Nassarius reticulatus* in 2005 and higher densities of *Pagurus bernhardus*, *Ophiura* species and common squid *Alloteuthis subulata* in autumn 2008.
- Difference 2005 - 2008 for the NW gullies: mainly due to higher densities of *Nassarius reticulatus*, *Ophiura* species, *Spisula solida* and *Crangon crangon* in autumn 2008.

7.4.10. Epibenthos: length-frecuency

7.4.10.1. Thortonbank and Bligh Bank: condition in 2008 and comparison 2005 - 2008

For four epibenthic species (cf. De Maersschalck *et al.*, 2006), the mean total length was determined. Additionally, the average length-frequency distribution was determined and visualized (Figure 25, Figure 26).

Brown shrimp *Crangon crangon*

The brown shrimp is a very common and abundant species in the Thorntonbank area: the species was encountered in all but one of the tows (WG2 in autumn 2005) taken in 2005 and 2008.

In 2008, the average length increased with 7mm from autumn to spring (45-52mm) but showed unimodal curves in both seasons. Similar patterns have been observed in 2005, but spring densities were about 3 times higher in the most abundant size classes (45-60mm) compared to 2008. Contrary to the results of 2005, no significant differences were observed in length between sandbank tops and gullies (Figure 22). There were no obvious differences between the concession area and both reference areas.

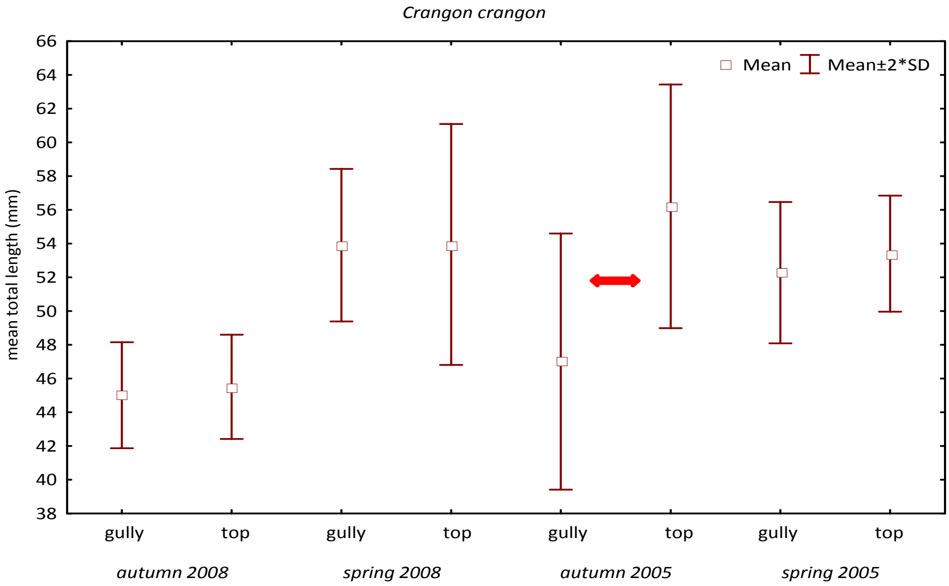


Figure 22. Whisker plot showing differences in mean total length between gully stations and sandbank top stations (red arrow indicates significant difference) - monitoring stations Thorntonbank, 2005 & 2008.

In the Bligh Bank area, brown shrimps were only encountered in half of the spring tows and in relatively low densities (maximally 0,2 ind/1000m² compared to 15 ind/1000m² in the same period in the Thorntonbank area). The unimodal curve however shows a similar shape as in the Thorntonbank area, with a dominant size class of 55mm and a mean total length of 56,8mm. No significant differences were observed in length between sandbank tops and gullies and between the concession area and both reference areas.

Allman shrimp *Crangon allmanni*

Similar to 2005, only low densities of Allman shrimp were encountered in 2008. The average length was higher in autumn compared to spring (40mm vs. 33mm). The dominant size classes were identical in autumn (35mm) and spring (40mm) of both years, but spring densities in all encountered size classes were significantly lower. This reduction is a reflection of a decreased percentage of tows in which this species was found (83% in 2005, 20% in 2008), and a lower density per station (Figure 23).

Similar to brown shrimps, Allmann shrimps were only encountered in spring in the Bligh Bank area in densities of a similar order of magnitude (0,04 – 0,1 ind/1000m²). The length range was very limited with specimens measuring 40-45mm.

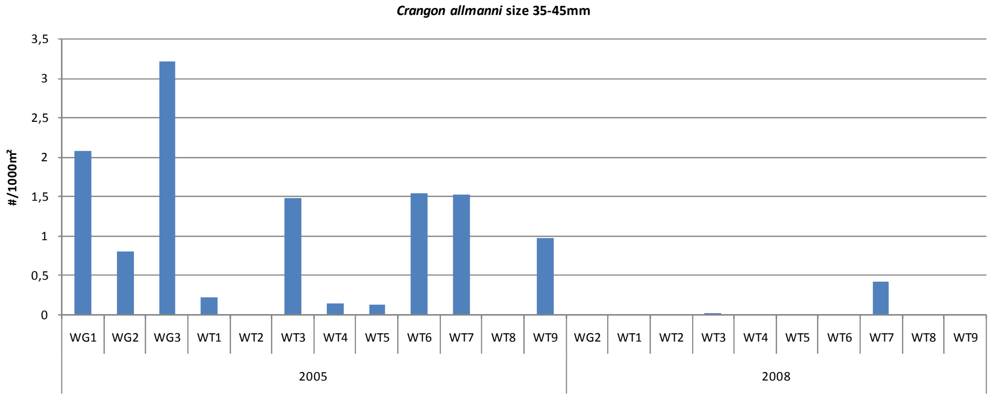


Figure 23. Column chart showing the density of Allman shrimp (length 35-45mm) at all stations between years - monitoring stations Thorntonbank, 2005 & 2008.

Flying crab *Liocarcinus holsatus*

This crab species was encountered in all autumn tows (both years) and in most spring tows (except WT4 and WT9 in 2008). An analysis of the sex distribution shows that males were dominant in 2005 (mean 76% in autumn, 77% in spring) and in autumn 2008 (mean 83%). In spring 2008 however, females constituted more than 50% of the flying crab catch. Females were absent in tracks WT5, WT8 and WT9.

In 2008, males had an average carapax width of 34mm in autumn and 32mm in spring. For females, carapax widths averaged 28 and 30mm in autumn and spring respectively. For neither of the sexes, significant differences were observed concerning total length between sandbank gullies and tops and between the concession zone and the reference zones.

The length frequency curves for 2005 and 2008 of male flying crabs shows a similar shape in autumn, although there is a shift in DSC from 40mm to 35mm. The shape of the spring curve, however, shows a drastic decrease of density in all size classes to values below 0,02 ind per 1000m². This reduction was mainly due to the absence of peak densities as observed at WT3, WT6 and WT7 in 2005 (Figure 24). A similar reduction in the densities per size class was observed concerning females in both seasons.

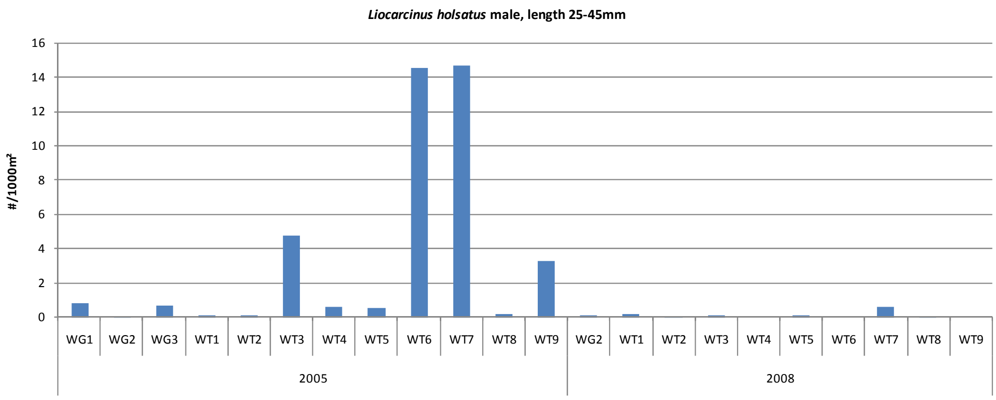


Figure 24. Column chart showing the density of male flying crabs (length 35-45mm) at all stations between years - monitoring stations Thorntonbank, 2005 & 2008.

In 2008, the flying crab population of the Bligh bank area was dominated by males in autumn (89%) and by females in spring (74%). This trend in seasonal sex distribution was also observed in the Thorntonbank area, but was more outspoken in the Bligh bank area. Both males and females were found in the majority of the tracks (males: 81% in autumn, 54% in spring – females:72% in autumn, 64% in spring).

Males had an average carapax width of 30mm in autumn and 32mm in spring. For females, carapax widths averaged 29 and 30mm in autumn and spring respectively. For neither of the sexes, differences were observed concerning total length between sandbank gullies and tops and between the concession zone and the reference zones.

Marbled swimming crab *Liocarcinus marmoreus*

Individuals of the marbled swimming crab were only sporadically found in 2005 and 2008 and were predominantly males. In 2008, males had an average carapax width of 29mm in autumn and 16mm in spring; females had an average carapax width of 31mm in autumn and 19mm in spring. Since the size-frequency distributions of this species were discontinuous, no trends could be described (figures not depicted).

The marbled swimming crab population of the Bligh bank area was dominated by males in both seasons (92% in autumn, 75% in spring). Females were found in only a few tracks (WBB04-5 in autumn, WBBO1-3-7 in spring). Marbled swimming crab males had an average carapax width of 26mm in autumn and 22mm in spring. For females, carapax widths averaged 29 and 30mm in autumn and spring respectively. No significant differences were observed in length between sandbank tops and gullies and between the concession area and both reference areas for males. Females were found in too few tracks to enable comparisons. Since the size-frequency distributions of this species were discontinuous, no trends could be described (figures not depicted).

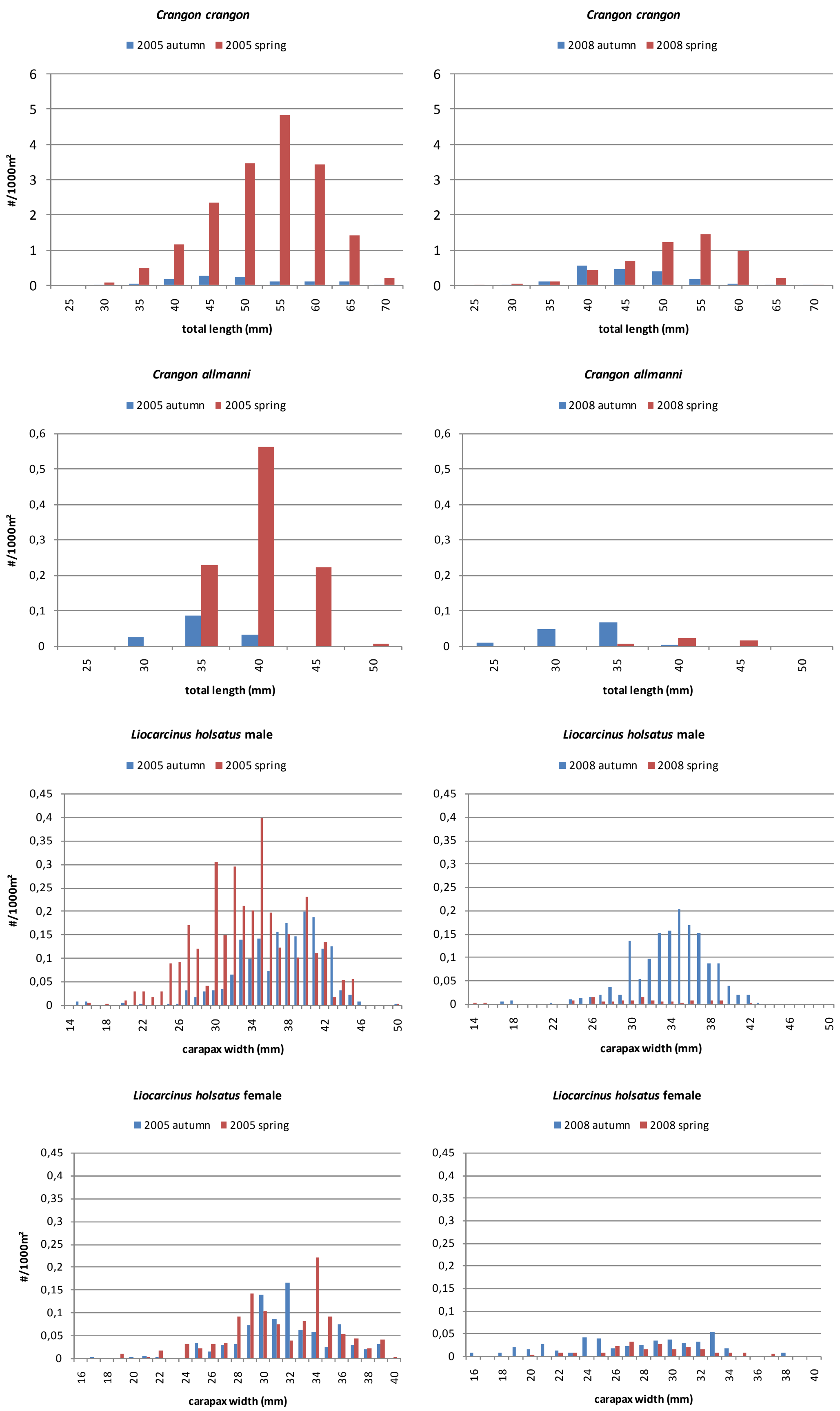


Figure 25. Averaged length-frequency distributions (all tracks) of three epibenthic species - monitoring stations Thorntonbank, 2005 & 2008.

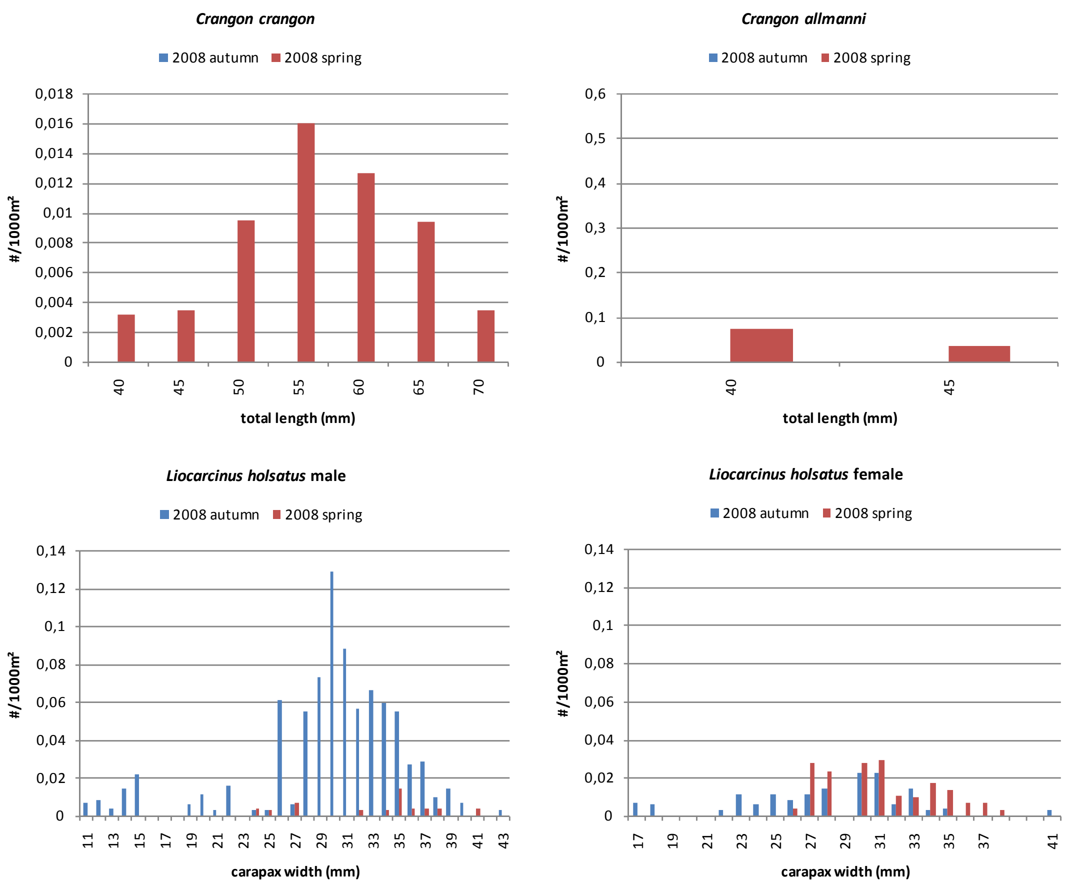


Figure 26. Averaged length-frequency distributions (all tracks) of 3 epibenthic species - monitoring stations Bligh Bank, 2008.

7.4.11. The state of the demersal fish fauna: a summary

In the Thorntonbank monitoring area, the spring density of demersal fish was found to be higher in the gullies and lower on the tops (both years; see annex 8). Within the gully samples, the SE gullies harbored the highest densities in 2005, but densities were comparable between all gullies in 2008. The high spring densities observed in 2005 were mainly due to the abundant presence of clupeids (sprat and herring), while densities in 2008 were lower (65%) and largely limited to perciforms (mainly dragonets and lesser weever) and flatfish (mainly dab and solenette). The reduction of the density of clupeids was visible in all stations and zones (see annex 8), implying that it was caused by interannual variation in the distribution and/or demography of these species.

When comparing the autumn samples, fish densities in 2005 and 2008 were comparable, but the differences between gullies and sandbank tops were less outspoken than in spring (except the sandbank top station WT8 with low densities). Just as in spring 2008, the fish community was dominated by perciforms (mainly dragonets, lesser weever and hooknose) and flatfish (mainly dab and solenette) in both years. Station WT7 showed an aberrant species composition in 2008 due to the presence of high densities of bib and poor cod.

The species richness of demersal fish did not show significant differences between years, between tops and gullies and between concession zones and reference zones. However, the values were somewhat lower in samples WT4 (SE gully of the Western Concession Zone) and WT8 (sandbank top sample in the Eastern Concession Zone) in both years. Generally, a high variation in evenness was observed between the different fish tracks.

The analysis of the length frequency distributions of 17 fish species showed some clear shifts between years, but none could be attributed to the construction works in the western concession zone of the Thorntonbank. The most striking results were related to differences between sandbank tops and gullies (e.g. significant differences in mean total length for plaice in autumn samples of 2008) or to differences between years (e.g. strong reduction per size class of sprat and hooknose at all stations in 2008). Differences between the years may also partly result from differences in the timing of the sampling; samplings are snapshots in time and differences can occur within the same sampling season, especially concerning the occurrence and the development of cohorts.

While the spatial difference between sandbank tops and gullies was equally important in the Bligh Bank monitoring area; the patterns differed from the ones observed in the Thorntonbank monitoring area:

- Thorntonbank: the spring density was higher in the gullies and lower on the tops; differences between gullies and sandbank tops were less outspoken in autumn
- Bligh Bank: densities from the tops were 1,3 to 2 times higher in autumn compared to spring, while densities in the gullies remained similar. The high densities on the tops were mainly the result of the abundance of lesser weever.

Generally, the Bligh Bank monitoring area was found to be denser and richer than the Thorntonbank monitoring area (see annex 8).

In the Bligh Bank monitoring area, tops were dominated by perciforms (mainly lesser weever), while pleuronectiforms (mainly dab, solenette and plaice) were of similar importance as perciforms in the gullies. Some of the gully stations showed local concentrations of the gadiforms whiting and cod.

The species number was higher on the Bligh Bank (both concession zone and reference zone) than in the Hinderbanken reference zone in both seasons (difference of 8 species in spring and 5 species in autumn). Additionally, values from the sandbank tops were lower than from the neighboring gullies in the three investigated zones.

The analysis of the length-frequency distributions of 10 fish species did not reveal any significant differences between the concession zones and both reference zones. Some significant differences in mean total length were observed between fish caught at gully stations and fish caught at sandbank tops stations: specimens of lesser weever and great sandeel were generally larger in gully samples than in top samples.

7.4.12. The state of the epibenthos fauna: a summary

Apart from the natural difference between spring and autumn samples (with much higher values in autumn), all community analyses, density, biomass and diversity plots clearly showed a difference between the top samples (and thus in the concession zones) vs. the deeper gully samples, both for the Thornton/Goote Bank area and the Bligh Bank/Hinderbanken area. In almost all cases the values in the gullies were much higher than those on the tops of the banks (see annex 8). Furthermore, almost all species that were found on the tops were also present in the gullies (be it in different proportions), which clearly shows that the gullies are more diverse and richer than the tops of the different sandbanks.

While the diversity did not differ that much between spring and autumn in the gullies surrounding both sandbank systems, the increase in number of species from spring to autumn, be it in total or on a per sample base, was much more pronounced for the top locations. On the other hand, where the different top samples showed very high similarities in density and biomass (up to 80%), the variation in the gully samples was much greater, especially during autumn. As was seen in 2005 for the Thorntonbank, the analyses prove that there is a (small) difference between the NW gullies and the SE gullies around the Thornton/Goote Bank area and around the Bligh Bank/Hinderbanken area. Furthermore, the NW gullies seem to be more uniform (at least in spring) than the SE gullies.

Next to the differences in diversity, the spatial, seasonal and interannual differences were due to higher (or lower) densities of only a few common epibenthic species. Although the species assemblage changed from spring to autumn, especially in the Thorntonbank area, the common species remained the same: i.e. brown shrimp *Crangon crangon* (mainly in spring on Thorntonbank, almost not found on Bligh Bank); lesser brittlestar *Ophiura albida* (always), common brittlestar *Ophiura ophiura* (higher densities on top, less common than *O. albida*), hermit crab *Pagurus bernhardus* (much more abundant in the gullies), flying crab *Liocarcinus holsatus* (much lower densities in 2008, almost exclusively in the gullies and higher densities in autumn), Atlantic bobtail *Sepiola atlantica* and the squid *Alloteuthis subulata* (both mainly in autumn in all samples), thick through shell *Spisula solida* and starfish *Asterias rubens* (mainly in the gullies in autumn).

It should be stated that the densities and biomasses in the Bligh Bank/Hinderbanken area were very (extremely) low in spring 2008 (see annex 8). Although no clear explanation can be given, this is probably due to natural variability since also in the Thorntonbank area the densities were much lower in spring 2008 vs. spring 2005. In autumn 2008, the epibenthic assemblage of the Bligh Bank was much more comparable with the assemblage of the Thorntonbank and showed the same order of magnitude concerning variability. In contrast to the spring situation, the density and biomass values for the Thorntonbank (both concession and reference zones) were higher in autumn 2008 than in autumn 2005. Up till now, no changes can be shown in the patterns in (and around) the concession zones, and as such they remain largely comparable with the reference areas.

The analysis of the length frequency distributions of 2 shrimp species and 2 crab species showed no significant differences in mean total length or carapax width resulting from sampling position (sandbank tops and gullies) or from sampling zone (reference zones and concession zones). The observed differences between the length-frequency distributions of 2005 and 2008 in the Thorntonbank monitoring area were mainly due to an overall reduction of the epibenthic density in all size classes.

7.5. Discussion

7.5.1. Representativity of the reference zones

Within the Thorntonbank monitoring area, references zones were delineated on the Thorntonbank and on the neighboring Goote Bank. Each reference area was sampled at one sandbank top station and two slope/gully stations. The study of De Maersschalck *et al.* (2006) indicated that the Goote Bank gully stations differed substantially from the Thorntonbank gully stations. Stations WG1 and WG3 were consequently abandoned as reference in the T_1 assessment. For the remaining reference stations, high similarities were found within the groups of sandbank top samples and gully samples per year (68-73% for fish, 60-80% for epibenthos), while no significant differences were observed between reference stations and stations from the concessions zones. Consequently, the reference stations are considered to be suitable as such. However, the reference zone for the study of the impact of windmills on the Thorntonbank is situated inside a concession area for sand extraction. Although no extraction activities have taken place so far, the value of the area as reference in the framework of windmill construction and exploitation is hypothecated. Consequently, the impact assessment monitoring of the C-Power windmill park (and of future sand extraction activities) would benefit from the establishment of a closed area inside the sand extraction concession zone.

Within the Bligh Bank monitoring area, reference zones were delineated on the Bligh Bank and on the neighboring Oosthinder within the Hinderbanken exploration zone. Again, each reference area was sampled at one sandbank top station and two slope/gully stations. For demersal fish, the patterns of density, taxonomic composition and length-frequency distributions in both reference zones reflected those from the concession zone. However, spring densities were higher in the Bligh Bank reference zone compared to the Hinderbanken reference zone, and gadiforms were far less abundant in the HRZ. Additionally, the species number was higher on the Bligh Bank (both concession zone and reference zone) than in the Hinderbanken reference zone in both seasons. For the epibenthos no differences could be shown between the concession zone and the reference zones. However, the reference zone on the Hinderbanken is situated within the current Hinderbanken sand exploration zone. Similar to the situation at the Thorntonbank, a problem might occur with this reference zone, when sand extraction would be allowed on the Hinderbanken in the future. Still, the reference zone on the Bligh Bank clearly fulfills its role.

7.5.2. Impact of the construction of six turbines on the Thorntonbank

The potential impact of windmill farms during the construction period can be divided into three categories: (1) destruction, (2) dredging and (3) disturbance (Petersen & Malm, 2006). The first factor involves the eradication of organisms at the site of the turbine footings, and is considered negligible since this is a very small surface compared to the entire concession zone. At the Thorntonbank construction site, no rare species or habitats are present and the loss of habitat at the position of the six turbines (490m² of foundations) is minimal. Dredging and disturbance due to construction of turbines and the establishment of cables, however, are considerably more important, especially for benthic and demersal fauna. During the study presented in this report, no obvious negative effects of the construction of six turbines have been detected for the ecosystem components epibenthos and fish. However, local effects in the vicinity of the turbines are hard to detect using long tracks, since all fauna over a length of 3500m are pooled in a single catch and information about the small-scale 'patchiness' of fauna is largely lost. An adaptation of the sampling design, as proposed in section 6.1, would result in a decrease in the detection level of local changes. These local changes are expected to manifest themselves more clearly after an increase of the size of impact following the construction of additional turbines.

Next to negative effects, effects of the presence of man-made constructions on the seabed include concentration of fish density and biomass around the solid structure (Wilhelmsson et al, 2006). Although physical structures have the potential to influence larger demersal fish species hundreds of metres away (Grove et al, 1991), significant effects have so far not been observed in the vicinity of the six windmills on the Thorntonbank.

Monitoring of the ecosystem components epibenthos and demersal fish will continue in the Thorntonbank area and in other windmill concession areas in order to detect any effects of additional construction activities and of specific effects during operation of the turbines. Since the results indicate that gullies are richer in density and biomass of demersal fish and epifauna, most effects are expected after the construction of turbines at the gullies of the Bligh Bank. In other words, the differences between sandbank tops and gullies indicate that turbines should preferably be placed on the sandbank tops for a minimal impact on demersal fish and epifauna.

7.5.3. Suggestions concerning sampling strategy

In 2008, a high sampling intensity (such as the one used in the Thorntonbank baseline study) was maintained for the evaluation of the Thorntonbank construction impact (T1), and was repeated for the Bligh Bank baseline study (T0). For the 2009 sampling campaigns, a modified sampling strategy is proposed, with which all required data will be obtained based on a reduced number of tracks within both research areas. This modification will reduce the work load and will allow the allocation of time and means to make concerted efforts in answering specific research questions (see section 6.2.2).

A reduction of the tracks can be justified based on:

- the fact that the construction activities of C-power have been paused until further notice and that the planned constructions in the concession zone of Belwind have yet to be started;
- the high similarity within the groups of gully samples and sandbank top samples that was demonstrated in the report for both demersal fish and epibenthos (see paragraph on representativity of reference areas).

In practice, parallel SE to NW tracks will be done on the Thorntonbank (northern concession zone), on the Bank zonder Naam[2] and on the Bligh Bank. Samples will be gathered from sandbank tops and neighboring gullies. Additionally, sandbank top samples will be taken in the Thorntonbank reference zone and the southern concession zone, in order to evaluate the effect of the six already constructed windmills.

In this sampling strategy proposal, the number of tracks in the Thorntonbank and Bligh Bank reference zones are limited. However, extra community analyses will be done to examine the suitability of a number of standard monitoring stations (sampled during other monitoring assignments) as representatives for gullies in the vicinity of the concession zones (Figure 27). Furthermore, extra attention will be given to the effects of specific construction activities such as large displacements of sand, after they are reported by the construction companies.

[2] The sampling station on the Bank zonder Naam was added in the light of the permit application by Eldepasco for the construction of a 216 megawatt windmill park.

Next to adapting the sampling strategy, it will be necessary to adapt the sampling technique, and more precisely the length of a fish track and the number of fish tracks. The cause for this specific adaptation is twofold:

1. The installation of cables on the seafloor for the transmission of the generated electricity will impair the passage of the beam trawl and hence the completion of a fish track of 3500m, which is the average length of the monitoring tracks so far.
2. Local effects in the vicinity of the turbines are hard to detect using long tracks, since all fauna over a length of 3500m are pooled in a single catch and information about the small-scale ‘patchiness’ of fauna is largely lost. A shortening of the tracks and an increase in the number of tracks would result in a higher spatial resolution in the analysis (especially in the close vicinity of the turbines), which would decrease the detection level of local changes.

However, before implementing shortened fish tracks in the monitoring program, the representativity of such tracks should be tested experimentally.

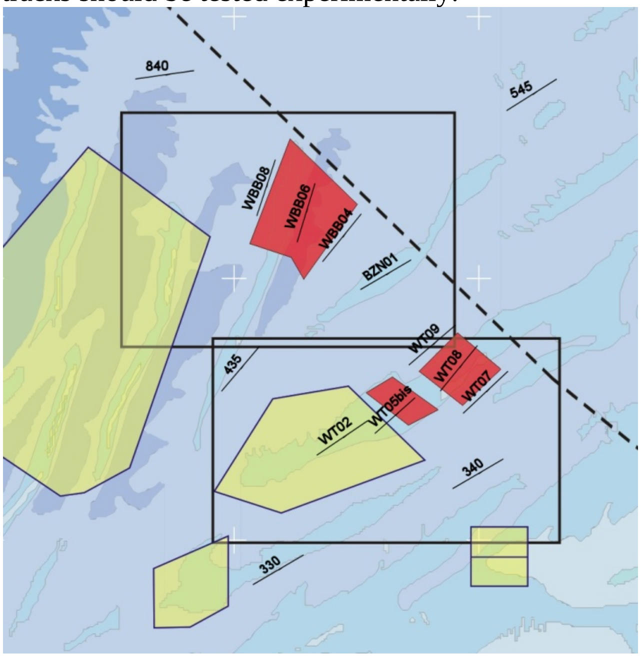


Figure 27. Sampling locations of the adapted sampling strategy, with fish tracks in the concession zones of Thorntonbank and Bligh Bank and their immediate vicinity, and a number of standard ILVO monitoring stations in the northern part of the Belgian Continental Shelf.

7.5.4. Suggestions for future monitoring and analyses

7.5.4.1. Demersal versus semipelagic fish

In the analyses of the data concerning both monitoring areas, the community analyses concerning demersal fish were heavily influenced by the presence and locally high densities of (semi)pelagic and schooling fish species, such as herring, sprat, horse mackerel, whiting, bib and poor cod. Since the dispersion patterns and the extent of the mobility of truly demersal and semipelagic fish differ substantially, it would be advisable to adapt the analyses accordingly during future investigations. Excluding semipelagic fish from the analyses cannot be considered since aggregation effects in the vicinity of turbines can be expected (Grift et al, 2004). It is, however, advisable to complement the beam trawl data with data from other techniques (e.g. use of trammel nets, acoustics, mark-recapture experiments).

7.5.4.2. The need for a broader ecosystem view

Although the impact of windmill parks is being studied at the level of different ecosystem components, a need has been recognized by the involved scientific parties to incorporate a broader ecosystem view regarding the links between macrofauna, epifauna and fish and between the fauna from the artificial hard substrates and the surrounding soft substrates. A number of topics to be addressed are:

- the impact of a closed area on fisheries and *vice versa*, using data on fishing effort (e.g. VMS data)
- the function of hard substrates such as cobbles and concrete blocks (boulders) as egg deposition sites for fish
- changes in predation pressure and the competition between demersal and pelagic fish, and between epifauna from hard substrates and soft bottoms
- feeding guild structure, based on stomach analyses of a number of species
- changes in population structure and length distribution
- the impact of the deposition of organic (fecal) matter by hard substrate fauna on the surrounding soft bottom fauna
- shifts in sources and sinks due to varying productivity of the biota of hard substrates and soft bottoms
- impact of different types of artificial hard substrates (material of the poles)
- the possibility of fishing in the vicinity of windmills using trammel nets instead of beam trawl
- the impact of noise generated by windmills

The outcome of these research topics would yield a better understanding of the processes underlying the (expected) changes in density, diversity, biomass and community structure resulting from windmill park construction and exploitation.

7.6. Conclusion

When comparing the data of 2005 and 2008, it is clear that the major driving forces of variation between the samples are (1) seasonality, (2) interannual differences, and (3) spatial differences (sandbank tops versus gullies). Significant differences due to the construction of the six present windmills have not been detected so far, and are rather expected to manifest themselves at the end of all construction works. However, this does not imply the *absence* of any effects. The results rather indicate that the (local) effects of the construction activities so far are subordinate to the natural variability within the ecosystem. Consequently, the detection of possible effects depends primarily on detailed comparisons on a spatial scale (impact stations versus reference stations) per year and season, rather than on long term trends per station (although effects will also manifest themselves eventually in long term analyses). This again stresses the importance of the choice of suitable reference areas, as they have been delineated in the present study, and their preservation throughout the monitoring period of the present and future windmill farms (cf. sand extraction concession in the Thorntonbank reference zone). Furthermore, impact areas and reference areas should be sampled adequately. During the construction activities of the six already present turbines, however, it became clear that sampling epifauna and demersal fish in their vicinity will present a challenge, since cables and other structures on the seafloor prevent the completion of the beam trawl tracks. Consequently, adaptations to the sampling strategy (mainly a shortening of the tracks) will be tested experimentally to evaluate their representativity and will then be implemented.

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Chapter 8. Seabirds & offshore wind farms: monitoring results 2008

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Photo Misjel Decleer

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Abstract

In 2008, n.v. C-Power started up the construction of the first offshore wind farm at the Belgian Part of the North Sea (BPNS). This wind farm will be located on the shallows of the Thorntonbank, about fifteen nautical miles offshore. At the time of writing six windmills are erected of which two are in operation, but in the near future the wind farm will comprise of 60 turbines in total, each with a capacity of 5MW. Following the reference study (Vanermen *et al*. 2006), this report presents an update of the reference situation and the results of the year-1 monitoring of the avifauna at the Thorntonbank. To assess possible impacts on seabirds, we implement a methodology based on the BACI-principles. Hence the before-situation (2005-2007) is compared with the situation in 2008, during which the first construction works took place. Possible changes in avian densities are put in perspective by performing the same before-after comparison in a control area (see Vanermen *et al*. 2006). Based on intensive monitoring in 2005-2007, it seems that Annex I species Little gull, Sandwich tern and Common tern all occur in increased densities at the Thorntonbank wind farm site. On the other hand, Vanermen *et al*. (2006) overestimated the importance of the area to Great skuas. Next to this, we set up a ranking of seabird species according to their suitability for monitoring. Auks seems the most suitable species, followed by Little gull, Sandwich tern and Common tern. Hence,

future monitoring will focus on these 5 species. A comparison of the monitoring results of the reference period (2005-2007) and the first construction year do not yet show clear effects. Meanwhile, n.v. Belwind has received their license for the construction and exploitation of a wind farm comprising of 110 3MW turbines on the Blighbank, 24 nautical miles offshore. Analogous to Vanermen *et al*. (2006), the Research Institute for Nature and Forest (INBO) carried out a reference study on the ornithological importance of the wind farm site at the BB, and selected a suitable control area. Based on intensive seabird monitoring, we know that the area is characterised by a typical offshore and relatively species-poor bird community. Black-legged kittiwakes and Common guillemots occur in high densities, while there are signs of increased densities of rarer species like Little gull and Great skua. As a control area, we selected an area including the rest of the Blighbank and the Oosthinderbank. Finally, we made a preliminary estimation of the number of collision victims at the future wind farm site at the Thorntonbank, based on flux counts, flying height observations and model calculations. Northern gannets and especially large gulls are most at risk. Meanwhile, this was an inventory of the needed (and lacking) parameters. It appears that radar research will be indispensable for determining data on bird movements, flying heights as well as avoidance behaviour.

Samenvatting

Gedurende het afgelopen jaar werden de eerste zes windmolens gebouwd op de Thorntonbank. Bovendien zal binnenkort ook aanvang genomen worden met de bouw van een windmolenpark op de Blighbank. Het Instituut voor Natuur en Bosonderzoek (INBO) voert een onderzoek uit naar de effecten van de bouw en exploitatie van deze windparken op zeevogels. In het onderhavige rapport worden de monitoringsresultaten voor 2008 voorgesteld. In navolging van de referentiestudie Vanermen *et al*. (2006), werd de referentiesituatie op de Thorntonbank beschreven zoals die werd opgemeten in de periode 2005-2007. Ook op basis van de bijkomende gegevens blijken Bijlage 1 soorten Dwergmeeuw, Grote stern en Visdief tijdelijk in verhoogde aantallen voor te komen in het windparkgebied. Vanermen *et al*. (2006) bleken het voorkomen van Grote jager echter te hebben overschat. Daarnaast werd een ranking opgesteld van soorten volgens hun geschiktheid voor monitoring. Criteria hiervoor zijn een homogene verspreiding over windpark- en controlegebied en een zo min mogelijke associatiegraad met visserij. Alkachtigen blijken het meest geschikt voor monitoring, onmiddellijk gevolgd door de Bijlage 1 soorten Dwergmeeuw, Grote stern & Visdief. Toekomstige monitoring zal zich dan ook in de eerste plaats toespitsen op deze 5 soorten. Een vergelijking van de monitoringsresultaten voor de referentieperiode (2005-2007) en het eerste constructiejaar 2008 laten nog geen duidelijke effecten zien. Voor het eerst werd ook intensief geteld op de Blighbank, dat nog verder in zee ligt dan de Thorntonbank. Het gebied wordt gekarakteriseerd door een pelagische en vrij soortenarme zeevogelgemeenschap. Drieteenmeeuwen en Zeekoeten komen er echter in hoge dichtheden voor en er zijn ook aanwijzingen van verhoogde aantallen Grote jager en Dwergmeeuw. Als referentiegebied werd een zone geselecteerd die onder meer de rest van de Blighbank en de Oosthinderbank omvat. Tenslotte werd een inschatting gemaakt van het aantal aanvaringsslachtoffers, op basis van fluxgegevens, waargenomen vlieghoogten en modelberekeningen. Uit deze resultaten blijkt dat de meeste slachtoffers zullen vallen onder Jan van genten en grotere meeuwen. Tegelijk vormde deze oefening een inventarisatie van de benodigde en nog ontbrekende parameters. Zo zal het toekomstige radaronderzoek onmisbaar blijken voor het nader bepalen van vogelbewegingen (flux) door het windpark, alsook voor de bepaling van vlieghoogtes en vermijdingsgedrag.

8.1. Seabirds at the Belgian part of the North Sea

8.1.1. Monitoring seabirds

Each month, the Research Institute for Nature and forest (INBO) performs standardized seabird counts along fixed monitoring routes across the Belgian part of the North Sea (BPNS) (Figure 1). These monitoring routes are chosen such that both the future wind farm sites at the Blighbank (BB) and Thorntonbank (TTB) are covered, as well as the control area for the TTB (Vanermen *et al*. 2006) and a preliminary control area for the wind farm site at the BB (see Chapter 8.6).

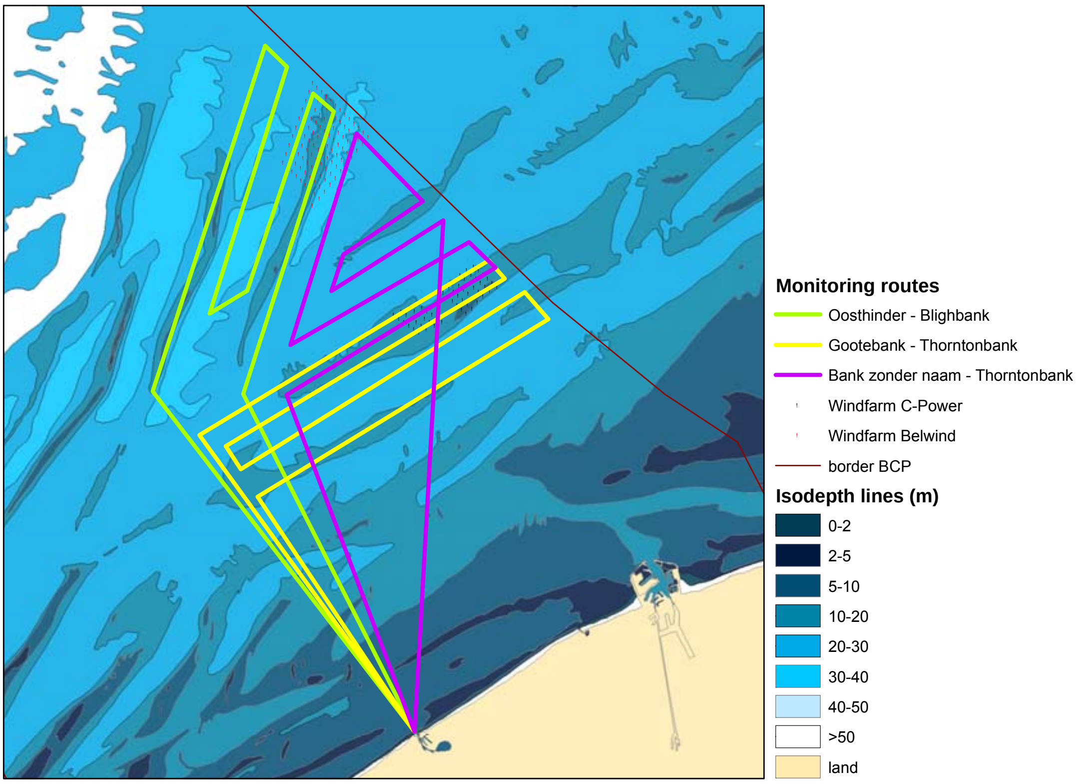


Figure 1. Monthly monitoring routes since April 2008.

The ship-based seabird counts are conducted according to a standardized and internationally applied method, as described by Tasker *et al*. (1984). While steaming, all birds in touch with the water (swimming, dipping, diving) located within a 300m wide transect along one side of the ship's track are counted ('transect counts'). For flying birds, this transect is divided in discrete blocks of time. During one minute the ship covers a distance of approximately 300m, and at the start of each minute all birds flying within a quadrant of 300 x 300 m are counted ('snapshot count'). The results of these observations are grouped in periods of ten minutes, resulting in so-called 'ten-minute counts'.

Taking the velocity of the ship in calculation, the count results can be transformed to seabird densities with specified X- en Y-coordinates (at the geographical middle point of each ten-minute count). The observed densities of most seabirds are corrected according to correction factors presented by Offringa *et al*. (1997). This accounts for the fact that small and dark birds are more difficult to detect at greater distances.

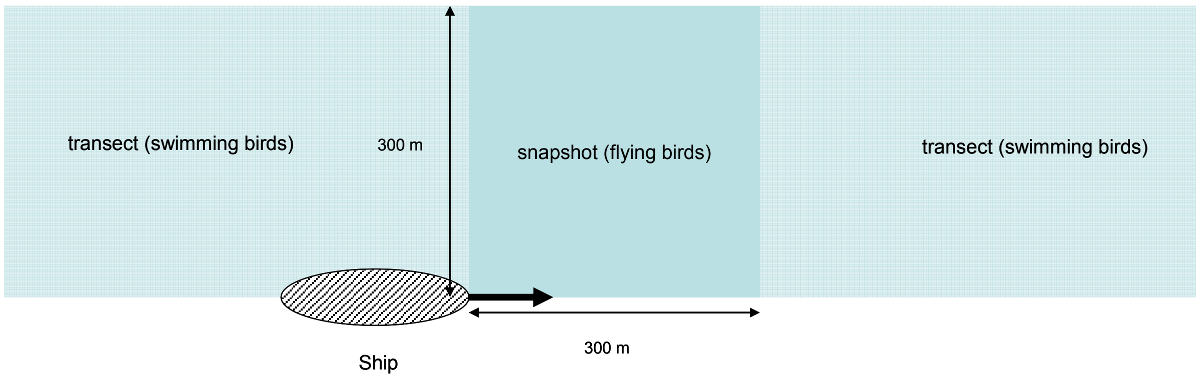


Figure 2. Methodology of standardized seabird counts using a 300m wide transect for swimming birds, and 'snapshot' counts (each minute) for flying birds.

Eventually, the original database is transformed to a database with observed densities of sixteen common seabirds (see §8.1.1) at more than 20,000 locations within the BPNS. Analogous to the reference study for the TTB (Vanermen *et al*. 2006), the following species will be included in the analysis: Red-throated diver, Crested grebe, Northern fulmar, Northern gannet, Common scoter, Great skua, Little gull, Common gull, Herring gull, Lesser black-backed gull, Greater black-backed gull, Black-legged kittiwake, Sandwich tern, Common tern, Common guillemot and Razorbill (see §8.1.2).

During the counts, birds observed outside the 'transect' and outside the 'snapshots' were noted too. These observations were not used for actual density calculations (n/km²), but when the total number of observed birds is divided by the number of sailed kilometres, this too provides a standardized measure of seabird density (n/km). In case of rare species, this kind of data, although much more biased, may provide a better insight in the birds' true distribution.

8.1.2. Seabirds at the BPNS: species discussion

In this chapter we discuss 16 seabird species commonly occurring at the BPNS. These species are all considered to be 'seabirds' since a significant part of their populations strongly depends on the marine environment during one or more seasons.

Red-throated diver (*Gavia stellata*)

(Conservation status: Annex I Birds Directive, Appendix II Bonn Convention, Appendix II Bern Convention)

The Red-throated diver is an inland and coastal breeder of N Europe, Russia and North America, wintering in shallow inshore or coastal waters. A large proportion of the NW European breeding population (50,000 to 150,000 pairs) spends the non-breeding season in the North Sea, along the coasts of Belgium, the Netherlands, Germany and Denmark (Cramp 1977, Stone *et al*. 1995, Wetlands International 2006).

Great crested grebe (*Podiceps cristatus*)

The Great crested grebe is an inland breeder, but lots of birds spend the non-breeding season in shallow marine waters near shore. Wintering numbers at sea are highly variable and are highest during prolonged periods of frost. In the North Sea, most Crested grebes are found along the continental coast from Belgium up to Denmark (Cramp 1977, Stone *et al*. 1995).

Northern fulmar (*Fulmaris glacialis*)

This true seabird has a widespread distribution across the northern hemisphere, and the NE Atlantic population holds an estimated 2.3 to 3.7 million breeding pairs. The species typically breeds on grassy cliffs, and spends most of its time at sea where it feeds on a variety of marine foods. It is one of the most numerous seabirds in the North Sea, with highest densities generally occurring above 54°N (Cramp 1977, Camphuysen & Leopold 1994, Stone *et al*. 1995, Mitchell *et al*. 2004).

Northern gannet (*Morus bassanus*)

The Northern gannet's breeding range is confined to the N Atlantic. The world population holds an estimated 390,000 breeding pairs, of which no less than 230,000 pairs breed on the British Isles. Northern gannets breed in large colonies (so-called gannetries) on inaccessible offshore islands, and to a lesser extent on imposing mainland cliffs. Across the North Sea, Northern gannets occur widespread throughout the year (Cramp 1977, Stone *et al*. 1995, Mitchell *et al*. 2004).

The southern North Sea is particularly important to Northern gannets during their southbound migration in autumn, and also as a wintering area for adults (Camphuysen & Leopold 1994). Stienen *et al*. (2007) estimated that annually 4 to 7% of the NE Atlantic biogeographical population migrates through this part of the North Sea.

Common scoter (*Melanitta nigra*)

Common scoters are inland breeders across N Europe, Russia and North America. The species winters in a marine environment, where it prefers shallow inshore waters to feed on benthic prey. In the North Sea their distribution is largely confined to waters close to land, along the coasts of Belgium up to Denmark (Cramp 1977, Stone *et al*. 1995).

Great skua (Stercorarius skua)

The world population of Great skua is confined to merely 16,000 breeding pairs, and no less than two-thirds of the whole world population breed on the Shetland and Orkney Isles. However, numbers have been increasing since 1900, and the species is progressively extending its breeding range (Mitchell *et al*. 2004).

During early summer and autumn internationally important numbers reside in the southern North Sea. During this part of their southward migration fishery discards are an important food source, but they are also frequently observed kleptoparasitising Northern gannets, gulls and terns (Camphuysen & Leopold 1994). Each autumn, an estimated 60% of the NW European population (Icelandic birds excluded) migrates through this part of the North Sea (Stienen & Kuijken 2003).

Little gull (*Larus minutus*)

(Conservation status: Annex I Birds Directive, Appendix II Bern Convention)

The European biogeographical population breeds across N Scandinavia, the Baltic states, W Russia, Belarus & Ukraine, and counts 24,000 to 58,000 breeding pairs. This population winters in W Europe and NW Africa (Wetlands International 2006).

During autumn most birds migrate via the Baltic Sea towards the North Sea and further on, while during spring an indefinable percentage of the population migrates north over land (Cramp 1983). An estimated 40 to 100% of the total European biogeographical population annually migrates through the bottleneck of the southern North Sea and the Strait of Dover. Since autumn migration is concentrated along the continental coast, the BPNS a very important area to this species (Camphuysen & Leopold 1994, Stone *et al*. 1995, Stienen *et al*. 2007).

Common gull (*Larus canus*)

Common gulls breed throughout Europe, Asia and North America, mainly above 50°N. Three quarters of the world population breed on the British Isles and Scandinavia (300,000 breeding pairs, Mitchell *et al.* 2004). The subspecies *canus*, breeding in NW Europe east to the White Sea, winters in W Europe, inland as well as at sea. The southern North Sea, and more particular the coastal strip along its continental coast, is a very important wintering area to this species (Cramp 1983, Camphuysen & Leopold 1994, Stone *et al*. 1995, Mitchell *et al*. 2004).

Lesser black-backed gull (*Larus fuscus*)

The distribution of Lesser black-backed gull is limited to the shores of W & NW Europe and N Russia. The breeding population of the subspecies *graelsii* (W Europe, SW Greenland, Iceland & Faeroer isles) numbers around 180,000 pairs, and winters along the Atlantic coasts of France, Spain and NW-Africa. The subspecies *intermedius* breeds in S Norway, W Sweden, Denmark, Germany, the Netherland & Spain (100,000-150,000 breeding pairs) and also migrates through the southern North Sea, towards the same winter quarters in W Europe and W Africa (Cramp 1983, Mitchell *et al*. 2004, Wetlands International 2006).

The southern North Sea, and in particular its continental coast, is of great significance to this species. The Belgian port of Zeebrugge harbours a large colony of up to 4,573 breeding pairs in 2006 (data INBO). Campuysen & Leopold (1994) estimated that 18% of the NE Atlantic population resides in Dutch waters during April and May, and Stienen *et al*. (2007) state that each autumn 28% of the *graelsii* population migrates through the Strait of Dover.

Herring gull (Larus argentatus)

Herring gulls (ssp. *argentatus* & *argenteus*) breed widespread in W and N Europe, the Baltic states, the Faeroer isles and Iceland. These populations are estimated to hold 800,000 to 1,400,000 breeding pairs. In the north of their range, Herring gulls are mainly migratory, in contrast to the W European breeding birds which are largely sedentary or dispersive (Cramp 1983, Van Waeyenberge *et al*. 2002, Wetlands International 2006).

In the North Sea highest spring and summer densities occur in coastal waters near the breeding colonies. In Belgium, a large breeding colony is located in Zeebrugge, with up to 1,986 breeding pairs in 2004 (data INBO). During winter however, the species occurs more widespread and in higher densities, since resident birds are joined by large numbers originating from northern breeding colonies (Stone *et al*. 1995).

Great black-backed gull (*Larus marinus*)

Great black-backed gulls breed along the coasts of the N Atlantic, with an estimated 110,000-180,000 breeding pairs in the NE Atlantic region. The most northern breeding birds are migratory, wintering south to the Atlantic shores of Spain and Portugal (Cramp 1983, Wetlands International 2006).

Outside the breeding season, Great black-backed gulls occur widespread across much of the North Sea (Stone *et al*. 1995). Camphuysen & Leopold (1994) state that the southern North Sea is a very important wintering area, with more than 13% of the NE Atlantic population residing in the Dutch Part of the North Sea in late autumn. Accordingly, a mean number of 5,400 Great Black-backed gulls resides in the BPNS during winter (Table 1), which exceeds the 1% level of the NE Atlantic biogeographical population.

Black-legged kittiwake (*Rissa tridactyla*)

Kittiwakes breed across the northern hemisphere, in the N Atlantic as well as the N Pacific. The NE Atlantic population counts 2.0–2.7 million breeding pairs. Outside the breeding season, these birds occur throughout the N Atlantic Ocean, north of 30°N (Cramp 1983, Mitchell *et al*. 2004, Wetlands International 2006).

In the North Sea, the summer distribution of Black-legged kittiwake is concentrated in NE English & Scottish waters near the main breeding colonies. During winter however, the species occurs widespread across the North Sea, with a preference for pelagic habitat. In the southern part of the

North Sea, the species is most common during autumn (Camphuysen & Leopold 1994, Stone *et al*. 1995).

Sandwich tern (Sterna sandvicensis)

(Conservation status: Annex I Birds Directive, Appendix II Bonn Convention, Appendix II Bern Convention)

The Sandwich tern breeds scattered along the coasts of the Atlantic and the Mediterranean. The European breeding population comprises of an estimated 55,000–57,000 breeding pairs, and winters along W and S African coasts (Cramp 1985, Wetlands International 2006).

Summer densities of Sandwich tern in the Southern North Sea are highest along the continental coasts, especially near the Frisian Isles and the German Bight (Stone *et al*. 1995). The port of Zeebrugge (Belgium) harbours an internationally important breeding colony of up to 4,067 breeding pairs (2004). Because of a strong interchange between several colonies along the North Sea coasts, breeding numbers in this colony show strong interannual variation. The BPNS is undoubtedly of high value to Sandwich tern, as a foraging area for breeding birds of the colonies of Zeebrugge, Oye-Plage (France) and the Delta Area (the Netherlands), but also as it is part of an important migration route through the southern North Sea. An estimated 67% of the total European population migrates through this area (Stienen *et al*. 2007).

Common tern (*Sterna hirundo*)

(Conservation status: Annex I Birds Directive, Appendix II Bonn Convention, Appendix II Bern Convention)

This species breeds widespread across the northern hemisphere, along coasts as well as inland. In Europe, an estimated number of 270,000–570,000 breeding couples occur. While the breeding population of W & S Europe winter along W African coasts, most of the N & E European breeding birds spend the winter more south near W to S African coasts. Both populations however migrate along the western coasts of the European continent (Cramp 1985, Stone *et al*. 1995, Wetlands International 2006).

The BPNS is very important as a foraging area for birds of the internationally important breeding colony located in the harbour of Zeebrugge (3,052 breeding pairs in 2004, data INBO). Furthermore, the BPNS is of exceptional importance as it is part of the migration bottleneck of the southern North Sea. According to Stienen *et al*. (2007), an estimated 56% of the total W & S European biogeographical population migrates through this area.

Common guillemot (*Uria aalge*)

Common guillemots breed on cliffs above 40°N, in the N Atlantic as well as the N Pacific. The NE Atlantic population comprises of 2.3–2.4 million breeding pairs (Cramp 1985, Mitchell *et al*. 2004).

From August onwards, Common guillemots arrive in the southern North Sea. In late autumn an estimated number of 240,000 birds reside in Dutch territorial waters. On the BPNS more than 12,000 individuals occur in winter (Table 2). The southern part of the North Sea is especially important as a wintering area for birds from the E Britain colonies, like Flamborough Head (Camphuysen & Leopold 1994, Stone *et al*. 1995).

Razorbill (*Alca torda*)

In contrast to the Common guillemot, the Razorbill's distribution is limited to the N Atlantic (above 40°N). NW Europe holds an estimated number of 530,000 breeding pairs (Cramp 1985, Mitchell *et al*. 2004).

Razorbills arrive a little later in the southern North Sea compared to Common Guillemots. Its maximum densities are reached in early spring (February-March), when an estimated number of 44,000 birds resides in Dutch territorial waters (Camphuysen & Leopold 1994). On the BPNS maximum numbers are also observed during February with a mean of 2,600 residing individuals (Table 2).

8.1.3. Seabirds at the BPNS: International context

Despite its limited surface, the Belgian Part of the North Sea (BPNS) holds internationally important numbers of seabirds. The area is exploited by birds in a number of ways, and its specific importance varies throughout the year. During winter, the offshore bird community is dominated by auks and kittiwakes, while important numbers of grebes, scoters and divers reside inshore. During summer, large numbers of terns and gulls exploit the area in support of the large breeding colony located in the port of Zeebrugge. Furthermore, the BPNS is part of a very important migration route through the southern North Sea: during autumn and spring, an estimated number of no less than 1.0 to 1.3 million seabirds annually migrate through this 'migration bottleneck' (Stienen *et al*. 2007).

Table 1 & Table 2 show the results of a conservative extrapolation of the observed densities at the BPNS, and give insight in the number of birds residing in Belgian territorial waters. To account for skewed counting efforts in different parts of the BNPS, mean densities were calculated separately for each one of three subzones, namely an inshore (< 16 km), a midshore (16 – 32 km) and an offshore zone (> 32 km). The resulting mean densities per subzone were multiplied with the respective zone's surface and then summed. The resulting numbers are also shown as a percentage of their total biogeographical populations. For Lesser black-backed and Herring gull, as well as Common tern, mean densities in the BPNS are compared to the 1% levels of two biogeographical populations, since birds of both populations migrate through the BPNS.

In general, mean numbers of seabirds residing at the BPNS are rather small compared to their biogeographical populations. Nevertheless, both Little gull and Great black-backed gull occur in numbers higher then the 1% level published by Wetlands International (2006) (Table 1). Take notice of the fact that these numbers are mean values resulting from observations over a period of 16 years, and need to be interpreted as such. Hence, maximum numbers residing at the BPNS are temporarily much higher than the presented values. For example, in years with good breeding numbers of terns in the port of Zeebrugge, the 1% level of Sandwich tern is easily exceeded (4,067 breeding pairs in 2004), which is clearly not reflected in the extrapolated numbers in Table 1.

Table 1
Mean numbers of birds residing at the BPNS during the season with highest densities, compared to the 1% level of relevant biogeographical populations according to Wetlands International (2006) – species in bold occur in mean numbers higher than the 1% level.

Species	Subspecies / Biogeographical population	1% Level	BPNS		
			Season	Mean number	% of Biog. Pop.
Red-throated diver	NW Europe	3,000	Winter	730	0.24%
Great crested grebe	N & W Europe	3,600	Winter	1,300	0.36%
Common scoter	ssp. *nigra*	16,000	Spring	1,900	0.12%
Little gull	N, C & E Europe	1,230	Spring	2,400	1.95%
Common gull	ssp. *canus*	20,000	Winter	5,100	0.26%
Lesser black-backed gull	ssp. *graellsii* + *intermedius*	5,500 + 3,800	Spring	9,000	0.97%
Herring gull	ssp. *argenteus* + *argentatus*	5,900 + 20,000	Summer	3,000	0.12%
Great black-backed gull	NE Atlantic	4,400	Winter	5,400	1.23%
Black-legged kittiwake	NE Atlantic	20,000	Winter	5,800	0.29%
Sandwich tern	W Europe	1,700	Summer	1,000	0.59%
Common tern	S & W Europe + N & E Europe	1,900 + 11,000	Spring	3,100	0.24%

Table 2
Mean numbers of birds residing at the BPNS during the season with highest densities, compared to their NE Atlantic populations (Mitchell *et al.* 2004) – population sizes are calculated by multiplying the number of breeding pairs by three.

Species	Biogeographical population	Number of breeding pairs	BPNS		
			Season	Mean number	% of Biog. Pop.
Northern fulmar	NE Atlantic	2,300,000 – 3,700,000	Autumn	3,200	0.04%
Northern gannet		310,000	Autumn	3,300	0.35%
Great skua		16,000	Autumn	150	0.31%
Common guillemot		2,300,000 – 2,400,000	Winter	12,200	0.17%
Razorbill		570,000	Winter	2,600	0.15%

The mean densities in Table 1 and Table 2 represent a static situation but give no insight in the turnover rate of the birds. Nevertheless, we have strong reasons to believe that these turnover rates may temporarily be very high, especially during migration seasons. Migrating seabirds do not rapidly fly through the area, but in contrast, exploit the area for sleeping as well as foraging. Stienen & Kuijken (2003) made estimations of the percentage of the biogeographical populations of seabirds annually migrating through the southern North Sea (Table 3). This estimation is based on the numbers in wintering areas, the position of breeding grounds in respect to these wintering areas and the number of birds seen during land-based observations (seawatch data). The numbers presented in Table 3 show the extreme high importance of the southern North Sea towards Great skua, Little gull, Common tern and Sandwich tern.

Table 3
Percentage of the biogeographical seabird populations [(1) Wetlands International (1997), (2) Lloyd *et al*. (1991), (3) Harris (1997) and (4) Hildén & Tasker (1997)] migrating through the southern North Sea.

Species (English)	Biogeographical population / Subspecies	% migrating through the Southern North Sea
Red-throated diver	(1) NW Europe (non-br)	<1
Great crested grebe	(1) N & W Europe (non-br)	10-20
Northern fulmar	(2) NE Atlantic	<1
Northern gannet	(2) NE Atlantic	4-7
Common scoter	(1) ssp. nigra	4-5
Great skua	(2) NW Europe (excl. Iceland)	>60
Little gull	(1) N, C & E Europe (br)	40-100
Common gull	(1) ssp. canus	3-6
Lesser black-backed gull	(1) ssp. graellsii	28
Herring gull	(1) ssp. argentatus	5
Great black-backed gull	(1) NE Atlantic	5
Black-legged kittiwake	(1) E Atlantic	<1
Sandwich tern	(1) ssp. sandvicensis, W Europe (br)	67
Common tern	(1) ssp. hirundo, S & W Europe (br)	56
Common guillemot	(3) NW Europe (excl. Iceland)	<1
Razorbill	(4) NW Europe (excl. Iceland)	<2

8.1.4. Seabirds at the BPNS: Seasonal and spatial distribution

Seabirds densities at the BNPS show strong seasonal fluctuations (Figure 3). Maximum densities occur during winter season, when on average more than 42,000 seabirds are present at the BPNS, and minimum densities during summer (17,000 birds present). These totals are calculated through extrapolation of mean zonal densities (see §8.1.3).

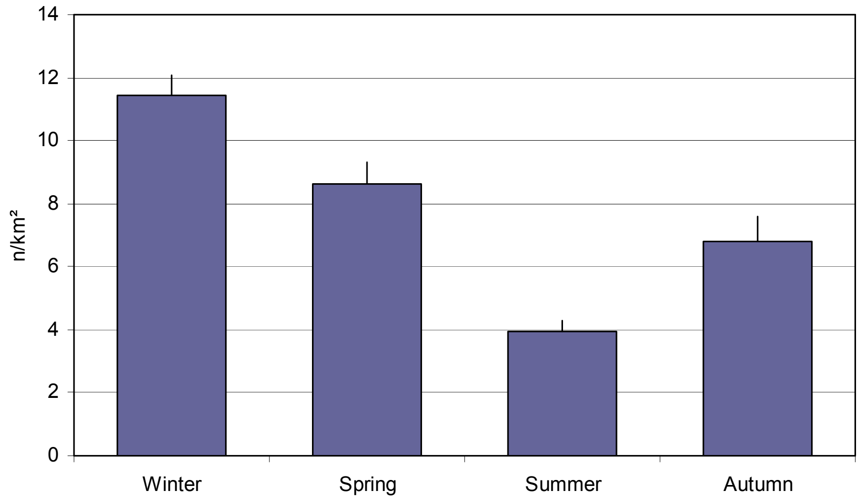


Figure 3. Seasonal variation in seabird densities at the BPNS (+SE).

Seabird community composition also shows strong seasonal variation (Figure 4). During winter, Common guillemot, Razorbill and Black-legged kittiwake account for more than 50% of the total bird density. Less important numbers of wintering gulls, grebes and divers occur. In the course of spring, most of these species leave the area and large numbers of Lesser black-backed gulls arrive at the BPNS, together with migrating Little gulls and Common scoters. The summer community in its turn is strongly dominated by local breeding birds like Lesser black-backed gull, Herring gull, Common tern and Sandwich tern. Terns leave the BPNS at the end of summer, and in autumn, Northern fulmar and Northern gannet migrate in large numbers, and the first wintering auks and kittiwakes arrive.

With the seasonal changes in species composition, seabird distribution patterns change accordingly. While some birds occur widespread, others show marked preference for the shallow inshore waters or clearly avoid the coast as illustrated in Figure 5.

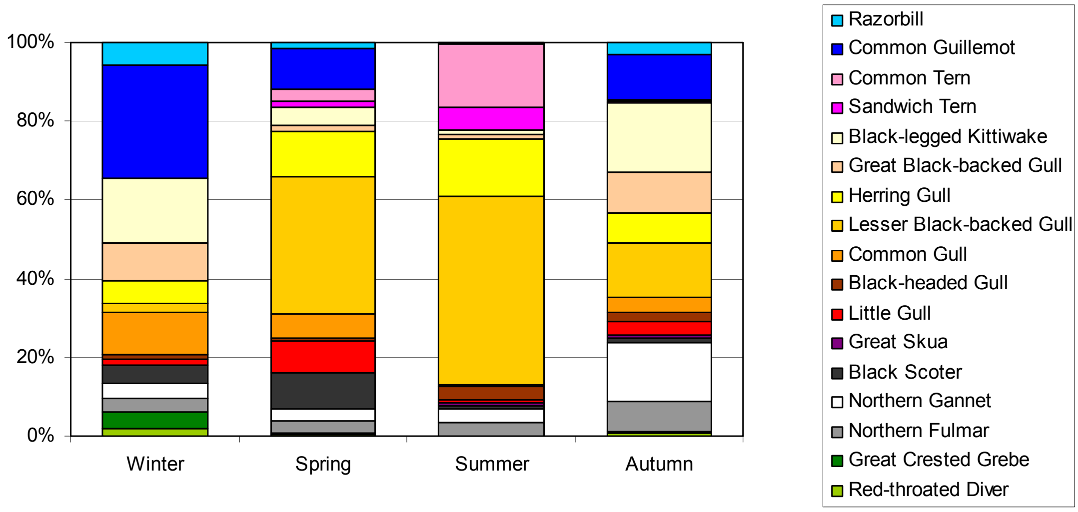


Figure 4. Seasonal variation in seabird community (blue = auks; pink = terns; yellow-orange-red = gulls; purple = Great skua; black = Common scoter; white = Northern gannet; grey = Northern fulmar; green = divers & grebes).

Figure 5. Seabird densities in relation to the distance from the coast, with typical inshore (black) and offshore species (red).

8.2. Avian importance of the Thorntonbank wind farm area

8.2.1. Methodology

In Vanermen *et al.* (2006), densities on the TTB were compared to densities on the BPNS as a whole. Relatively few data were available at that time, but already, some preliminary conclusions could be drawn. Several species, like Red-throated diver, Great crested grebe and Common scoter mainly occur inshore and thus the wind farm area is situated outside their normal distribution. Other species, like for example Northern gannet, Black-legged kittiwake and Common guillemot, did occur in high densities at the TTB, mainly during migration periods. But considering their wide distribution across the North Sea, the area could not be acknowledged as being particularly important to these species. On the other hand, Vanermen *et al.* (2006) found that several vulnerable species appeared in relatively high densities at the TTB. Based on the sparse data available, they alerted that the area could play an important role in the migration of four species, being Great skua, Little gull, Sandwich tern and Common tern.

Here we present an update of the results Vanermen *et al*. (2006) based on intensive monitoring of the TTB area during the period 2005-2007. Table 4 compares the mean seasonal densities of 16 species of seabird in the impact area of the wind farm (WFA-TTB) with the mean density on the BPNS as a whole. Since there is substantial seasonal variation in numbers as well as species composition, the dataset was first split into seasons:

- Winter: December – February
- Spring: March – May
- Summer: June – August
- Autumn: September – November

The impact area WFA-TTB corresponds to the wind farm area surrounded by a buffer zone of 3km. The width of this buffer zone was chosen based on literature research. Extensive radar and visual observation studies in Denmark and Sweden showed that migrating birds may already show avoidance behaviour from up to 3 km (Christensen *et al*. 2004, Kahlert *et al*. 2005, Pettersson *et al*. 2005). Hence, a buffer zone of 3 km assures that potential effects are limited to the impact zone exclusively. Thereafter, the BPNS was overlaid by a grid of 2x2 km cells. Every grid cell overlapping for at least one third of its surface with the impact area was assigned to the subzone WFA-TTB, while all grid cells with their centroid within the boundaries of the Belgian part of the North Sea were assigned to the subzone BPNS (Figure 6). The mean densities in the WFA-TTB and the BPNS were calculated by first calculating the means for each grid cell, before calculating the means per subzone. This way, we compensated for the skewed counting effort throughout the area.

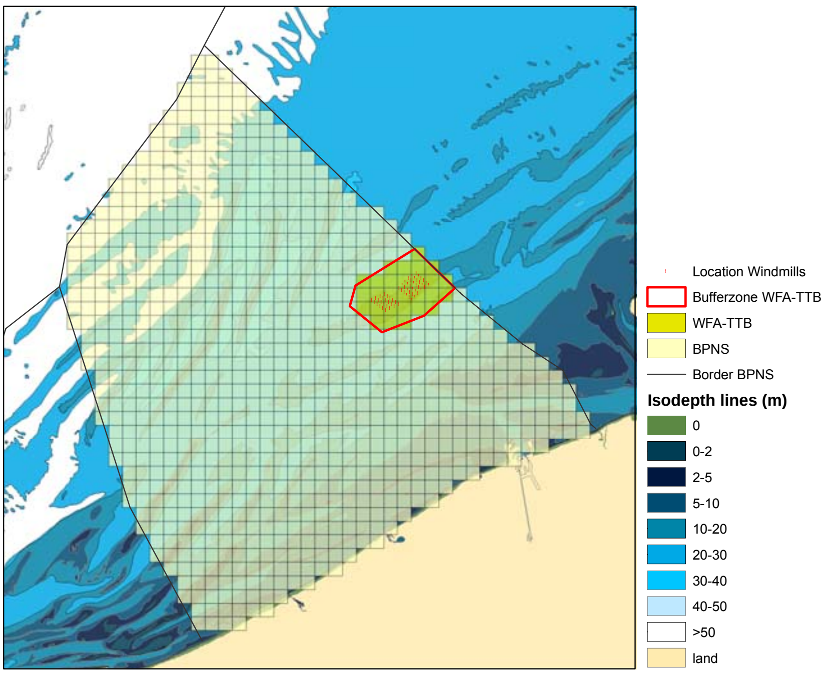


Figure 6. Grid of 2x2km cells used as a base for comparison of seabird densities in the impact area WFA-TTB and the BPNS.

8.2.2. Avian importance of the Thorntonbank wind farm area

8.2.2.1. General

Compared to the preliminary results in Vanermen *et al*. (2006), some species are slightly more abundant in this study (Table 4). This is the case for Lesser black-backed gull, Great black-backed gull, Black-legged kittiwake, Common guillemot and Razorbill.

The importance of the WFA-TTB towards Little gull, Sandwich tern and Common tern, is now confirmed by recent monitoring. The Little gull occurs concentrated in the WFA-TTB during winter months and the area is also part of its south bound autumn migration route (Figure 7 & Figure 9). Densities are highest during winter with 0.84 Little gulls per km². Significant numbers of terns occur in the WFA-TTB during summer months and especially during migration, from the end of July onwards to August (§8.2.2.2). On the other hand, densities of Great skua were seemingly overestimated in Vanermen *et al*. (2006), and the WFA-TBB now seems to be rather insignificant for this species.

Table 4
Seasonal bird densities (n/km²) in the future wind farm area at 'Thorntonbank' (WFA-TTB) compared to densities at the BPNS as a whole (1992-2007). (species marked in bold meet one of following criteria: density in the WFA exceeds 1 bird/km² during one or more seasons; density in the WFA exceeds 0,25 bird/km² during one or more seasons in case of a protected species (*); WFA-density is at least 50% higher than the BPNS-density)

	Winter		Spring		Summer		Autumn	
	WFA-TTB	BPNS	WFA-TTB	BPNS	WFA-TTB	BPNS	WFA-TTB	BPNS
Number of grid cells	26	769	23	649	23	602	27	726
Red-throated diver	0,12	0,24	0,02	0,04	0,00	0,00	0,02	0,04
Great crested grebe	0,00	0,44	0,00	0,04	0,00	0,00	0,00	0,05
Northern fulmar	0,15	0,39	0,13	0,21	0,20	0,14	0,70	0,52
Northern gannet	0,18	0,39	0,36	0,25	0,17	0,13	1,14	1,04
Common scoter	0,07	0,57	0,00	0,86	0,00	0,05	0,00	0,08
Great skua	0,00	0,01	0,00	0,00	0,02	0,02	0,00	0,04
Little gull*	0,81	0,16	0,40	0,57	0,00	0,04	0,43	0,25
Common gull	2,56	0,98	0,07	0,59	0,00	0,01	0,04	0,27
Lesser black-backed gull	0,06	0,12	21,64	2,79	4,42	1,93	0,18	0,97
Herring gull	0,38	0,60	0,37	1,07	0,02	0,64	0,01	0,53
Great black-backed gull	2,73	1,05	0,04	0,14	0,21	0,05	3,25	0,80
Black-legged kittiwake	5,97	1,79	0,09	0,39	0,00	0,04	5,24	1,37
Sandwich tern*	0,00	0,00	0,11	0,16	0,59	0,25	0,02	0,02
Common tern*	0,00	0,00	0,02	0,26	0,38	0,66	0,02	0,03
Common guillemot	4,42	3,23	0,65	0,94	0,00	0,01	3,67	0,90
Razorbill	1,33	0,69	0,08	0,14	0,00	0,00	0,58	0,21

8.2.2.2. Species discussion

Little gull (*Larus minutus*)

In Vanermen *et al*. (2006), it was already suggested that the WFA-TTB was important to Little gulls, mainly during autumn migration. It has now become clear that relatively high densities occur in the area from September until April. Densities are even higher than initially calculated by Vanermen *et al*. (2006).

In general, the Little gull's distribution at the BPNS is concentrated within a 40km wide band along the coast, including the WFA-TTB. Especially during winter, Little gulls occur concentrated in the impact area (Figure 7). In autumn however, highest concentrations occur near the ports of Zeebrugge and Ostend, while the WFA-TTB shows increased densities too (Figure 7).

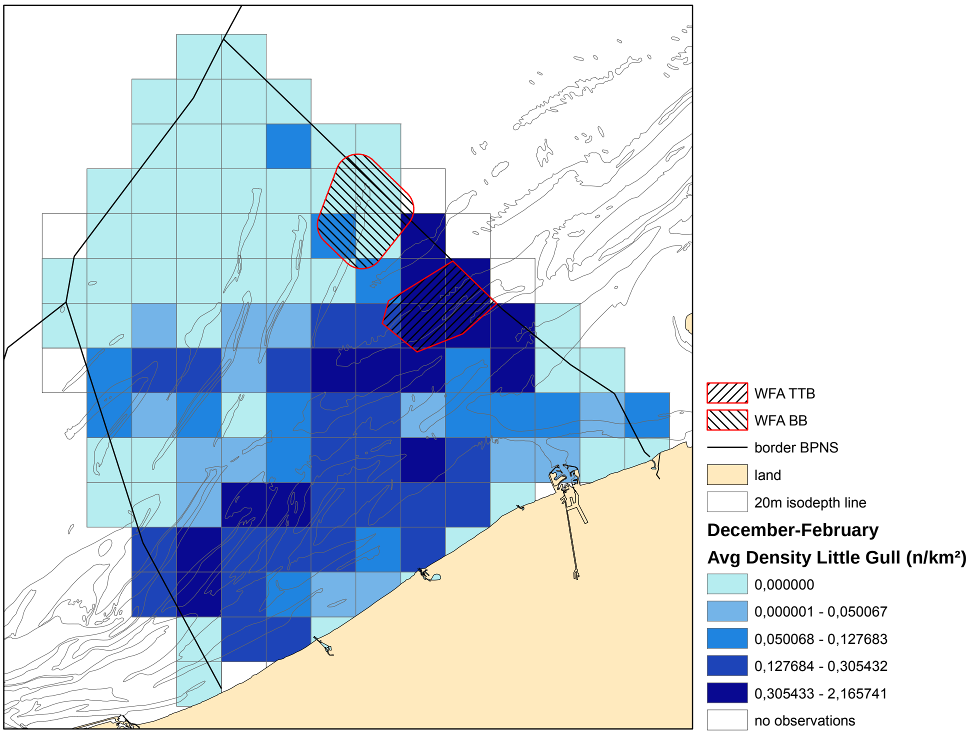


Figure 7. Winter distribution of Little gull on the BPNS (number per km²).

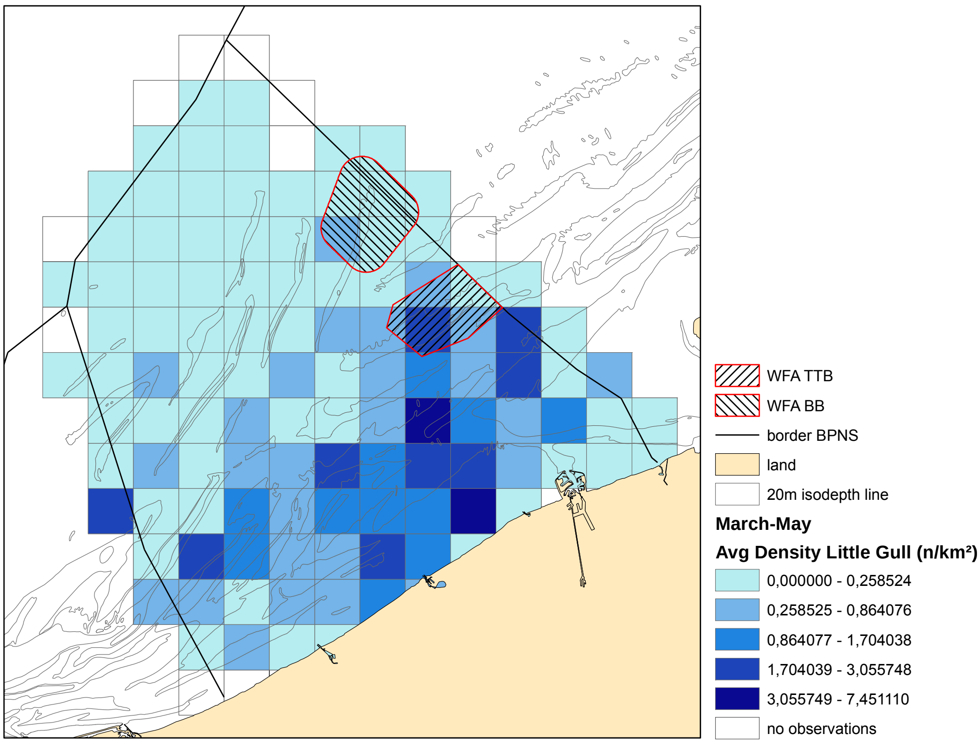


Figure 8. Spring distribution of Little gull on the BPNS (number per km²).

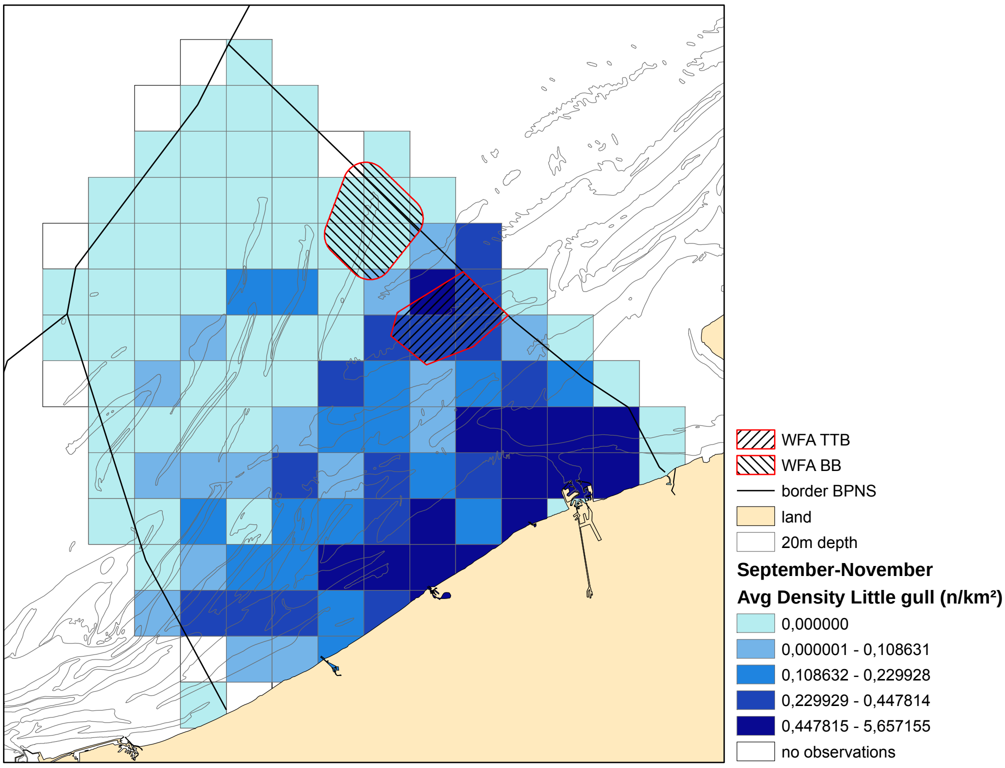


Figure 9. Autumn distribution of Little gull on the BPNS (number per km²).

Sandwich tern (Sterna sandvicensis)

Following the discussion in Chapter 1 of Vanermen *et al*. (2006), the distribution maps shown are based on an adapted seasonal classification: March-April (spring migration), May-June (breeding season) and July-August (autumn migration). In spring, migration occurs widespread across the BPNS, with equally high densities near shore and further offshore (Figure 10). During the breeding season, highest densities occur near shore, with a clear concentration of Sandwich terns within 15km of the breeding colony in Zeebrugge (Figure 11). Table 4 suggests that mainly during summer, the WFA-TTB holds important numbers of Sandwich tern. This is illustrated by the distribution map in Figure 12, which shows that Sandwich terns concentrate near the port of Zeebrugge and within the WFA-TTB during July to August.

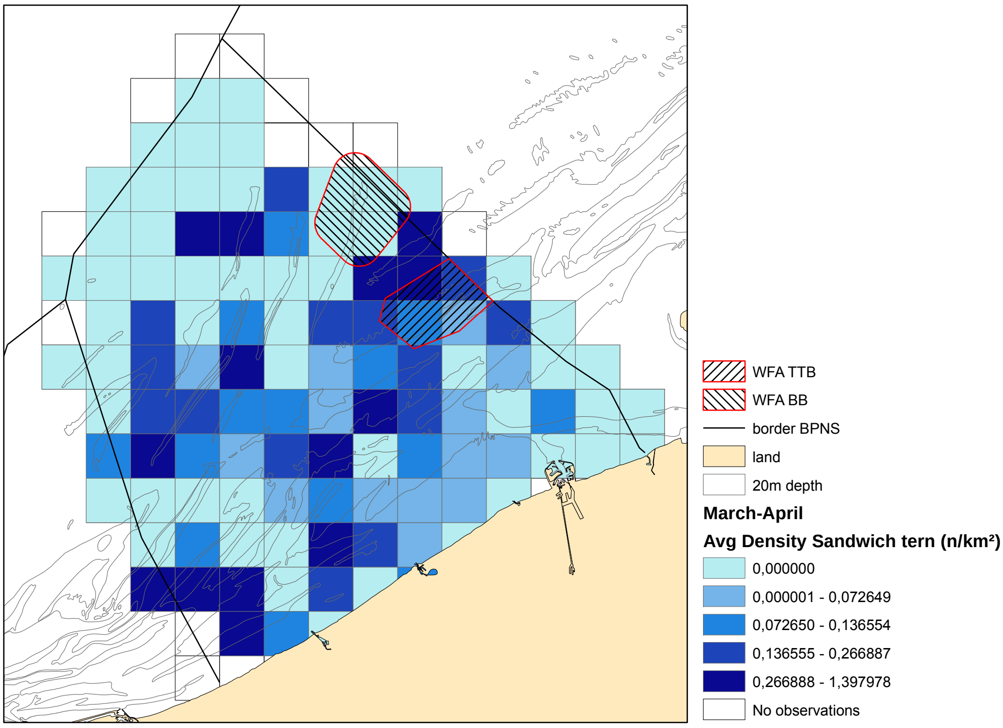


Figure 10. Distribution of Sandwich tern on the BPNS during spring migration (March-April).

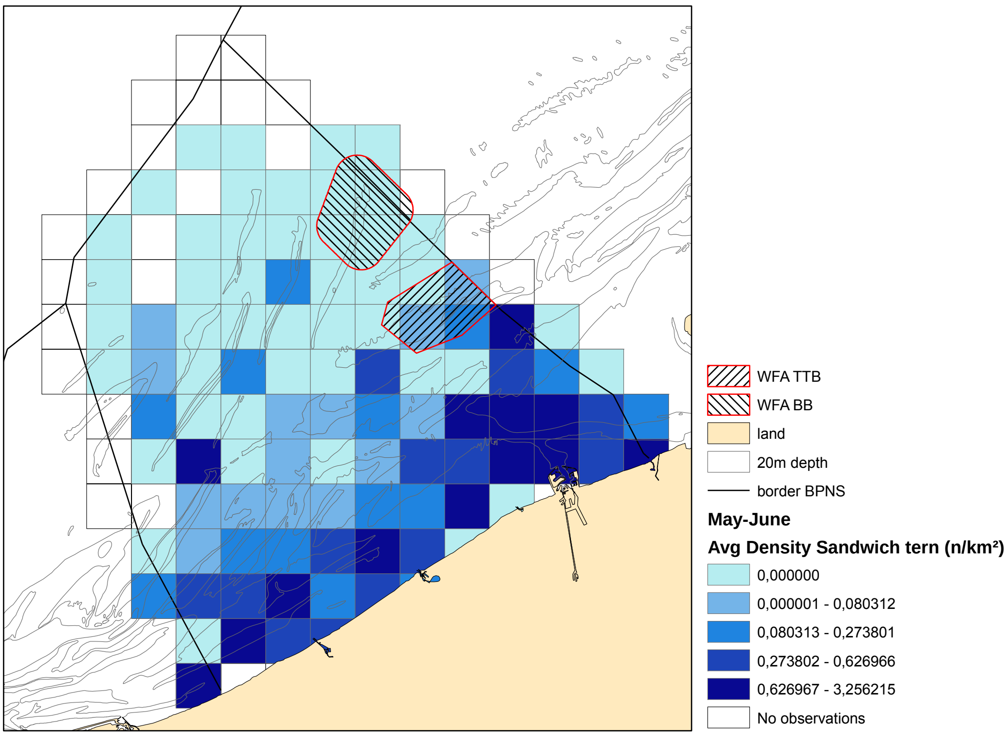


Figure 11. Distribution of Sandwich tern on the BPNS during breeding season (May-June).

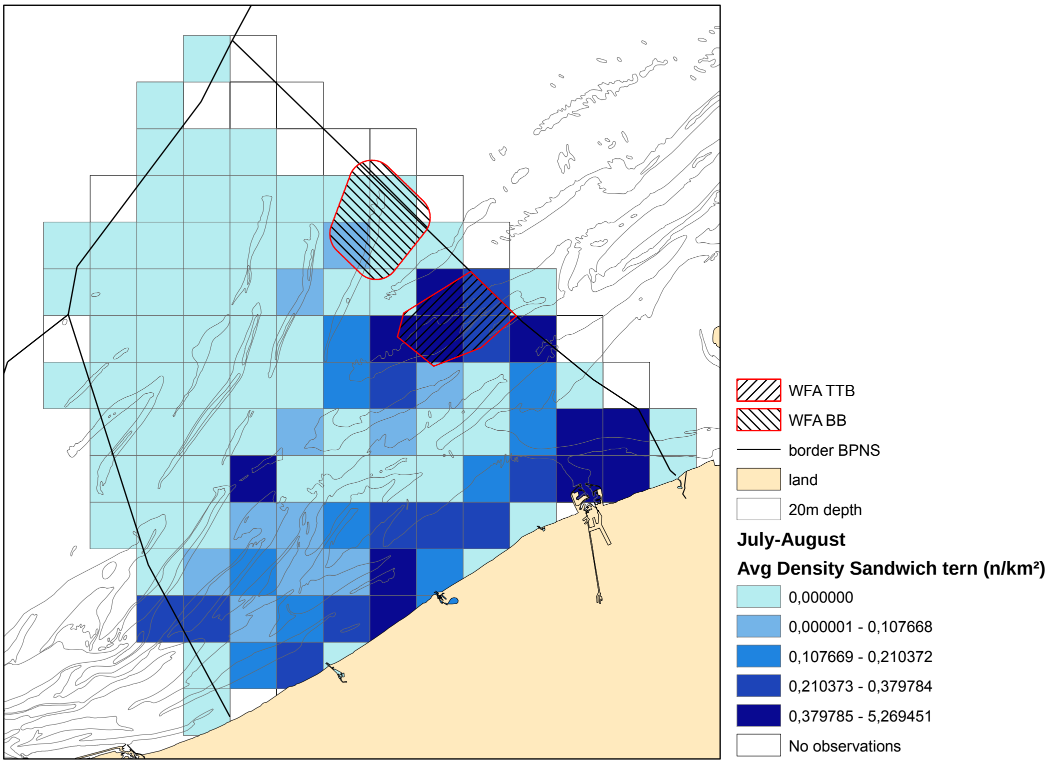


Figure 12. Distribution of Sandwich tern on the BPNS during summer (July-August).

Common tern (*Sterna hirundo*)

In early spring Common terns occur scattered around the BPNS, with high densities already building up near the ports of Zeebrugge and Ostend. In that period, Common terns are observed as far offshore as the 'Hinderbanken'. In contrast, the species is limited to the near shore zone during breeding season, with very high densities near the breeding colony of Zeebrugge. More than 20km offshore zero densities are standard. The foraging range of breeding Common tern usually does not exceed 15 km, and hence the WFA-TTB is not important to the birds of Zeebrugge. The species already takes on its southbound migration in late summer (July-August). That period, the species' distribution is most widespread and the WFA-TTB holds increased densities (Table 4 & Figure 15).

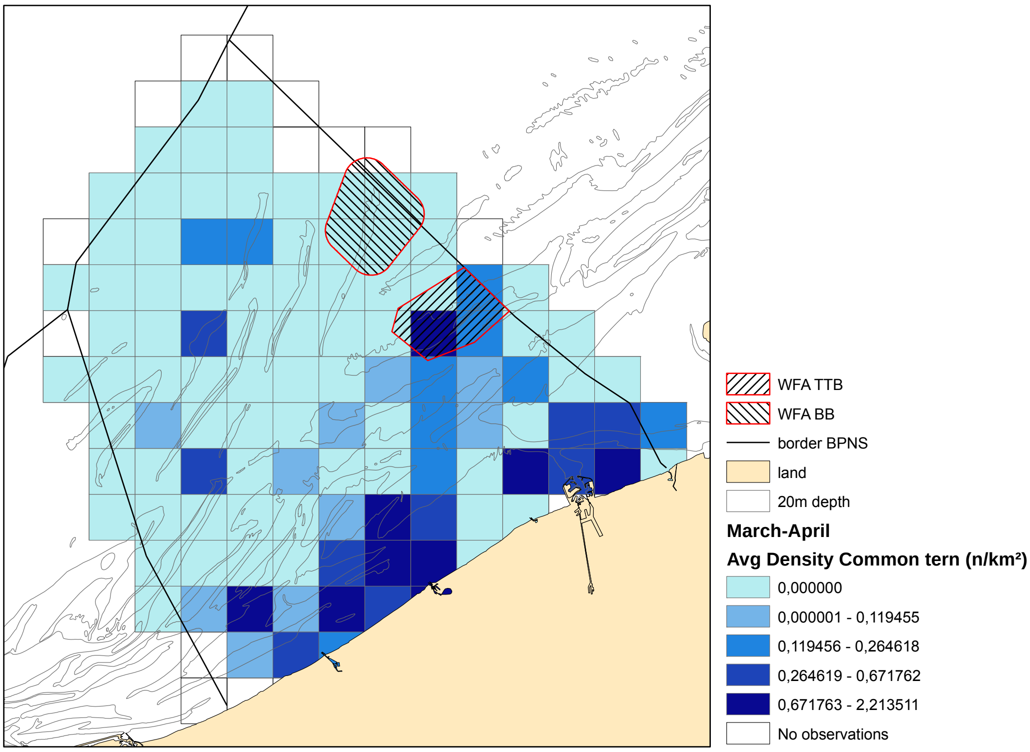


Figure 13. Distribution of Common tern on the BPNS during spring migration (March-April).

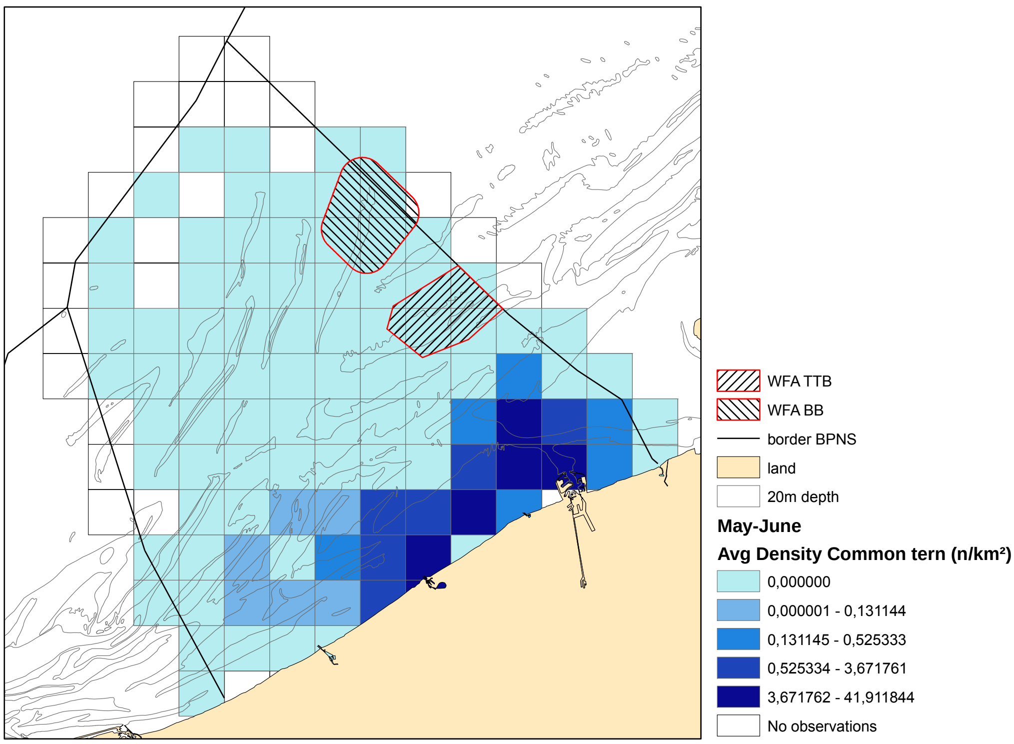


Figure 14. Distribution of Common tern on the BPNS during breeding season (May-June).

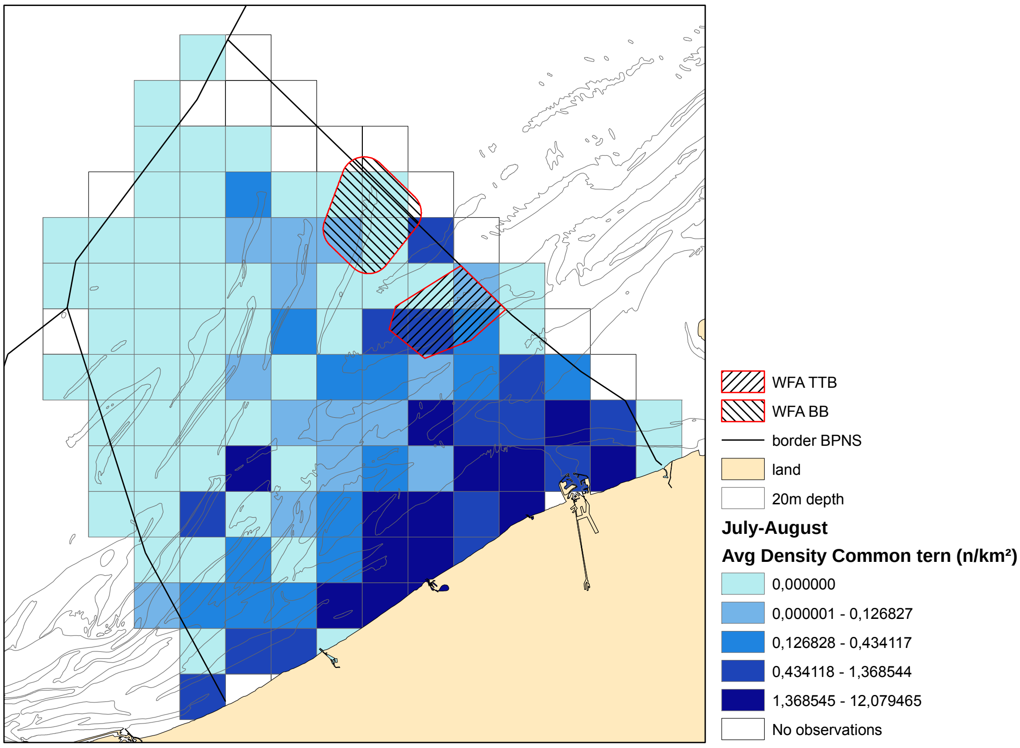


Figure 15. Distribution of Common tern on the BPNS during summer (July-August).

8.2.2.3. Conclusion

Based on the information gathered during three years of intense monitoring (2005-2007), we conclude that:

The WFA-TTB is has no particular value to Red-throated diver, Great crested grebe, Northern fulmar, Common scoter, Great skua and Herring gull

The WFA-TTB is not particularly valuable to the following species, although high densities may occur: Northern gannet, Common gull, Lesser black-backed gull, Great black-backed gull, Black-legged kittiwake, Common guillemot, Razorbill

→ Considering their high densities in the reference period, these species are well suitable for monitoring regarding displacement effects by the future wind farm.

The WFA-TTB is of particular value to **Little gull**, **Sandwich tern** and **Common tern**

→ To accurately assess possible effects of the future wind farm, migration behaviour and occurrence of these birds in the TTB-WFA needs to be investigated in detail. Research should also focus on displacement through avoidance behaviour, as well as migration flux and collision risk.

8.3. Evaluation of the control area of the Thorntonbank wind farm area

To accurately assess the impact of human structures at sea, it is not sufficient to perform a before-after comparison. Ideally, the changes in the impact area are put in perspective by comparing them with possible changes in a control area. Naturally, changes in bird community and densities are not necessarily induced by local changes in the marine environment, and might as well be induced by larger scale processes. Such large scale events include temporary influxes of seabirds due to specific weather conditions or food availability elsewhere, as well as changes in population level.

In the reference study (Vanermen *et al*. 2006), a control area was delineated for the future wind farm site at the Thorntonbank (WFA-TTB). Obviously, the bird community in this area had to correspond as much as possible to that occurring in the WFA-TTB. Additionally, the chosen control area had to account for the fact that seabird distribution and densities are highly variable on a temporal as well as a spatial scale. Hence, several logistic considerations had to be made. Since seabird occurrence is highly variable even on a short time scale, it was necessary to choose a control area that could be monitored the exact same day as the wind farm area itself. Secondly, the control area should not suffer from adverse effects caused by the wind farm, which was countered by applying a 3km wide buffer zone (Christensen *et al*. 2004, Kahlert *et al*. 2005, Pettersson *et al*. 2005). Finally, the area had to be large enough to be able to include sufficient data for statistical analysis. This is especially important for scarce species like terns, Little gull and Great skua.

After analysing the local seabird densities and taking in account the aforementioned logistic and practical considerations, one single control area (CA-TTB) was delimited for year-round monitoring. The chosen control area largely surrounds the WFA-TTB, extending from the Dutch border to the southwest tip of the Gootebank, measuring 329 km². The WFA-TTB itself measures 105 km², the 3km wide buffer zone included (Figure 16). Vanermen *et al*. (2006) compared the seabird densities in the WFA-TTB and CA-TTB based on monitoring results of the year 2005. In this chapter we perform a likewise analysis for the data obtained during the period 2005-2007, and evaluate the suitability of the control area.

8.3.1. Methodology

8.3.1.1. Selectivity Index

Analogous to the monitoring programmes performed in Denmark (e.g. Christensen *et al*. 2004, Kahlert *et al*. 2005), the Jacobs selectivity index (Jacobs 1974) was used as a base for comparison between WFA-TTB and CA-TTB. The Jacobs selectivity index (JSI) is calculated as follows:

$$D = (r - p) / (r + p - 2rp)$$

With
r = % of birds in the WFA-TTB compared to the number of birds in the total study area;
p = % of the count effort (see §8.3.1.2) in the WFA-TTB compared to the effort in the total study area.

The index obtained through this formula results in values ranging from -1 to +1. When birds occur homogeneously dispersed throughout both areas, a value of 0 is obtained. In contrast, a value of +1 stands for 100% preference to the WFA, and -1 for complete preference to the CA. During the reference period, the JSI should be as small as possible.

8.3.1.2. Count effort

Figure 16 shows the count locations for the period 1992-2007, which makes clear that prior to 2005 counting effort was strongly skewed in favour of the CA-TTB. Therefore, only count results of the years 2005-2007 were included in the analysis, and Figure 17 compares the count effort in the CA-TTB and the WFA-TTB for this period. The count effort is expressed as the number of square kilometres monitored (km²), which is calculated by multiplying the sailed kilometres with the transect width (0.3km). In autumn, the area monitored in the CA-TTB was more than twice the area monitored in the WFA-TTB. Otherwise, despite the large dimensions of the CA-TTB compared to the WFA-TTB, the count effort was relatively well partitioned between both areas.

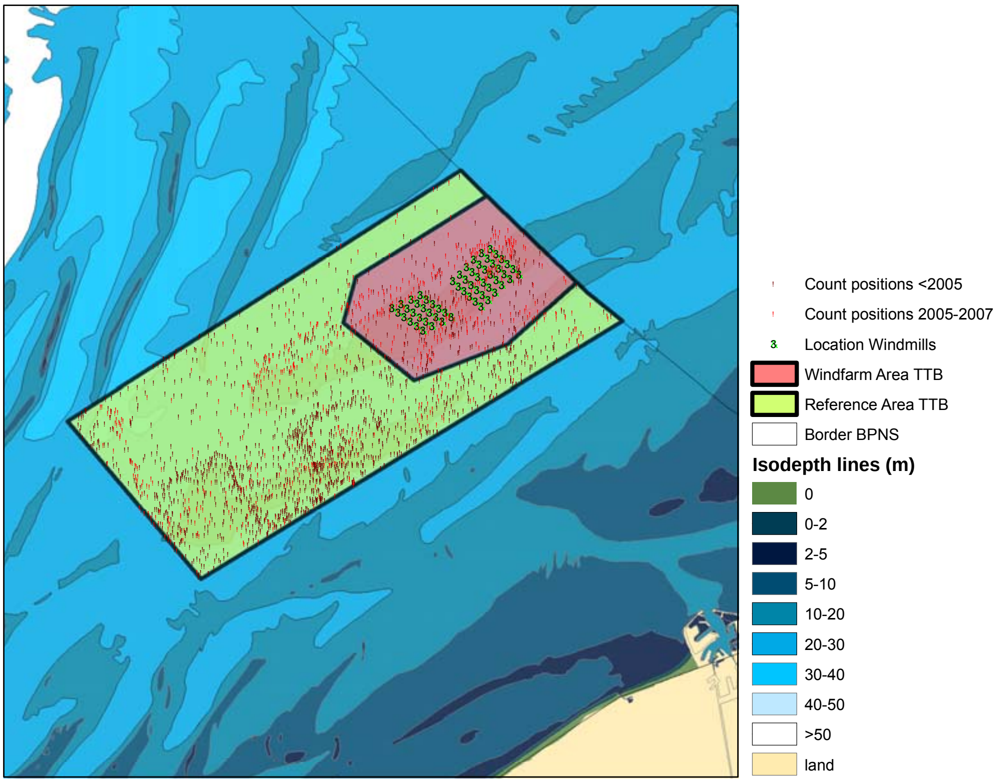


Figure 16. The control area (CA-TTB) and wind farm area (WFA-TTB) at the Thorntonbank – the brown dots represent all count locations prior to 2005, the red dots those from 2005 to 2007.

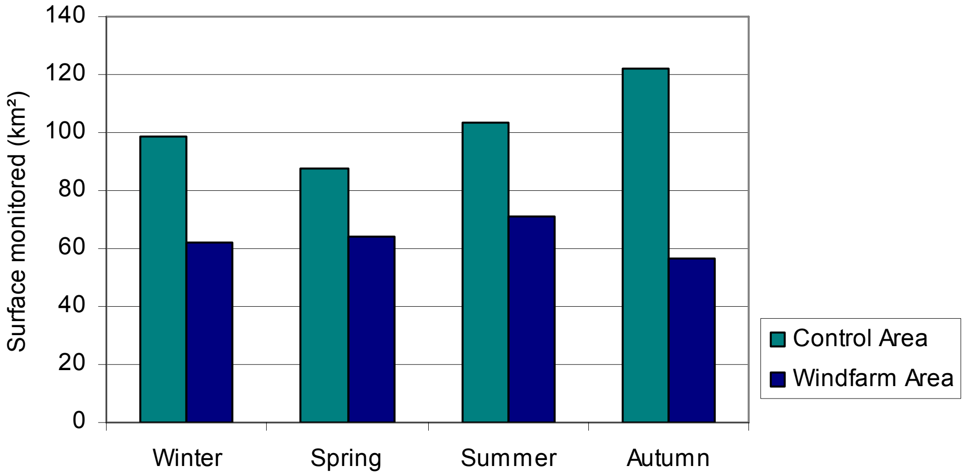


Figure 17. Count effort in the control area (CA-TTB) compared to the impact area (WFA-TTB) at the 'Thorntonbank', expressed in km² of area monitored (2005-2007).

8.3.2. Results

Northern gannet (*Morus bassanus*)

Northern gannets occur in relatively high densities, with highest numbers during autumn. The species occurs in well corresponding numbers in both subzones, which is confirmed by a JSI of 0.11.

Nevertheless, seasonal densities show poor correspondence.

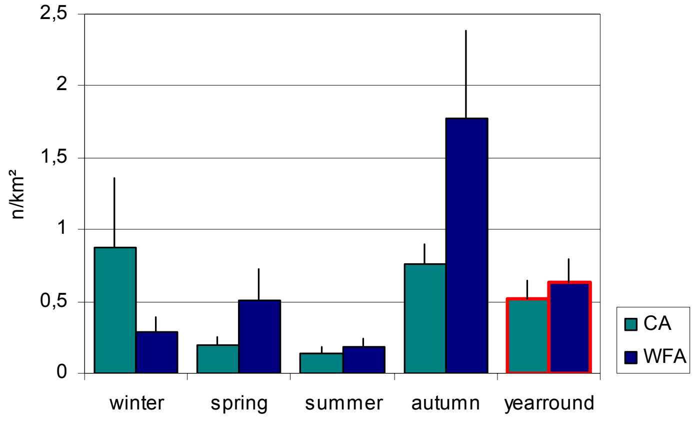


Figure 18. Seasonal and year-round densities of Northern gannet in the CA-TTB compared to the WFA-TTB (+ std. error) (2005 – 2007).

Little gull (*Larus minutus*)

Both the WFA-TTB and CA-TTB hold moderately high densities of Little gulls (Figure). In contrast to the BPNS as a whole, where the species is most common during spring, densities of Little gull are highest during winter months. Year-round densities indicate a preference to the WFA-TTB (JSI = 0.25), mainly resulting from high densities observed there during winter.

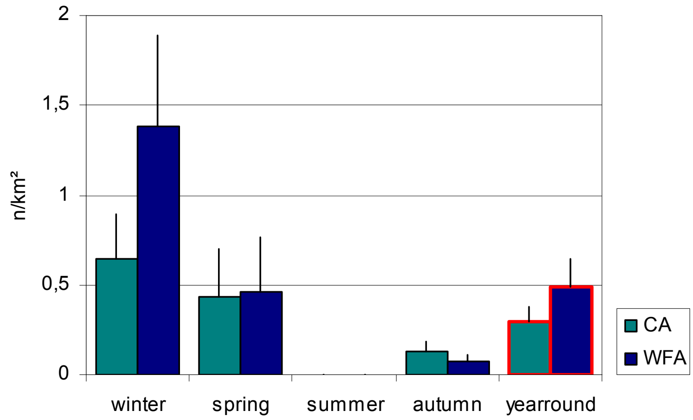


Figure 19. Seasonal and year-round densities of Little gull in the CA-TTB compared to the WFA-TTB (+ std. error) (2005 – 2007).

Common gull (*Larus canus*)

In our study area, Common gulls were almost exclusively observed during winter months, with densities of more than 3 birds per km² in the WFA-TTB as well as the CA-TTB. This results in a fairly low selectivity index of -0.13.

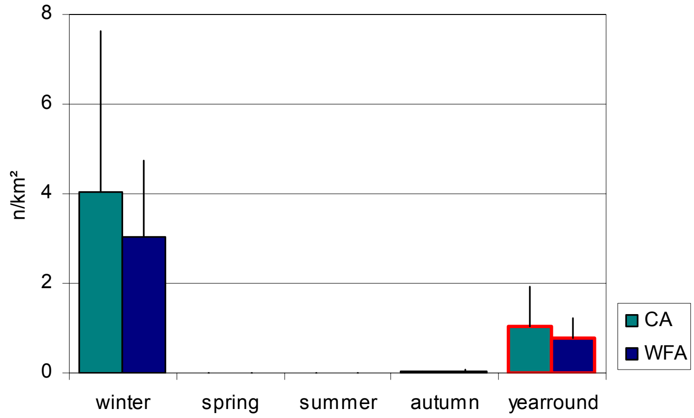


Figure 20. Seasonal and year-round densities of Common gull in the CA-TTB compared to the WFA-TTB (+ std. error) (2005 – 2007).

Lesser black-backed gull (*Larus fuscus*)

Lesser black-backed gulls show a selectivity index strongly in favour of the WFA-TTB (JSI = 0.55). Since gulls often aggregate in large numbers around fishing vessels, these results need to be interpreted with care. In the study area, densities of more than 150 birds/km² were observed at five locations, of which four were within the WFA-TTB. Such large concentrations are inevitably associated with nearby fishing activities, and on such a small scale encounters with a towing fishing vessel mainly rely on coincidence.

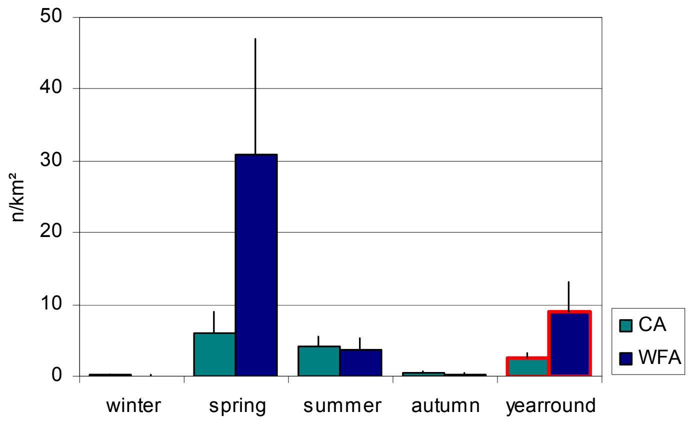


Figure 21. Seasonal and year-round densities of Lesser black-backed gull in the CA-TTB compared to the WFA-TTB (+ std. error) (2005 – 2007).

Great black-backed gull (*Larus marinus*)

In the study area, the Great black-backed gull is a winter visitor which is present in high numbers during winter and autumn. Mean densities amount up to 9 birds per km² in the CA-TTB, and up to 6 birds per km² in the WFA-TTB. While the seasonal densities in both subzones show poor correspondence (especially in autumn), the overall selectivity appears to be very low (-0.01). Great black-backed gulls too show high association with fishing activity, which makes the species unsuitable for a reliable 'control area' versus 'impact area' comparison.

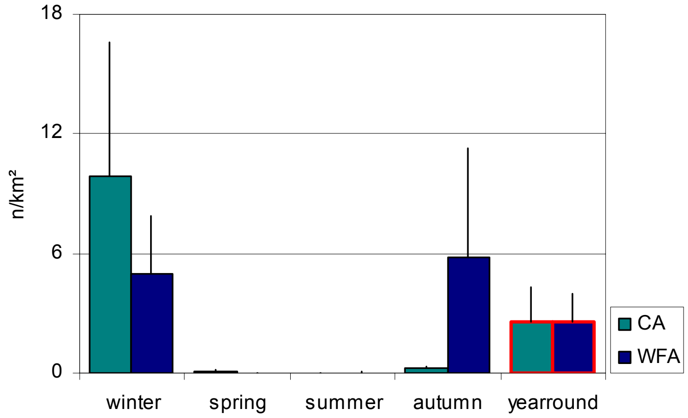


Figure 22. Seasonal and year-round densities of Great black-backed gull in the CA-TTB compared to the WFA-TTB (+ std. error) (2005 – 2007).

Black-legged kittiwake (*Rissa tridactyla*)

Black-legged kittiwakes are winter and autumn visitors in the study area. While winter densities correspond well, the autumn density in the WFA-TTB is much higher than in the CA-TTB. Resulting, the selectivity index is in favour of the WFA-TTB (0.27).

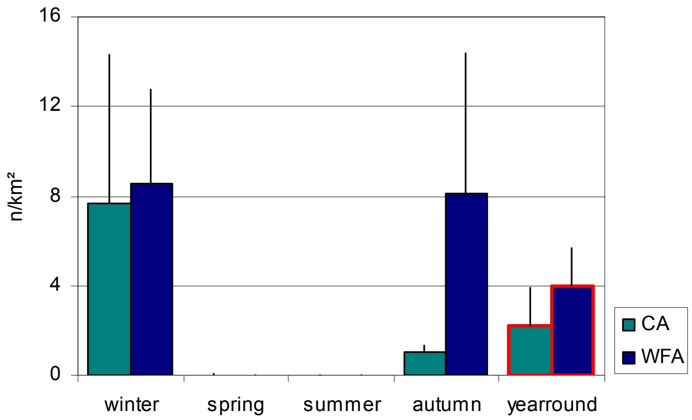


Figure 23. Seasonal and year-round densities of Black-legged kittiwake in the CA-TTB compared to the WFA-TTB (+ std. error) (2005 – 2007).

Sandwich tern (Sterna sandvicensis)

Sandwich terns occur in low densities in the study area, mainly during spring and summer. While the seasonal densities show poor correspondence between WFA-TTB and CA-TTB, the overall selectivity appears to be very low (-0.05).

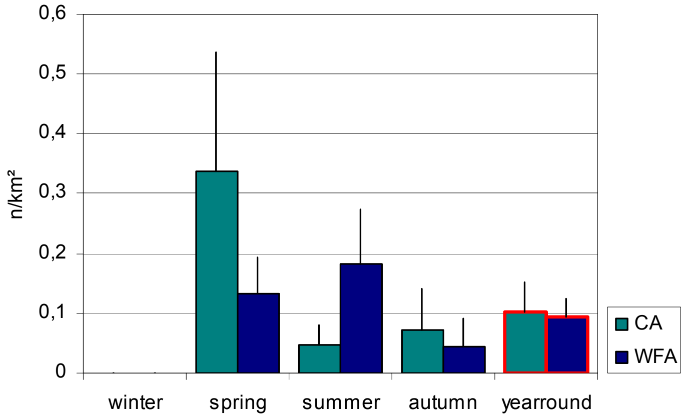


Figure 24. Seasonal and year-round densities of Sandwich tern in the CA-TTB compared to the WFA-TTB (+ std. error) (2005 – 2007).

Common tern (*Sterna hirundo*)

As well as the previous species, Common terns are mainly present during spring and summer. Numbers in both areas correspond well, resulting in a fairly low JSI-value of 0.14.

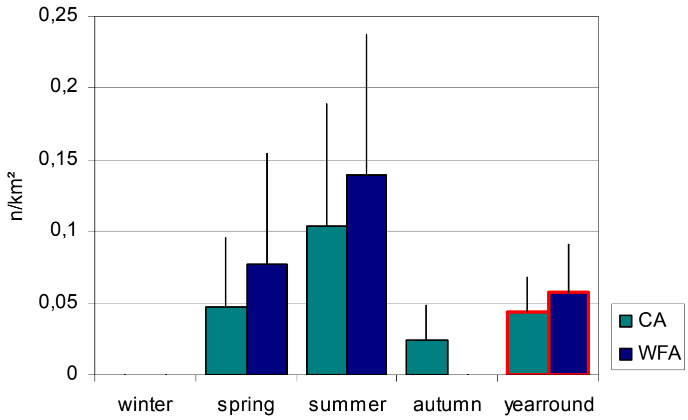


Figure 25. Seasonal and year-round densities of Common tern in the CA-TTB compared to the WFA-TTB (+ std. error) (2005 – 2007).

Common guillemot (*Uria aalge*)

Common guillemots are present in high numbers in both subzones during winter and autumn. During both seasons the species is more numerous in the WFA-TTB compared to the CA-TTB, with densities amounting up to 7 birds per km². This results in a selectivity index of 0.23, in favour of the WFA-TTB.

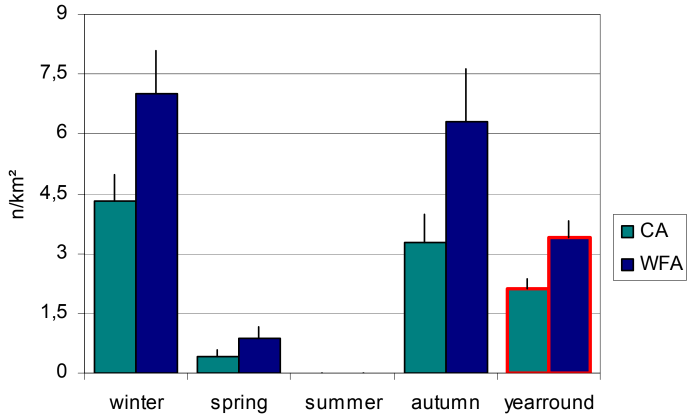


Figure 26. Seasonal and year-round densities of Common guillemot in the CA-TTB compared to the WFA-TTB (+ std. error) (2005 – 2007).

Razorbill (*Alca torda*)

While numbers are insignificant during spring and summer, densities of more than 1 Razorbill per km² occur during winter and autumn. There is good agreement in densities of Razorbill in the WFA-TTB and CA-TTB, resulting in a low selectivity index of 0.05.

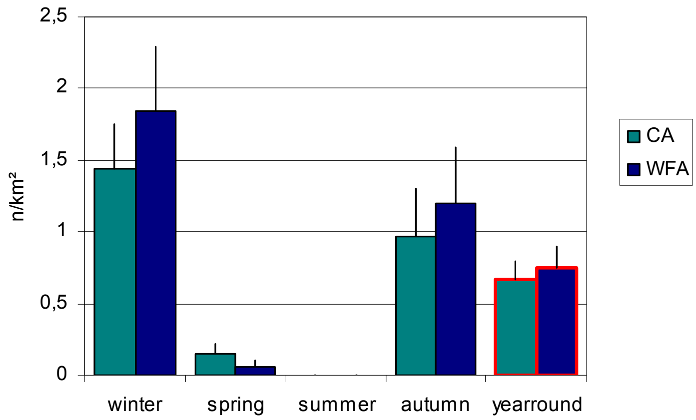


Figure 27. Seasonal and year-round densities of Razorbill in the CA-TTB compared to the WFA-TTB (+ std. error) (2005 – 2007).

8.3.3. Summary

In this chapter we calculated the Jacob's selectivity index (JSI) of ten species of seabird, as a measure for the deviation of densities in the control area (CA-TTB) compared to the impact area (WFA-TTB). During the reference period, JSI-values are favourably close to zero.

We calculated the index for two periods, 1992-2007 and 2005-2007. Since 2005, the monthly monitoring routes covered both the WFA-TTB and the CA-TTB, which results in smaller JSI's (Figure 28). Based on the generally good agreement in seabird occurrence in both areas we regard the CA-TTB proposed by Vanermen *et al*. (2006) as suitable for future monitoring.

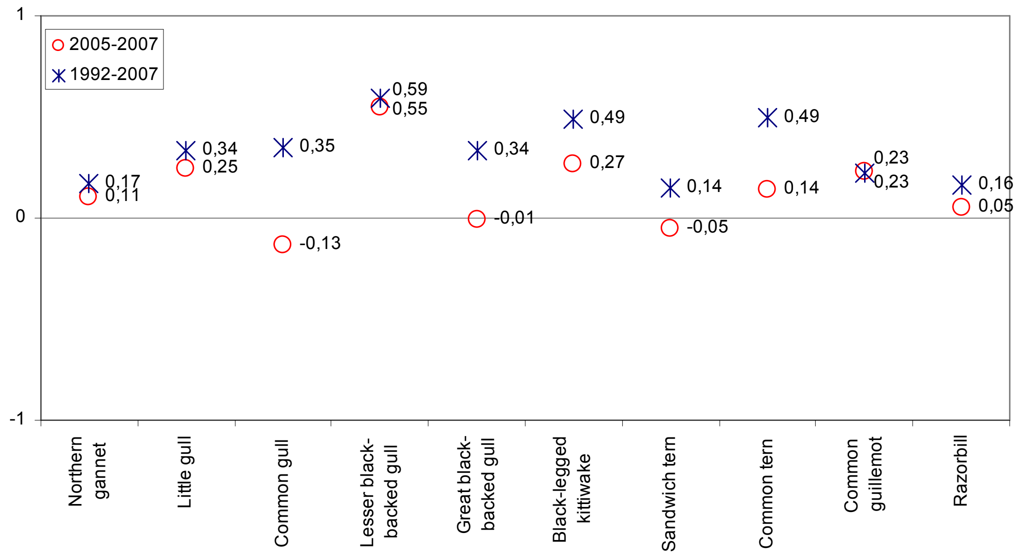


Figure 28. Results for two different JSI calculations (+1 = 100% preference to the WFA-TTB / -1 = 100% preference to the CA-TTB).

In chapter 8.1 we selected 10 out of 16 species of seabirds on which future monitoring should be focused on, based on their conservational value and/or abundant occurrence in the WFA-TTB. The information gathered in this chapter allows us to further determine the remaining species' suitability.

Suitable monitoring species should agree on the following criteria. A reliable 'control area' versus 'impact area' comparison requires highly comparable seabird densities in both areas during the reference period and hence, a small JSI. For data as variable as seabird densities, it will never be possible to obtain zero JSI-values. Therefore, future monitoring will mainly focus on the procentual changes in the WFA and CA, rather than on absolute differences in densities between both areas (see §8.4.1). Nevertheless, large JSI-values during the reference period may be a reflection of a high and unwanted spatial variability in the species' occurrence, due to, for example fishing activities.

Secondly, Figure 28 shows the JSI's for the whole reference period 2005-2007. However, a low JSI does not necessarily result from a good agreement in seasonal densities (in Great black-backed gull for example, Figure 22). Therefore we calculated the standard deviation of the (relevant) seasonal JSI's, as a measure of seasonal variation in selectivity.

Lastly, for each species we calculated a percentage of association with fisheries. As already mentioned, monitoring of species with a strong association with fishing activities is less reliable. Obviously, the encounter with a large number of birds concentrated near fishing activities is highly coincidental. Moreover, the observed distribution reflects the distribution of fishing activity rather than it reflects an inherent preference to a certain marine area.

Each of these three parameters was ranked from low to high and split up in three categories. The three lowest values were scored as 0 and the three highest as 2, the four remaining 'middle' values were scored as 1 (Table 5). These categorical values were then summed, resulting in one value based on which we are able to sort the species according to their suitability for future monitoring. As expected, specialists like auks, terns and Little gulls are better suited compared to generalists like gulls. While the specialists occur relatively homogeneously dispersed, generalists concentrate more aggregated, resulting in strongly skewed JSI's.

Table 5
Ranking of the species' suitability for future monitoring.

Species	Association with fishery (%) (1)	JSI (absolute value) (2)	SD of seasonal JSI (3)	(1)	(2)	(3)	Σ [(1),(2),(3)]
Razorbill	0.00	0.05	0.01	0	0	0	0
Common guillemot	0.00	0.23	0.05	0	1	0	1
Common tern	0.06	0.14	0.06	1	1	0	2
Little gull	0.02	0.25	0.33	0	2	1	3
Sandwich tern	0.06	0.05	0.72	1	0	2	3
Common gull	0.20	0.13	0.24	2	1	1	4
Northern gannet	0.13	0.11	0.52	1	1	2	4
Black-legged kittiwake	0.16	0.27	0.49	1	2	1	4
Great black-backed gull	0.33	0.01	0.86	2	0	2	4
Lesser black-backed gull	0.39	0.55	0.49	2	2	1	5

8.4. Results of the year-1 monitoring in the Thorntonbank wind farm area

In 2008, C-Power started up the construction works in the wind farm area at the Thorntonbank (WFA-TTB). At the time of writing, six wind turbines are in place, of which two are in operation. Clearly, construction works were conducted at a relatively small scale, considering the fact that upcoming years another 54 wind turbines will be build. In this chapter, we investigated whether changes in seabird densities have already taken place, and if so, if these could be assigned to the construction activities in the wind farm area.

Based on the results in Table 5, we focus our results on 6 species of seabirds, namely Northern gannet, Little gull, Sandwich tern, Common tern, Common guillemot and Razorbill.

8.4.1. Species discussion

Northern gannet *(Morus bassanus)*

While densities in the WFA-TTB were almost halved, densities in the control area remained the same, suggesting a negative effect due to the construction of the windmills. In reality however, Northern gannets did not seem to bother much about the presence of the turbines, and more than once they were observed flying through the wind farm.

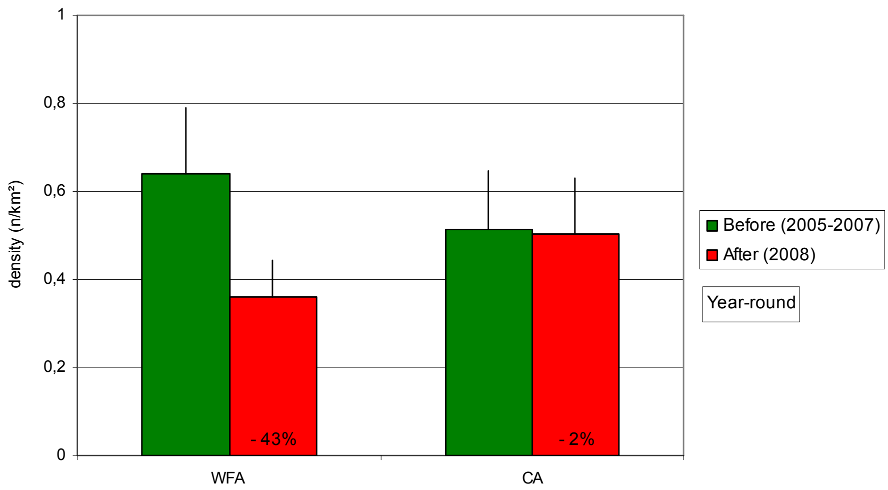


Figure 29. Comparison of the year-round densities of Northern gannet in the WFA-TTB and the CA-TTB during the reference period 2005-2007 and 2008 (+ std. error).

Little gull (*Larus minutus*)

Compared to the reference period, Little gull densities in the WFA-TTB were higher in 2008. However, a comparative change in densities has occurred in the control area, suggesting that in 2008, Little gulls were more common throughout the area.

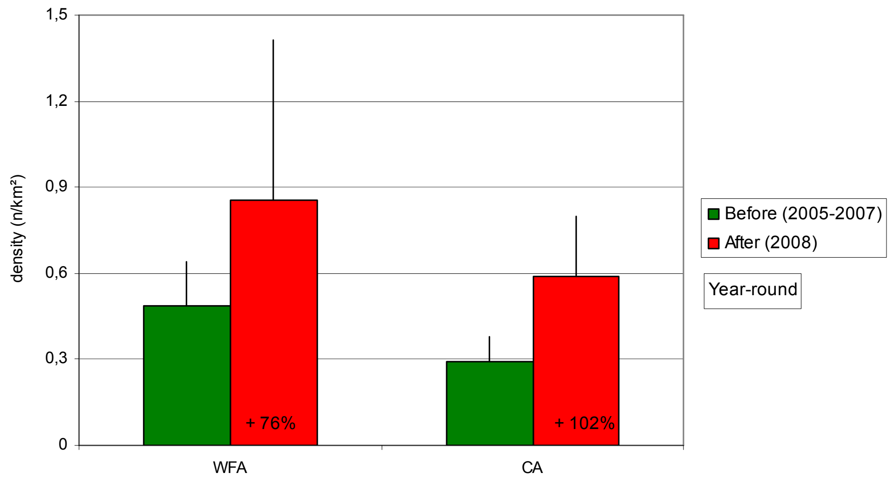


Figure 30. Comparison of the year-round densities of Little gull in the WFA-TTB and the CA-TTB during the reference period 2005-2007 and 2008 (+ std. error).

Sandwich tern (Sterna sanvicensis)

In the WFA-TTB as well as the CA-TTB, densities of Sandwich tern stayed more or less the same.

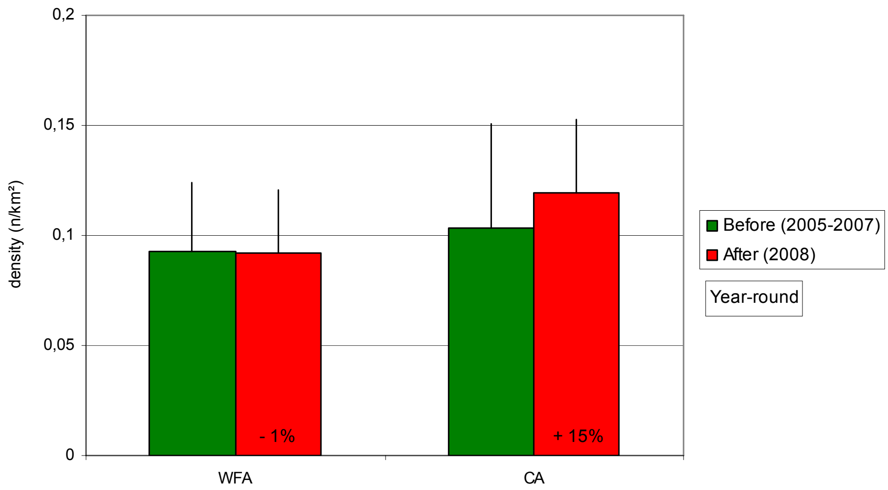


Figure 31. Comparison of the year-round densities of Sandwich tern in the WFA-TTB and the CA-TTB during the reference period 2005-2007 and 2008 (+ std. error).

Common tern (*Sterna hirundo*)

In 2008 densities in the WFA-TTB increased with a factor 5. The increased density in the WFA-TTB is due to a very high density of Common terns observed at one location in April 2008, and is probably rather coincidental. However much less dramatic, an increase in densities was noticed in de CA-TTB too.

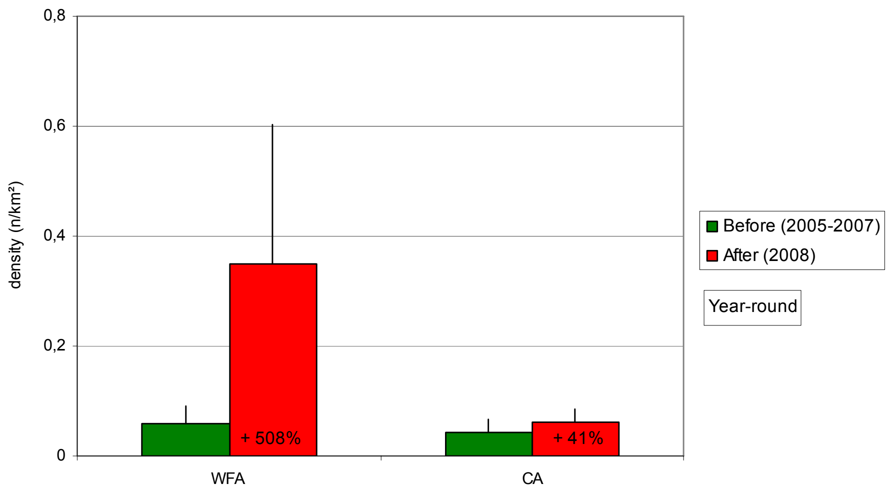


Figure 32. Comparison of the year-round densities of Common tern in the WFA-TTB and the CA-TTB during the reference period 2005-2007 and 2008 (+ std. error).

Common guillemot (*Uria aalge*)

Compared to the reference period, numbers of Common guillemot have dropped considerably in 2008. However, an equally dramatic change in densities has occurred in the CA-TTB, suggesting that the Common guillemot was far less common throughout the area as a whole. Hence, the drop in numbers can not be assigned to the construction of the first wind turbines.

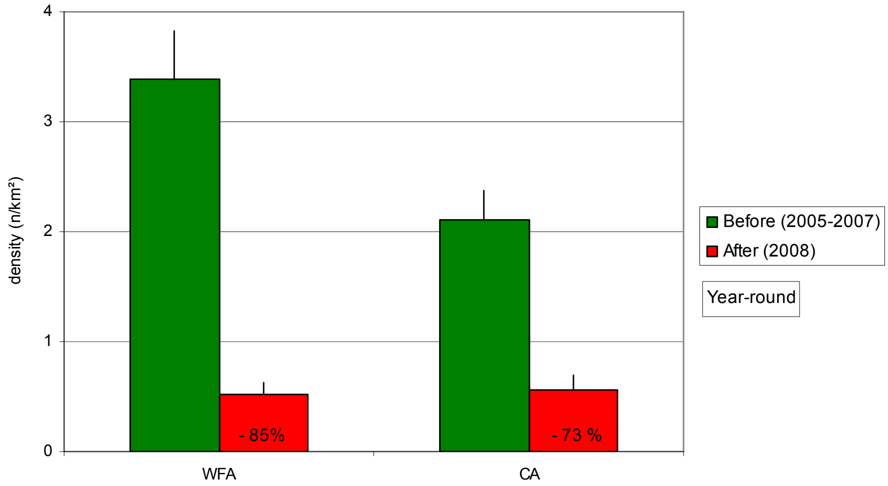


Figure 33. Comparison of the year-round densities of Common guillemot in the WFA-TTB and the CA-TTB during the reference period 2005-2007 and 2008 (+ std. error).

Razorbill (*Alca torda*)

The pattern in Razorbill shows strong comparison to that of its relative the Common guillemot, with a strong decrease in numbers in the WFA-TTB as well as in the CA-TTB.

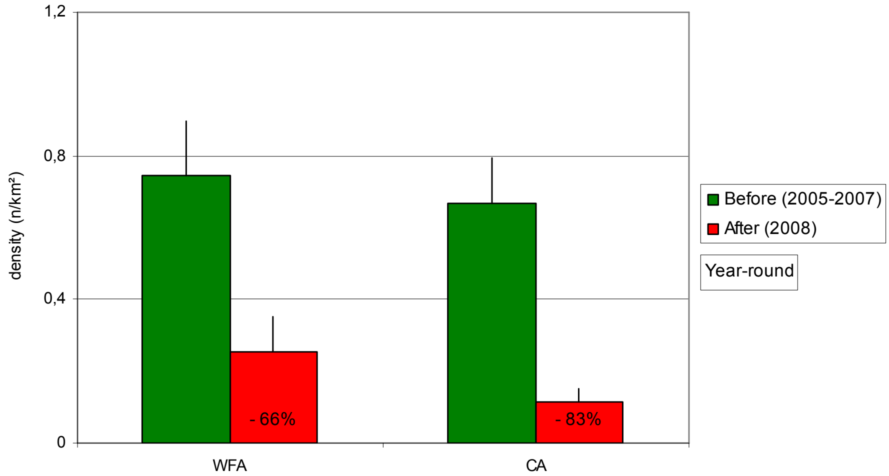


Figure 34. Comparison of the year-round densities of Razorbill in the WFA-TTB and the CA-TTB during the reference period 2005-2007 and 2008 (+ std. error).

8.4.2. Summary

Except for Sandwich tern there were clear changes in seabird densities in 2008 compared to the reference period. However, in the case of Little gull, Common guillemot and Razorbill, these changes must have taken place on a wider scale than the wind farm area since comparable changes were observed in the control area. Densities of Northern gannet in the WFA-TTB were almost halved which was not the case in the CA-TTB. Future monitoring must reveal if this decrease is in fact due to the presence of the wind farm. Contrastingly, densities of Common terns in the WFA-TTB increased strongly. This was due to a single observation and therefore should be considered with care.

Up until now, there was a major logistic shortcoming since it was prohibited to enter the wind farm itself. Resulting, the presented WFA-TTB densities reflect seabird presence in the immediate surroundings of the first wind turbines (buffer zone), rather than occurrence inside the wind farm. In terms of reliable monitoring, it is absolutely necessary that in coming years, we are allowed to enter the wind farm.

8.5. Avian importance of the Blighbank wind farm area

8.5.1. Introduction

In this chapter we discuss the ornithological importance of the future wind farm area at the Blighbank (BB). Before April 2008 very few information was available regarding seabird presence in this part of the BPNS. From April 2008 onwards however, the BB and its immediate surroundings were included in the monthly seabird counts performed by the Research Institute for Nature and Forest (INBO) (Figure 1). This discussion will include all available data up until December 2008.

To assess the relative importance of the future wind farm site at the BB, we compare the observed seabird densities in the area with the mean densities at the rest of the BPNS. Since there is substantial seasonal variation in numbers as well as species composition, the dataset was first split into seasons:

- Winter: December – February
- Spring: March – May
- Summer: June – August
- Autumn: September – November

Analogous to the methodology in Chapter 2, the 'impact area' (WFA-BB) corresponds to the wind farm area surrounded by a buffer zone of 3km. The width of this buffer zone was chosen based on literature research. Extensive radar and visual observation studies in Denmark and Sweden showed that migrating birds may already show avoidance behaviour from up to 3 km (Christensen *et al*. 2004, Kahlert *et al*. 2005, Pettersson *et al*. 2005). Hence, a buffer zone of 3 km around the wind farm area makes relatively sure that potential impacts are limited to this zone exclusively. Thereafter, the BPNS was overlaid by a grid of 2x2 km cells. Every grid cell overlapping for at least one third of its surface with the impact area was assigned to the subzone WFA-BB, while all grid cells with their centroid within the boundaries of the Belgian part of the North Sea were assigned to the subzone BPNS (Figure 35). The mean densities in the WFA-BB and the BPNS were calculated by first calculating the mean for each grid cell, before calculating the means per subzone. This way, we compensated for the skewed counting effort throughout the area. Take notice of the fact that part of the WFA-BB falls on Dutch territorial waters. In this part of the WFA-BB very few counts took place since counts were only to be conducted on Belgian territory.

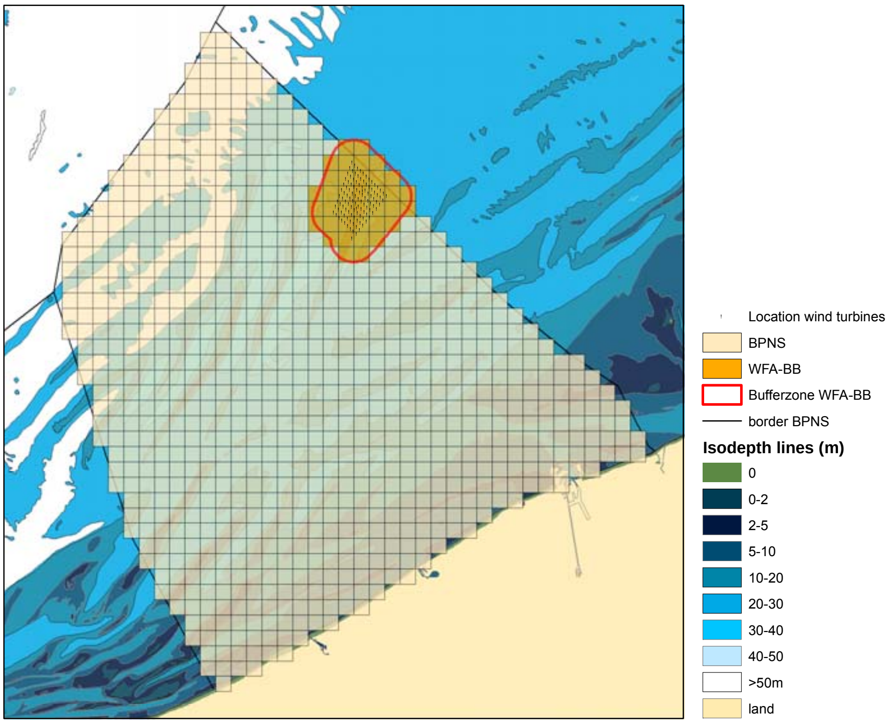


Figure 35. Grid of 2x2 km cells used as a base for comparison of seabird densities in the impact area WFA-BB and the BPNS.

8.5.2. Seabird densities at the Blighbank

8.5.2.1. General

Throughout the year, mean densities in the WFA-BB never exceed those on the BPNS as a whole (Figure 36). During spring and summer months, densities in the WFA-BB are very low. This is not surprising since that time of year, the seabird community is largely dominated by coast bound species like gulls and terns. In contrast, densities are relatively high during autumn and especially winter, when the area holds seabird densities of respectively 5 and 8 birds per km².

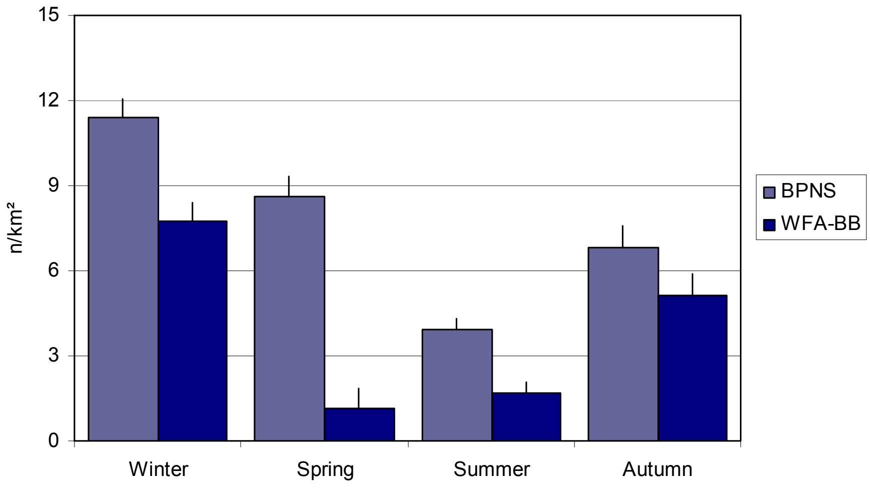


Figure 36. Seabird densities (n/km²) at the WFA-BB compared to the BPNS as a whole.

Figure 37 shows the composition of the seabird community in the WFA-BB (compare with Figure 4). The species composition is generally spoken less rich compared to that on the BPNS. Inshore birds like Common scoter, Great crested grebe and Black-headed gull are completely absent in the impact area. Other inshore birds like terns and divers were observed occasionally, but in much lower densities compared to the inshore zone.

Diversity is at its highest during winter months, when Northern gannet, Kittiwake, Common guillemot and several species of gull dominate the seabird community. In spring, the seabird densities are generally low, but small numbers of Little gull, Common guillemot and Lesser black-backed gull occur. Densities remain low during the course of summer, with Lesser black-backed gull being the most common species. In autumn, large numbers of 'true' seabirds arrive and migrate through, especially Black-legged kittiwake and Northern gannet.

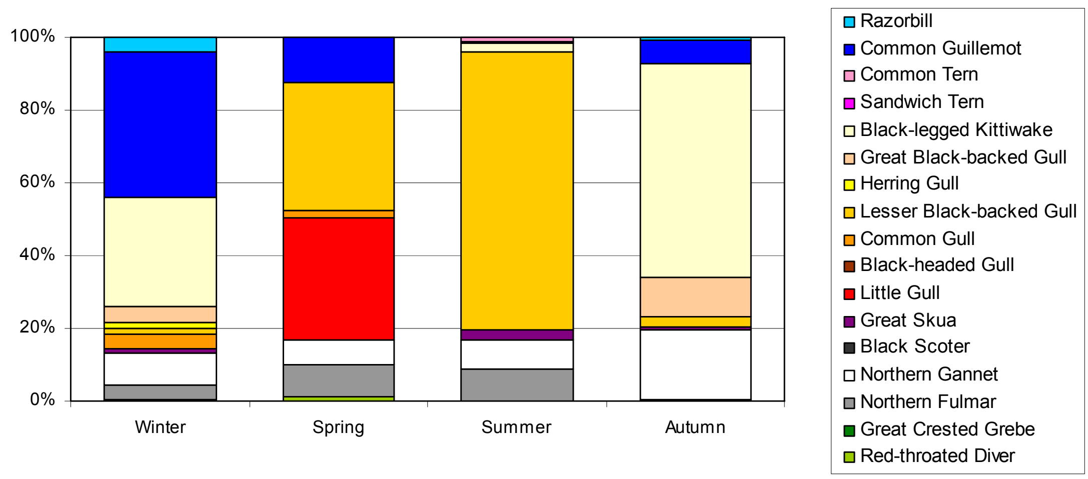


Figure 37. Seasonal variation in seabird community (blue = auks; pink = terns; yellow-red = gulls; purple = Great skua; black = Common scoter; white = Northern gannet; grey = Northern fulmar; green = divers & grebes).

Table 6 compares seasonal densities in the WFA-BB and the BPNS. Seen its far shore location, the WFA-BB is of no importance to divers, grebes, scoters and terns. Six seabird species do occur in relatively high densities, namely Northern gannet, Great skua, Little gull, Lesser black-backed gull, Black-legged kittiwake and Common guillemot. These are discussed in detail in §8.5.2.2.

Table 6
Seasonal bird densities (n/km²) in the future wind farm area at the Blighbank (WFA-BB) compared to densities at the BPNS as a whole (1992-2008). (species marked in bold meet one of following criteria: density in the WFA exceeds 1 bird/km² during one or more seasons; density in the WFA exceeds 0,25 bird/km² during one or more seasons in case of a protected species (*); WFA-density is at least 50% higher than the BPNS-density)

	Winter		Spring		Summer		Autumn	
	WFA-BB	BPNS	WFA-BB	BPNS	WFA-BB	BPNS	WFA-BB	BPNS
Number of grid cells	27	778	17	676	25	642	29	736
Red-throated diver	0,02	0,23	0,01	0,03	0,00	0,00	0,00	0,04
Great crested grebe	0,00	0,46	0,00	0,04	0,00	0,00	0,00	0,05
Northern fulmar	0,31	0,43	0,10	0,25	0,15	0,14	0,02	0,51
Northern gannet	0,67	0,42	0,08	0,27	0,14	0,13	0,98	1,02
Common scoter	0,00	0,53	0,00	0,78	0,00	0,04	0,00	0,08
Great skua	0,10	0,01	0,00	0,01	0,05	0,03	0,04	0,05
Little gull*	0,00	0,17	0,38	0,70	0,00	0,03	0,00	0,25
Common gull	0,32	1,24	0,02	0,53	0,00	0,01	0,01	0,26
Lesser black-backed gull	0,12	0,27	0,40	3,00	1,29	1,89	0,13	0,95
Herring gull	0,13	0,63	0,00	0,98	0,00	0,56	0,00	0,51
Great black-backed gull	0,34	1,12	0,00	0,15	0,00	0,05	0,56	0,70
Black-legged kittiwake	2,31	1,87	0,00	0,38	0,05	0,04	2,99	1,22
Sandwich tern*	0,00	0,00	0,00	0,15	0,01	0,23	0,00	0,01
Common tern*	0,00	0,00	0,00	0,26	0,02	0,64	0,00	0,02
Common guillemot	3,10	3,26	0,14	0,88	0,00	0,01	0,34	0,80
Razorbill	0,30	0,67	0,00	0,13	0,00	0,00	0,04	0,20

8.5.2.2. Species discussion

Northern gannet (*Morus bassanus*)

Densities at the BPNS peak in October – November, and resulting, the BPNS holds a mean of 1.02 gannets per km² during autumn. Meanwhile, the WFA-BB holds a corresponding number of Northern gannets (0.98 ind./km²). During winter, the density of Northern gannets in the WFA-BB (0.67 ind./km²) exceeds the BPNS density (0.42 ind./km²).

The distribution maps in Figure 39 & Figure 40 show that Northern gannets generally occur homogenously dispersed outside the near shore zone, with a concentration around the Hinderbanken. Considering this, the WFA-BB cannot be designated as being particularly important to this species.

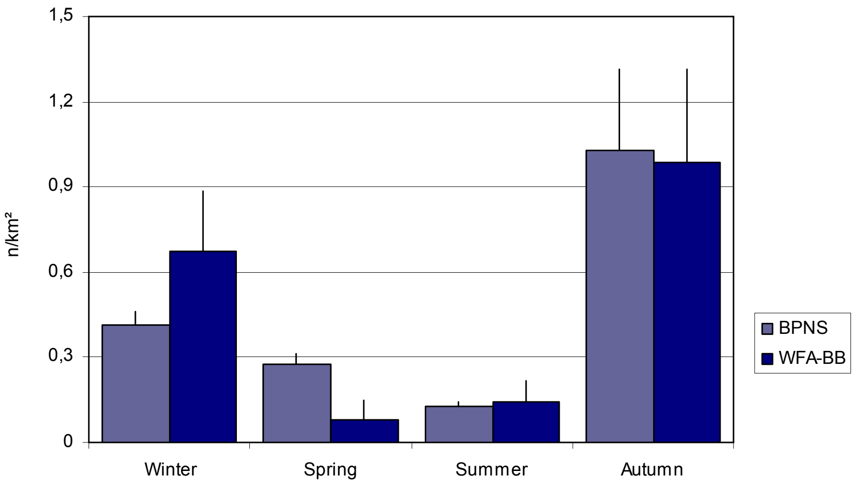


Figure 38. Seasonal densities of Northern gannet in the BPNS and in the WFA-BB (+ std. error).

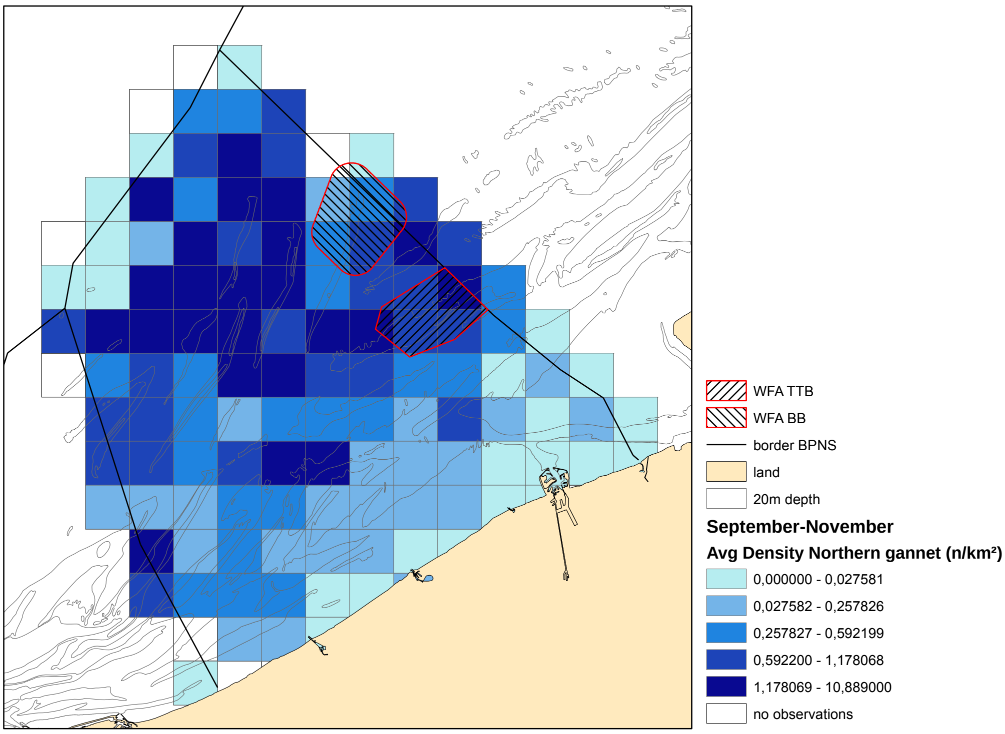


Figure 39. Autumn distribution of Northern gannet in the BPNS.

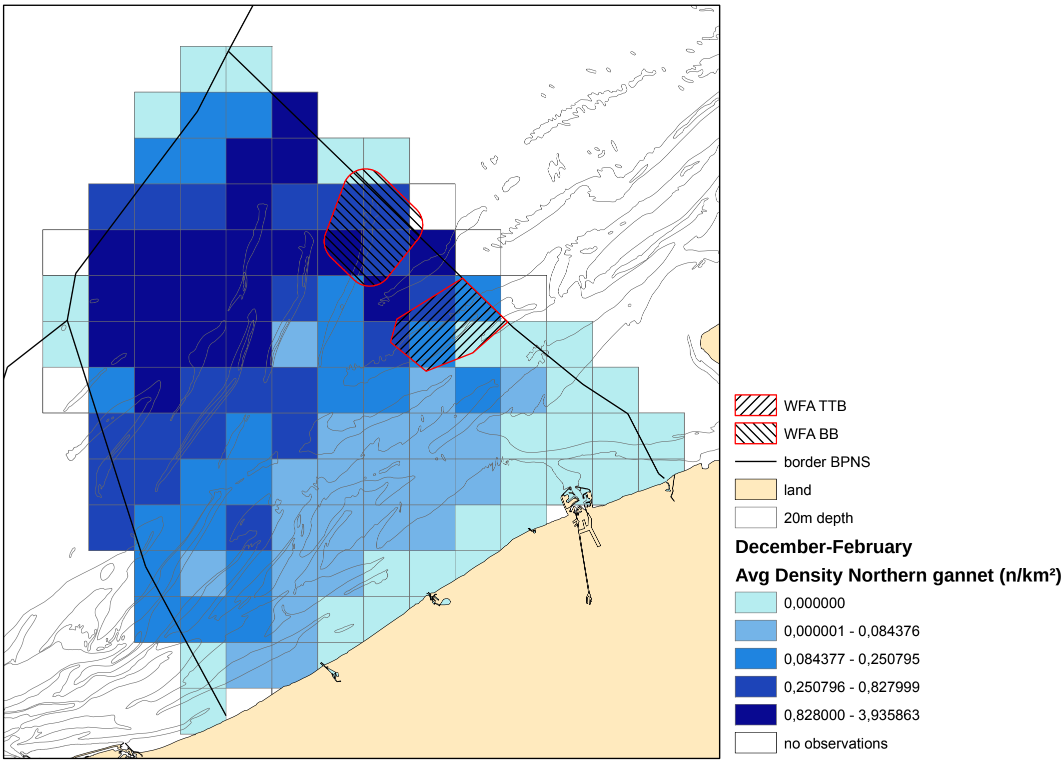


Figure 40. Winter distribution of Northern gannet in the BPNS.

Great skua (Stercorarius skua)

Great skuas occur in low to very low densities throughout the BPNS. It is most common during autumn, with a mean of 0.05 individuals per km². At the WFA-BB, this rare and vulnerable species is present in increased numbers during winter and summer, when it holds a mean of 0.10 and 0.05 individuals per km² respectively.

The winter distribution map (Figure 42) shows that Great skuas are concentrated in two areas, one in the southwest of the BPNS (Vlaamse banken) and one in and around the WFA-BB. Because of this, we will pay careful attention to the occurrence of Great skuas in the WFA-BB in future monitoring years.

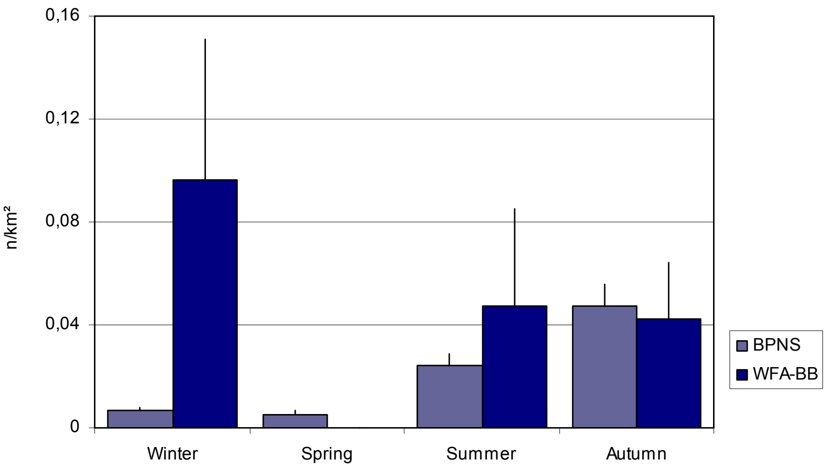


Figure 41. Seasonal densities of Great skua in the BPNS and the WFA-BB (+ std. error).

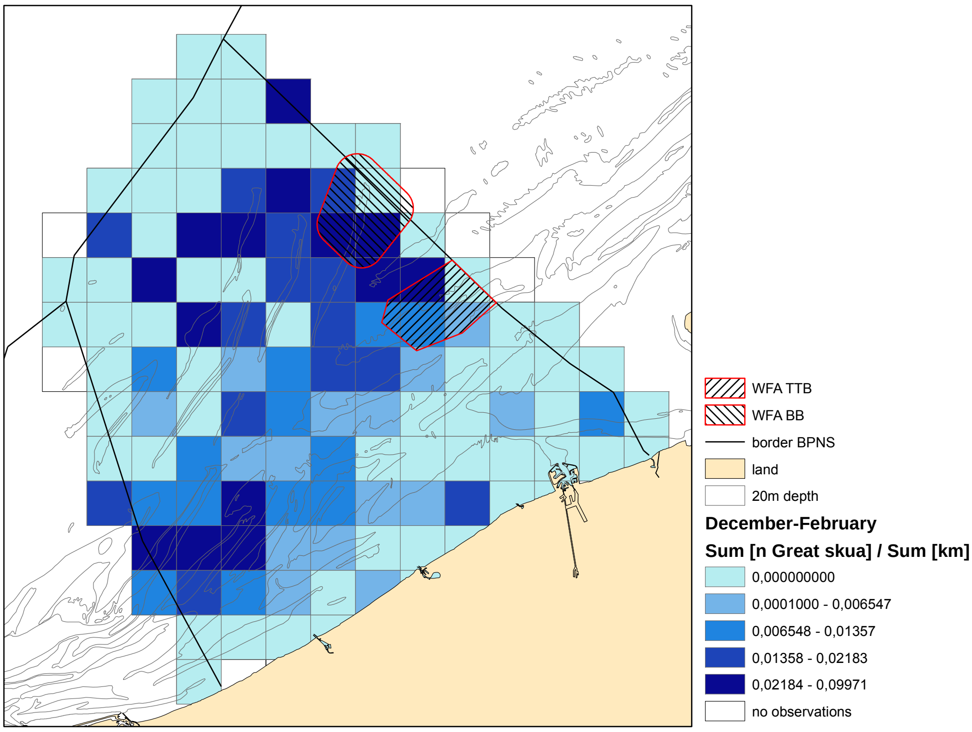


Figure 42. Numbers of observed Great skuas per km sailed (n/km) during winter months.

Little gull (*Larus minutus*)

At the BPNS, Little gulls are present almost year round, with marked seasonal variation. Highest densities are present during spring and autumn migration periods, mainly in April and September. Mean seasonal density reaches 0.70 individuals per km² during spring months. During the same period, the mean density at the WFA-BB amounts up to 0.38 individuals/km². Apparently this protected species migrates through the area during spring.

The spring distribution map (Figure 8) however shows that migration is mainly confined to a 40km wide band along the coast and the WFA-BB is located just outside this migration corridor. Nevertheless, considering the species' protection status, the occurrence of Little gulls in the WFA-BB will be further monitored.

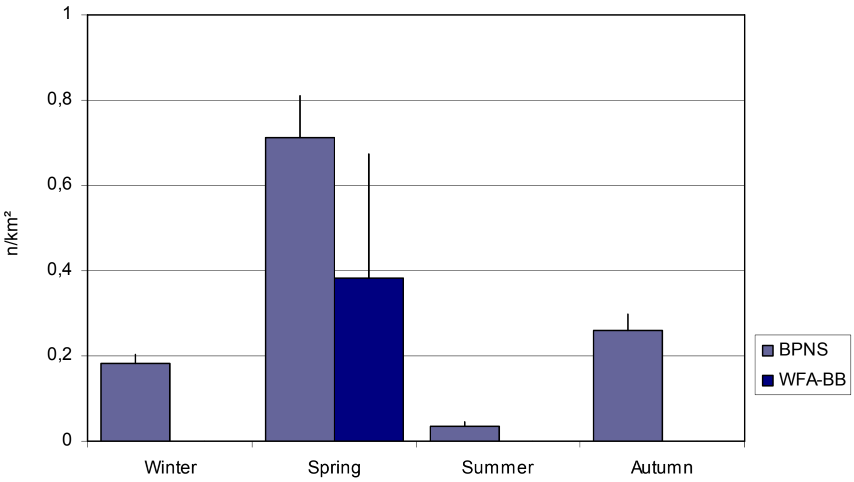


Figure 43. Seasonal densities of Little gull in the BPNS and the WFA-BB (+ std. error).

Lesser black-backed gull (*Larus fuscus*)

This gull species is the most common seabird at the BPNS during spring and summer, with mean densities of more than 3.0 birds per km². The species is less coast bound compared to the closely related Herring gull, and especially during spring migration Lesser black-backed gulls occur widespread across the BPNS. The WFA-BB holds relatively high densities during summer with a maximum density of 1.29 birds per km². The WFA-BB appears to be located right on the edge of the species' main summer distribution within 40km from the coast (Figure 45). However, the densities in the WFA-BB never exceed those on the BPNS as a whole, and the area cannot be considered to be of particular value to this species.

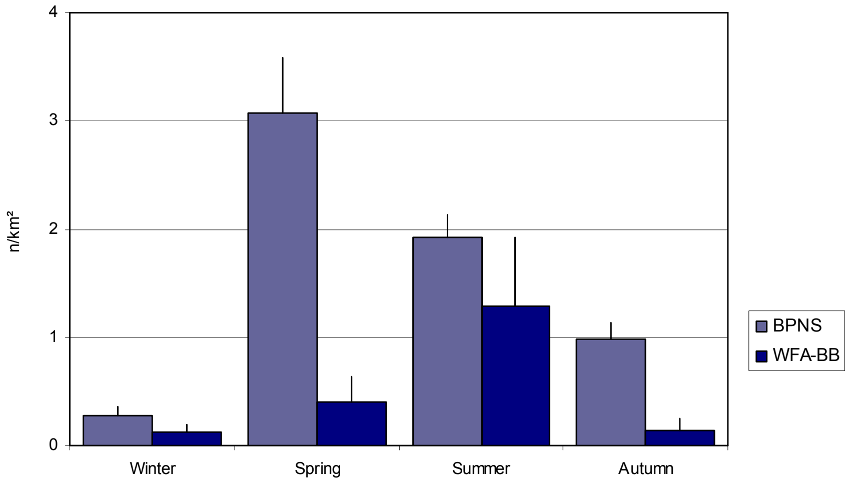


Figure 44. Seasonal densities of Lesser black-backed gull in the BPNS and the WFA-BB (+ std. error).

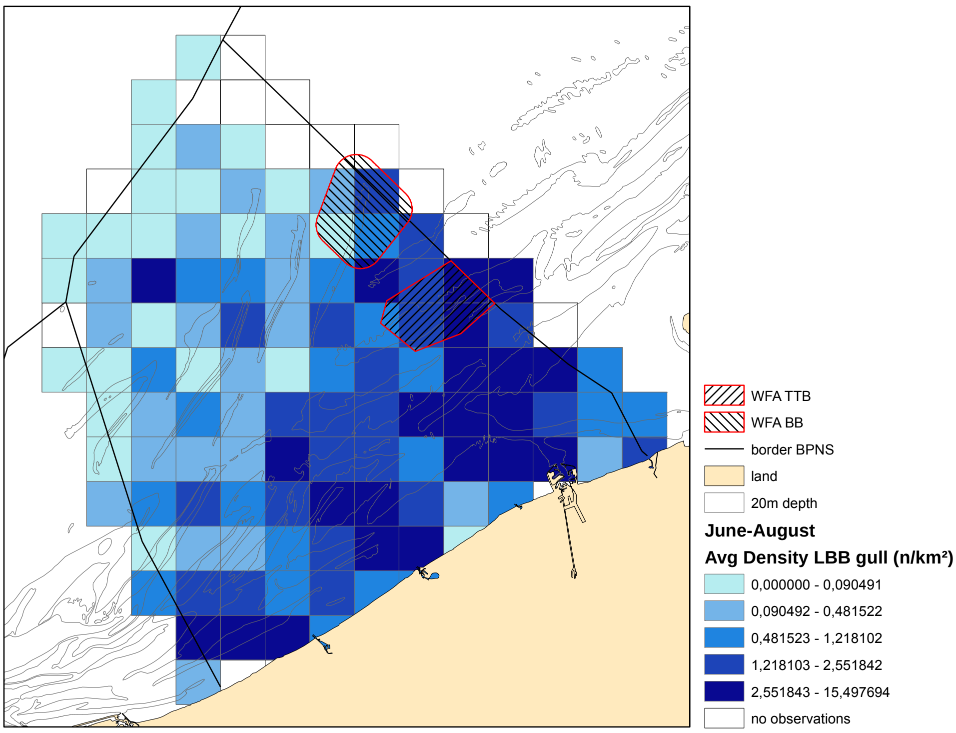


Figure 45. Summer distribution of Lesser black-backed gull in the BPNS.

Black-legged kittiwake (*Rissa tridactyla*)

This offshore species is present at the BPNS in highest numbers during autumn and winter (respectively 1.31 and 1.87 individuals per km²). While during winter, corresponding numbers are present in the WFA-BB and the BPNS, Black-legged kittiwakes appear to be much more common in the WFA-BB during autumn.

Based on the distribution maps in Figure 47 & Figure 48, Black-legged kittiwakes occur relatively homogenously dispersed outside the near shore zone, and the WFA-BB cannot be acknowledged to be more important compared to other offshore areas. Therefore, the WFA-BB is of no particular value to this species.

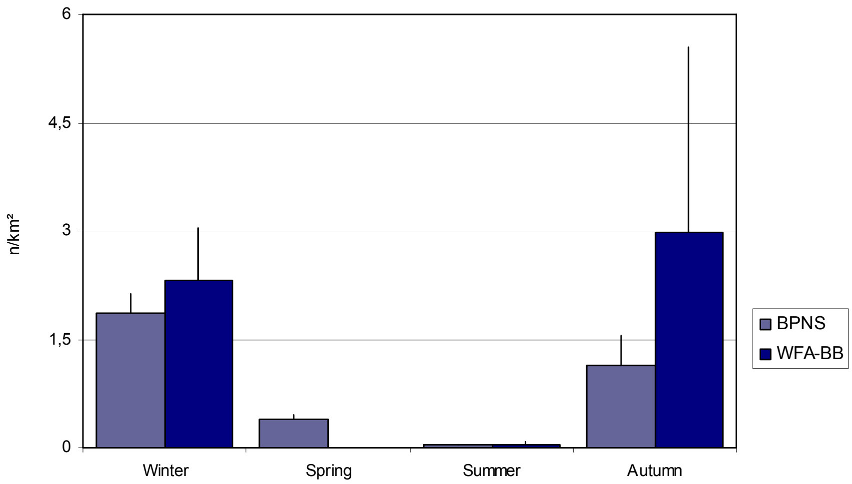


Figure 46. Seasonal densities of Black-legged kittiwake on the BPNS and the WFA-BB (+ std. error).

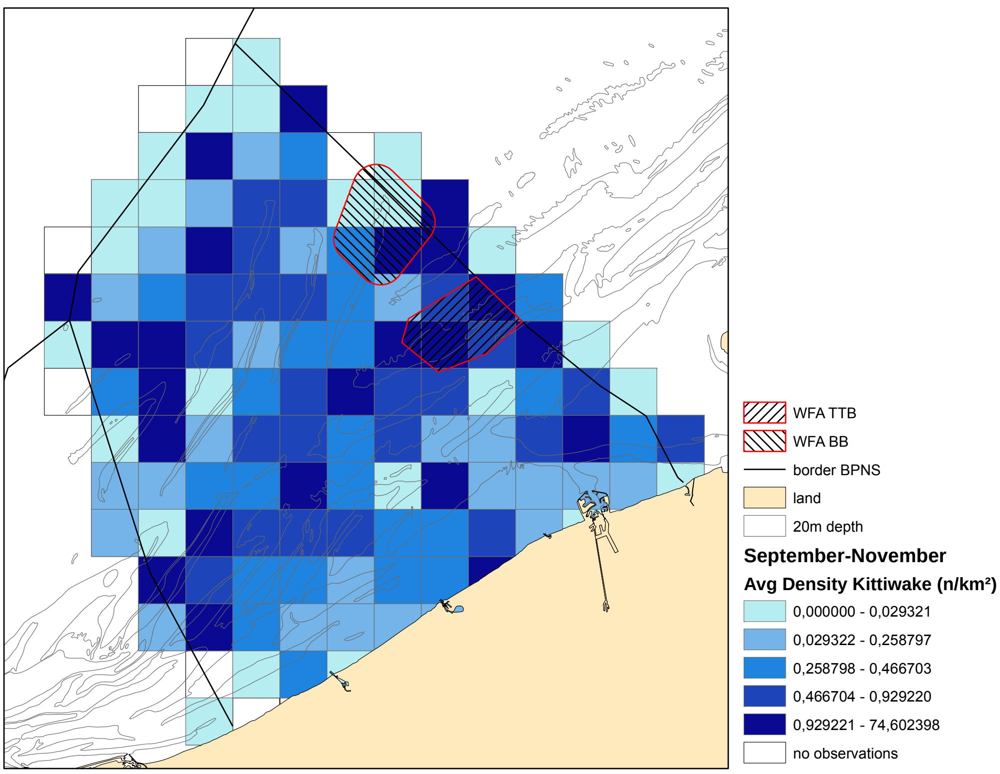


Figure 47. Autumn distribution of Black-legged kittiwake on the BPNS.

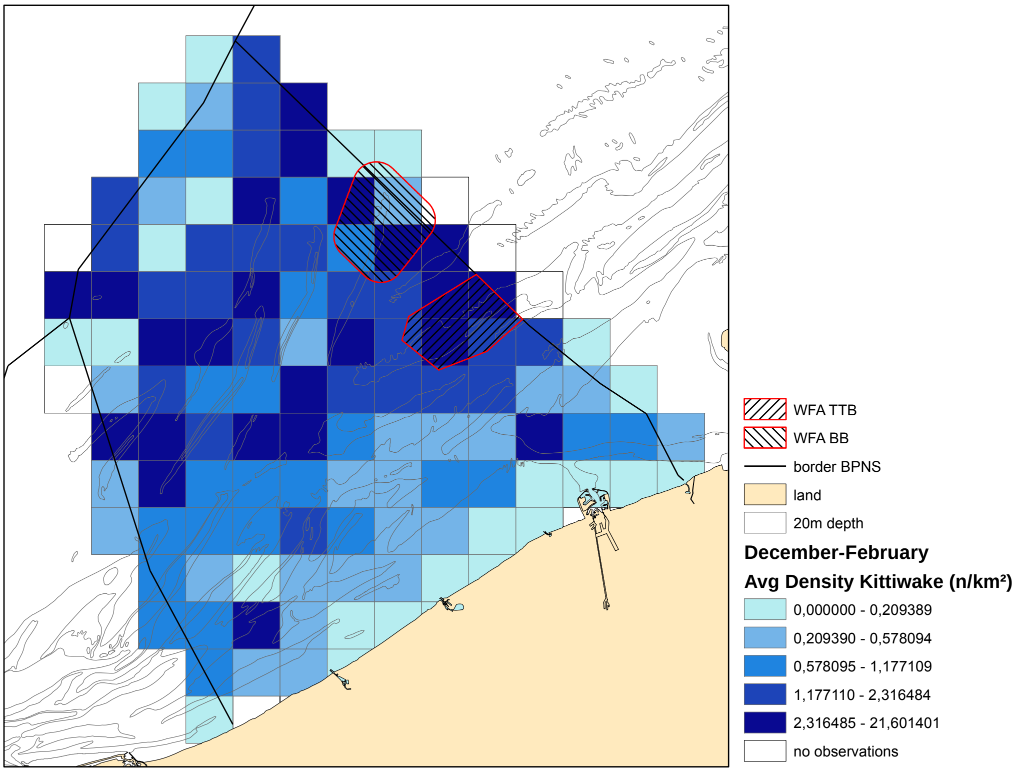


Figure 48. Winter distribution of Black-legged kittiwake on the BPNS.

Common guillemot (*Uria aalge*)

With a mean density of 3.26 individuals per km², the Common guillemot is the most common seabird at the BPNS during winter. The species is almost equally common at the WFA-BB, with a mean winter density of 3.10 Common guillemots per km².

Apart from the near shore zone east of Ostend, Common guillemots occur homogenously spread throughout the BPNS in moderately high to high densities. Based on the observed densities and the distribution pattern displayed in Figure 50, the WFA-BB cannot be assigned as being of particular importance to this species. Its high winter densities do make Common guillemot a suitable monitoring species.

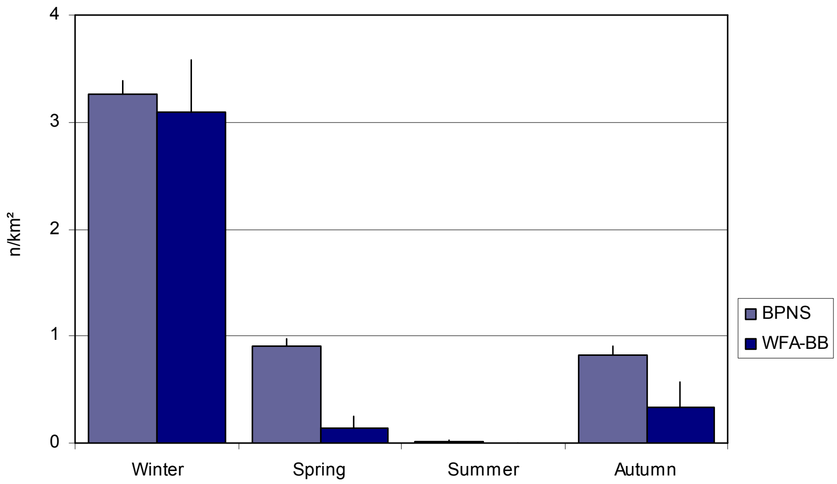


Figure 49. Seasonal densities of Common guillemot on the BPNS and the WFA-BB (+ std. error).

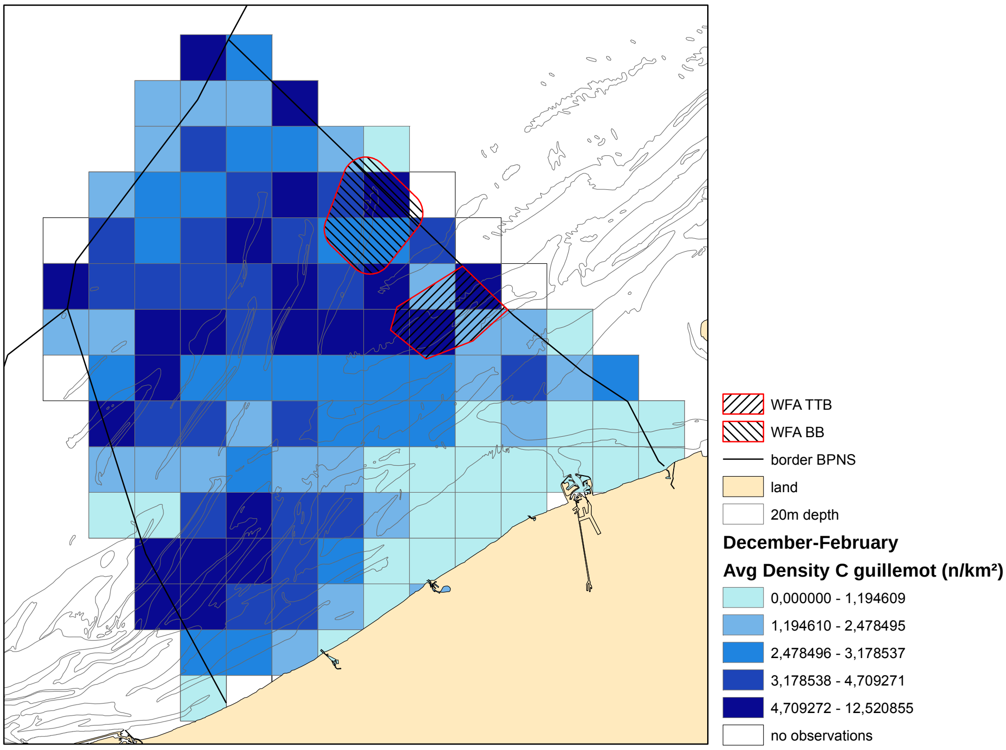


Figure 50. Winter distribution of Common guillemot on the BPNS.

8.5.2.3. Conclusions

Based on the previous discussion we conclude that:

The WFA-BB is of no particular value to Red-throated diver, Great crested grebe, Northern fulmar, Common scoter, Common gull, Herring gull, Great black-backed gull, Sandwich tern, Common tern and Razorbill

The WFA-BB is not particularly valuable to the following species, although increased or high densities may occur: Northern gannet, Lesser black-backed gull, Black-legged kittiwake, Common guillemot

→ Considering their high densities in the reference period, these species are well suitable for monitoring regarding displacement effects by the future wind farm

The WFA-BB is probably of particular value to Great skua and Little gull

→ Future monitoring is needed to assess the actual value of the WFA-BB to these species. To accurately assess possible effects of the future wind farm, migration behaviour and occurrence of these birds in the WFA-BB needs to be investigated in detail. Research should also focus on displacement through avoidance behaviour, as well as migration flux and collision risk.

8.6. Control area Blighbank

8.6.1. Introduction

To accurately assess the impact of human structures at sea, it is not sufficient to perform a before-after comparison. Ideally, the changes in the impact area are put in perspective by comparing these with possible changes in a control area. Naturally, changes in bird community and densities are not necessarily induced by local changes in the marine environment, and might as well be induced by larger scale processes. Such large scale events include temporary influxes of seabirds due to specific weather conditions or food availability elsewhere, as well as changes in population level.

In this chapter we will delineate a suitable control area (CA-BB) for the future wind farm at the Blighbank (WFA-BB). Analogous to earlier analyses performed for the Thorntonbank (Vanermen *et al*. 2006), we took in account a buffer area of 3km surrounding the future turbines. Extensive radar and visual observation studies in Denmark and Sweden showed that migrating birds may already show avoidance behaviour from up to 3km (Christensen *et al*. 2004, Kahlert *et al*. 2005, Pettersson *et al*. 2005). Hence, a buffer zone of 3km ensures that potential impacts are largely restricted to this zone. During all seasons, the bird densities in the CA-BB have to correspond as much as possible to those in the WFA-BB. In Vanermen *et al*. (2006), a control area (CA-TTB) for the wind farm area at the Thorntonbank (WFA-TTB) was already delineated. To this end, avian occurrence at the Thorntonbank was compared with 13 areas of equal depth, by visually interpreting graphs displaying seasonal bird densities and bird community, supported by several statistical analysis (cluster analysis, correspondence analysis and TWINSPAN). Based on the results obtained during this study, and taking in consideration several logistical and practical aspects, we are now able to simplify this process. Hence, two possible areas are proposed. Naturally, it would be very practical if the current CA-TTB could serve as a control area for the WFA-BB as well. On the other hand, when we compare the results of the reference situation of the marine avifauna in the WFA-BB (see Chapter 5) with the results in Vanermen *et al*. (2006), we expect the bird community to be more closely related to that of the far shore community of the Hinderbanken. Therefore, an area adjacent to the CA-TTB was delineated including the remaining part of the Blighbank itself and the nearby sandbank Oosthinder (Figure 51).

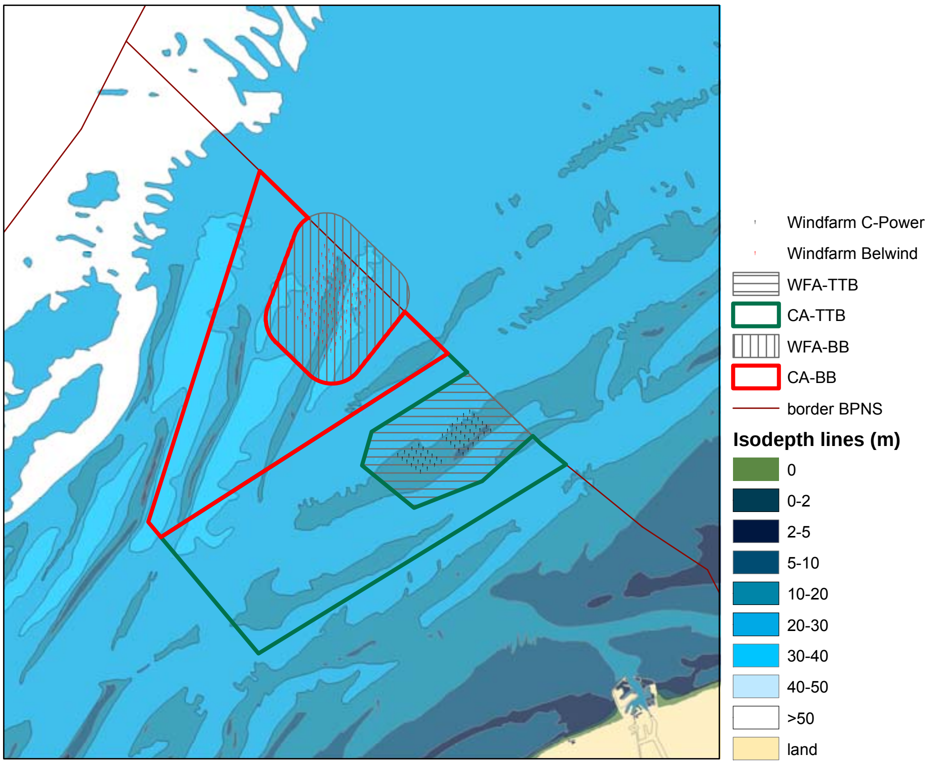


Figure 51. Proposed control areas for the future wind farm area at the Blighbank (WFA-BB).

8.6.2. Results

8.6.2.1. Seabird community

Since seabird densities in the WFA-BB are generally very low during spring and summer (see §8.5.2.4.1), this section will mainly focus on winter and autumn densities.

During winter, seabird composition in the WFA-BB is most comparable to the near CA-BB (Figure 52). These areas hold corresponding numbers of Northern gannets, Northern fulmars, Black-legged kittiwakes and auks. Densities in the CA-TTB are twice those observed in the WFA-BB. This is mainly due to a higher abundance of gulls (Black-legged kittiwake, Great black-backed gull, Common gull).

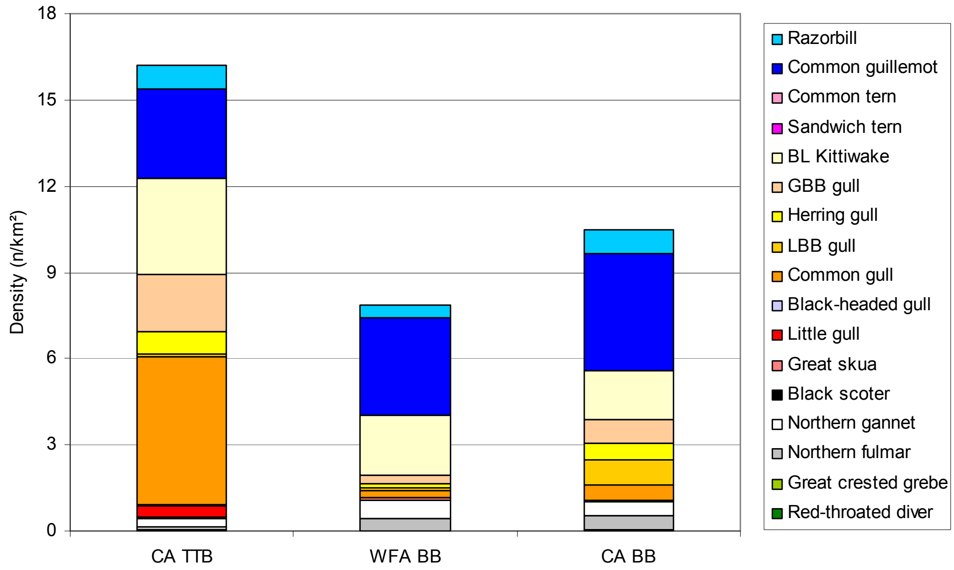


Figure 52. Winter densities of seabirds in the future wind farm area at the Blighbank (WFA-BB) and two proposed control areas CA-TTB and CA-BB.

During autumn, the seabird community in the WFA-BB is dominated by Northern gannets, Great black-backed gulls and Black-legged kittiwakes. Unfortunately, there is poor correspondence with both proposed control areas.

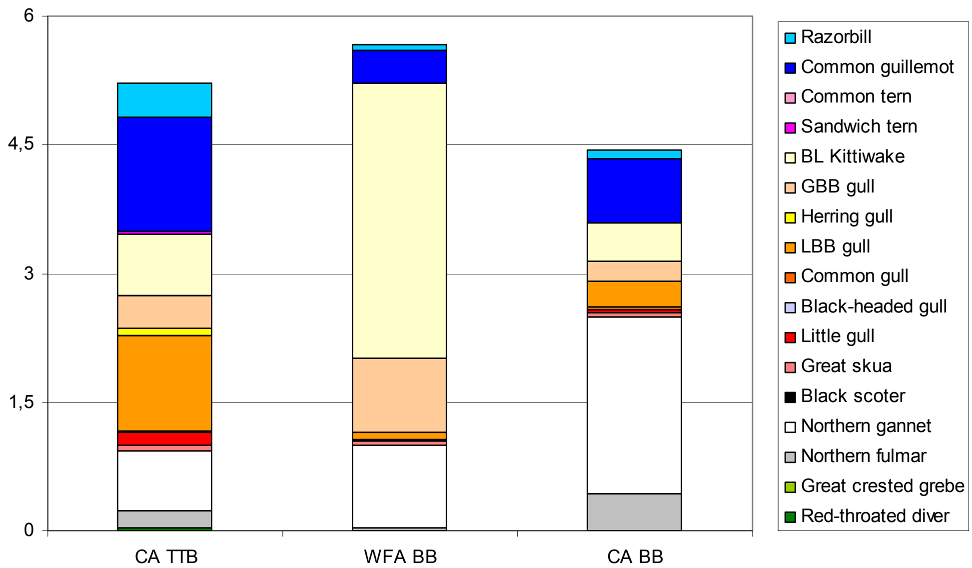


Figure 53. Autumn densities of seabirds in the future wind farm area at the Blighbank (WFA-BB) and two proposed control areas CA-TTB and CA-BB.

8.6.2.2. Species discussion

Northern gannet (*Morus bassanus*)

There is poor agreement in densities between the WFA-BB and both proposed control areas. In general, the species is most common during autumn, when densities in the WFA-BB correspond most to those in the CA-TTB. Regarding winter densities however, the WFA-BB shows more agreement with the CA-BB.

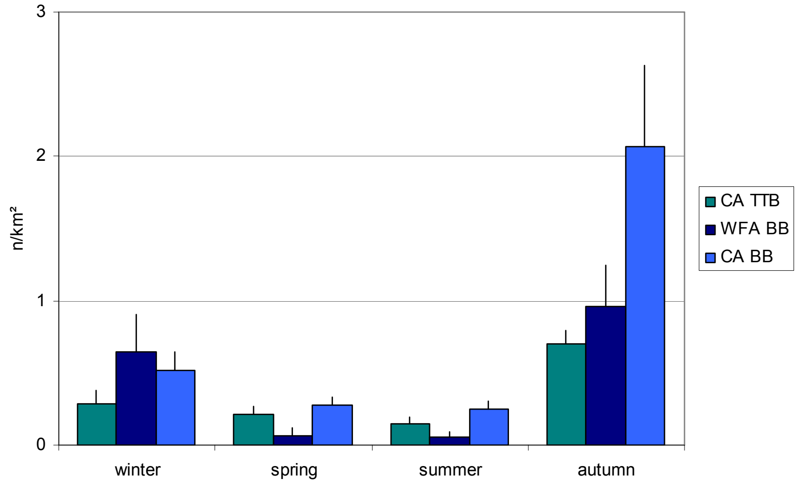


Figure 54. Seasonal densities of Northern gannet in the WFA-BB, CA-TTB & CA-BB (+ std. error).

Great skua (Stercorarius skua)

In winter, the WFA-BB holds a high density of Great skuas, which is almost six times higher than in the proposed control areas. Rare species are difficult to monitor, since encounters are more coincidental compared with common species, often resulting in skewed results. During summer and autumn however, almost equal densities of Great skua occur in the WFA-BB and the CA-BB. Based on these well corresponding numbers, the CA-BB seems most suitable as a control area for the WFA-BB.

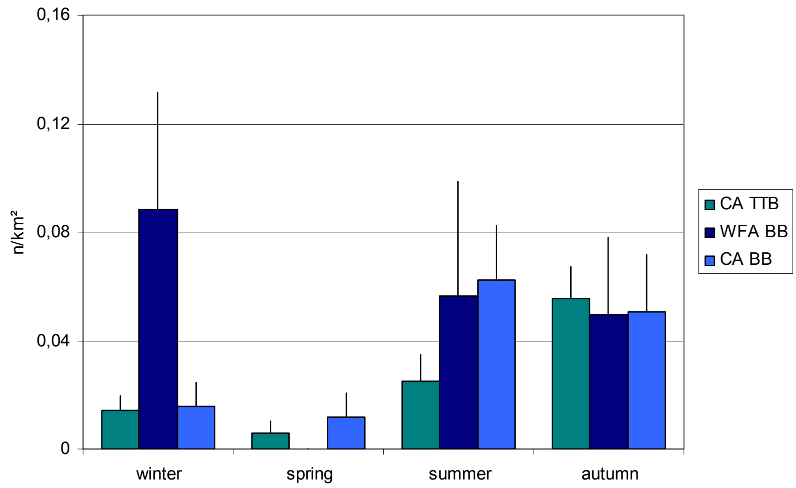


Figure 55. Seasonal densities of Great skua in WFA-BB, CA-TTB & CA-BB (+ std. error).

Little gull (*Larus minutus*)

As can be deducted from Figure 7 to Figure 9, Little gulls are mainly confined to a 40km wide band along the coast. Both the WFA-BB and CA-BB are located just outside this distribution range, and resulting, Little gulls are much more common in the CA-TTB (Figure 56). Hence, the CA-BB is most suitable as a control area for the WFA-BB.

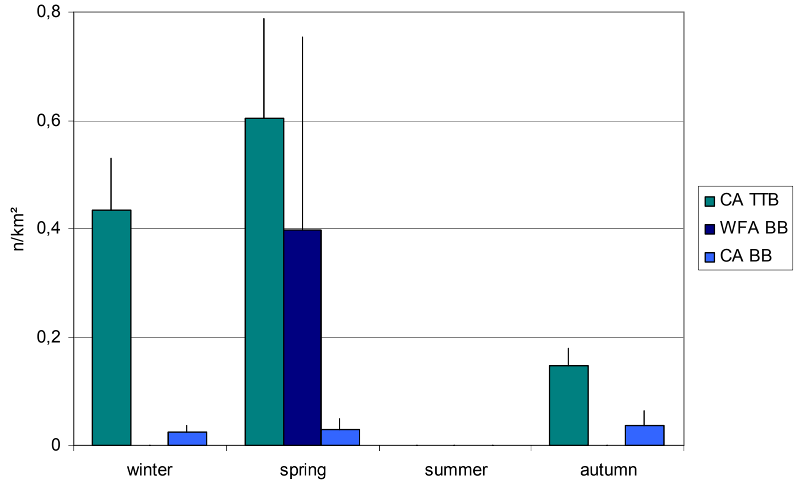


Figure 56. Seasonal densities of Little gull in the WFA-BB, CA-TTB & CA-BB (+ std. error).

Lesser black-backed gull (*Larus fuscus*)

Except for winter, the CA-TTB holds much higher densities of Lesser black-backed gull compared to the WFA-BB and CA-BB. To this species also, the CA-BB is most suitable as a control area.

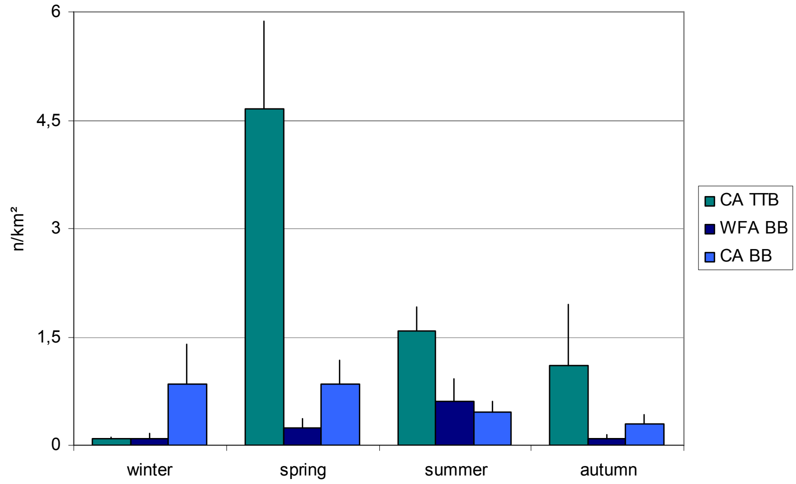


Figure 57. Seasonal densities of Lesser black-backed gull in the WFA-BB, CA-TTB & CA-BB (+ std. error).

Black-legged kittiwake (*Rissa tridactyla*)

During winter, the WFA-BB and CA-BB hold well corresponding densities of Black-legged kittiwake. Meanwhile the species is almost twice as common in the CA-TTB. In autumn, a highly increased density of kittiwakes occurs in the WFA-BB, which is due to one observation of a very a large number of birds in the transect, associated with a fishing vessel. Aggregated occurrence may result in strongly skewed data, as is the case here. Based on the winter occurrence however, the CA-BB seems of slightly higher suitability than the CA-TTB.

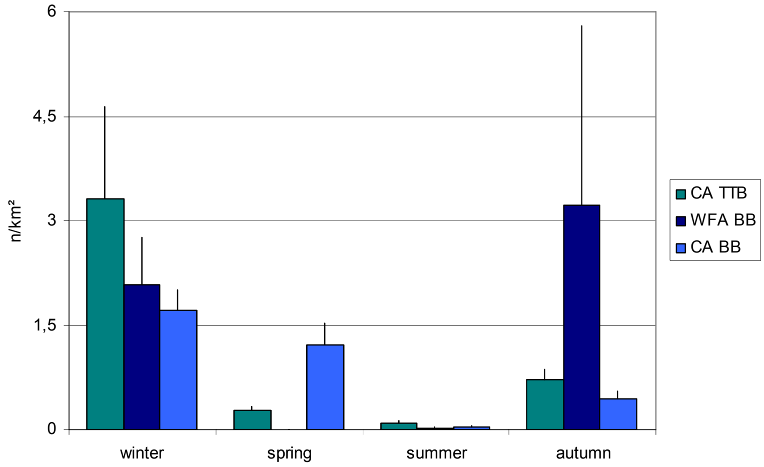


Figure 58. Seasonal densities of Black-legged kittiwake in the WFA-BB, CA-TTB & CA-BB (+ std. error).

Common guillemot (*Uria aalge*)

The winter density of Common guillemot in the WFA-BB corresponds well to those in proposed control areas. During spring and autumn, observed densities in the WFA-BB were clearly lower than in the CA-TTB and CA-BB. Based on these results both areas seem suited.

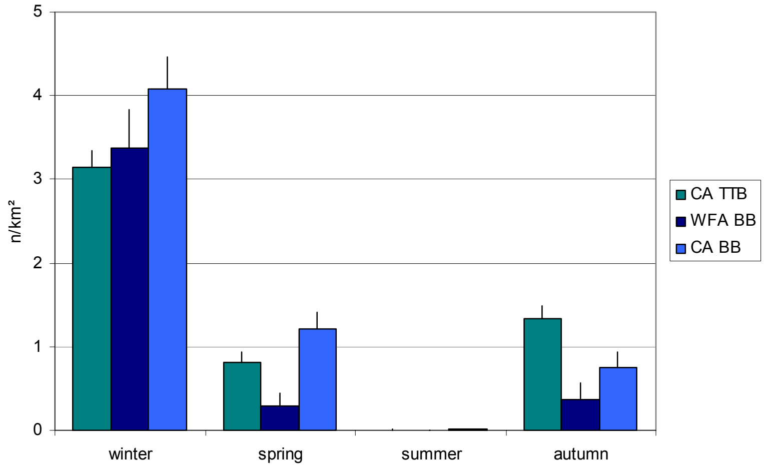


Figure 59. Seasonal densities of Common guillemot in the WFA-BB, CA-TTB & CA-BB (+ std. error).

8.6.2.3. Conclusion

In Chapter 5 it was concluded that six species of seabird occur in high or increased densities in the WFA-BB. In this chapter these species' seasonal densities in the WFA-BB were compared to those in two proposed control areas. Based on a visual interpretation of the graphs displayed in the above paragraphs, the CA-BB seems slightly more suitable than the CA-TTB. To provide a more objective measure for equality, the differences in seasonal bird densities between the WFA-BB and both proposed control areas were summed (Table 7).

The numbers in the first 2 columns in Table 7 represent the sum of the absolute differences in (relevant) seasonal densities in the WFA-BB on the one hand and both control areas on the other hand. The last two columns provide a standardised measure, which equals the weighted mean of the proportional differences in seasonal densities. Either way, absolute as well as standardized differences in bird densities are in favour of the control area CA-BB including the 'Oosthinderbank' and the 'Blighbank'.

Table 7
Differences in seabird densities between the WFA-BB on one hand and CA-TTB and CA-BB on the other hand.

Species	Seasons	CA-TTB	CA-BB	CA-TTB	CA-BB
		Sum absolute difference		Standardized difference	
Nothern gannet	Autumn / Winter	0.62	1.24	0.38	0.77
Great skua	Winter / Summer / Autumn	0.11	0.08	0.57	0.41
Little gull	Autumn / Winter / Spring	0.79	0.43	0.51	0.92
Lesser black-backed gull	Spring / Summer	5.39	0.75	6.38	0.88
Black-legged kittiwake	Spring / Summer	3.73	3.15	0.70	0.59
Common guillemot	Autumn / Winter	1.19	1.08	0.32	0.29
Total		11.82	6.72	8.87	3.87

8.7. Collision risk migrating seabirds

In this chapter we will model the expected number of collision fatalities among seabirds at the Thorntonbank wind farm. First, we present the results of the flying height assessments. Clearly, the number of victims through collision depends on the proportion of birds flying at rotor height, which is strongly species-specific. Secondly, since the number of collisions is positively correlated to the number of flight movements we estimated the flux of birds through the wind farm area. And lastly, we modelled the chance that birds approaching the wind farm actually collide with the turbine blades. Integrating these results, we are able to make a preliminary estimation of the number of collision victims.

8.7.1. Flying height

8.7.1.1. Visual flying height assessment during transect counts

During the seabird counts along fixed monitoring routes, the flying height of all birds was visually estimated and scored as follows:

- 0= beneath the rotor sweep area <31m
- 1= in the rotor sweep area 31-157m
- 2= above the rotor sweep area

Table 8 includes all data collected on flying height during 2005 and 2008. The conclusion is more or less equal to the one presented in Vanermen *et al*. (2006). Some species were never observed flying above 31m, like Northern fulmar, Common guillemot and Razorbill. In contrast, more than 15% of the large gull species Lesser black-backed, Herring and Great black-backed gulls were observed flying at rotor height.

There seems to be considerable day to day variation in the number of birds flying at rotor height, illustrated by the boxplots in Figure 60. Some observation days more than 60% of the Lesser black-backed and Herring gulls flew higher than 31m, which was mainly observed in calm and sunny weather. Collision risk will vary accordingly, in which the weather conditions play a key role.

Table 8
Proportion of birds flying at rotor height, sorted from low to high proportions.

Species	N	% flying at rotor sweep heights
Great crested grebe	78	0,0%
Northern fulmar	1251	0,0%
Common scoter	801	0,0%
Common guillemot	280	0,0%
Razorbill	59	0,0%
Common tern	3166	0,4%
Sandwich tern	1318	1,1%
Little gull	973	1,3%
Red-throated diver	239	2,5%
Black-legged kittiwake	2682	4,5%
Black-headed gull	1314	5,0%
Northern gannet	2064	5,7%
Great skua	133	7,5%
Common gull	2135	7,9%
Herring gull	1903	14,5%
Lesser black-backed gull	8044	16,7%
Great black-backed gull	1482	17,1%

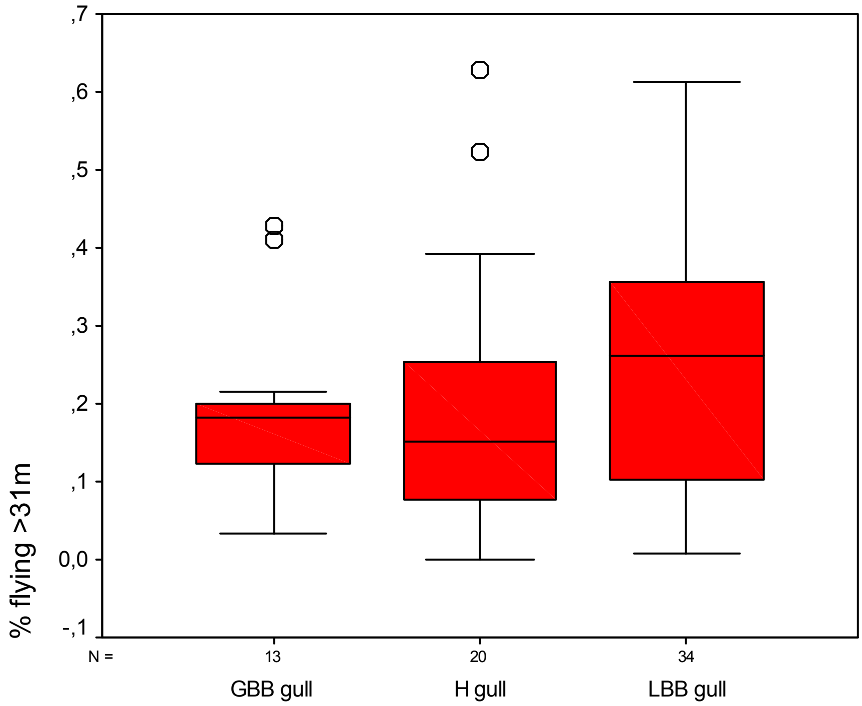


Figure 60. Boxplot of percentages of birds flying at rotor height (only days with more than 10 observations were included in the analysis).

8.7.1.2. Flying height assessment during flux counts

By means of calibrating our visual height estimations, we used an alternative method to assess flying height during flux counts on 2 observation days in September and October 2008 (see also

§8.7.2). We did so by determining the flight angle and estimating the horizontal distance.

8.7.1.2.1. Methodology

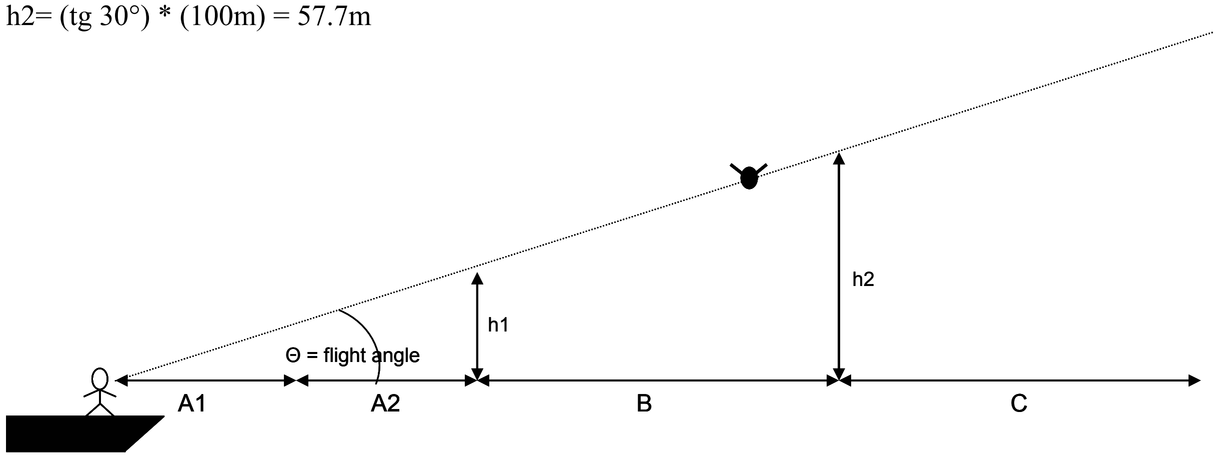
For this type of assessment, only birds within 200 metres away from the boat were withheld. As in the transect counts, it was visually estimated whether the birds were flying at rotor sweep height or not. Meanwhile, their flight angle was measured using a clinometer, and the distance at which they were flying was estimated (categories: A1=0-25m / A2=25-50m / B=50-100m / C=100-200m).

The flying height is then obtained by multiplying the distance with the tangent of the flight angle. Since distances were estimated in categories, a range of flying heights is obtained (h1-h2, see Example). Nevertheless, in the presented results, the mean of h1 and h2 was used.

Example:

For a bird flying at a distance of 50-100m (B) and in an angle Θ of 30°, the bird's flying height will range between h1 and h2.

h1= (tg 30°) * (50m) = 28.9m
h2= (tg 30°) * (100m) = 57.7m



8.7.1.2.2. Results

Based on the results of the clinometer method (Table 9), proportionally more birds seemed to fly at rotor sweep heights compared to the results in Table 8. More than 50% of the Lesser black-backed and Herring gulls were estimated to fly between 31 and 157 m of height.

This does not necessarily mean that flying heights were underestimated during visual assessments. Based on Figure 60, we already pointed out that there was a large day-to-day variation in observed flying heights. Therefore these results should only be compared with the results of the simultaneously performed visual assessments (§8.7.1.2.3).

Table 9
Estimated percentage of birds flying at rotor sweep height according to clinometer method (excl. birds of which less than 10 observations are available).

Species	Number	% flying at rotor sweep height
Northern gannet	66	12%
Common gull	15	20%
Lesser black-backed gull	278	56%
Herring gull	28	54%
Great black-backed gull	22	18%
Black-legged kittiwake	31	16%

With this type of analysis it was also possible to make frequency distributions of observed flying heights as shown in Figure 61 to Figure 66.

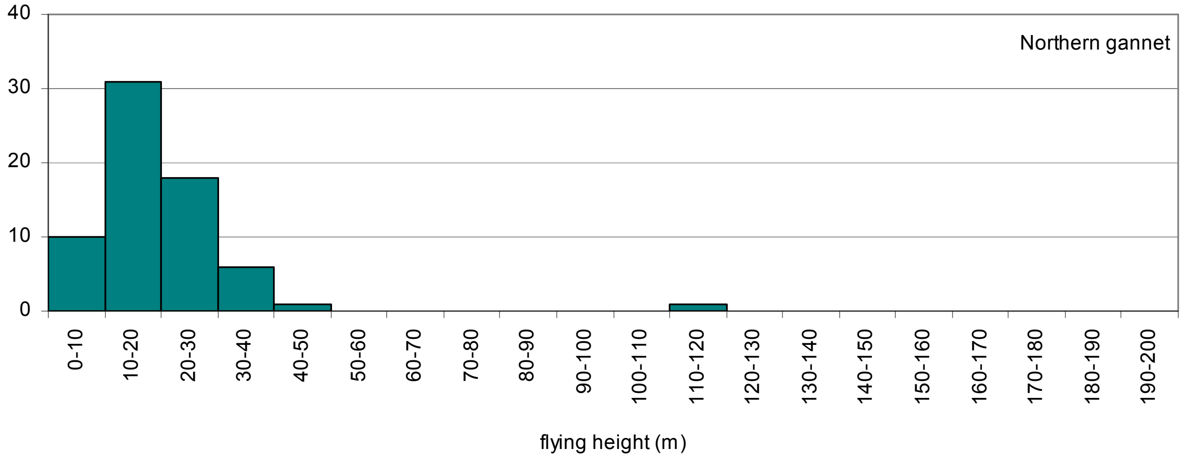


Figure 61. Frequency distribution of flying heights of Northern gannet.

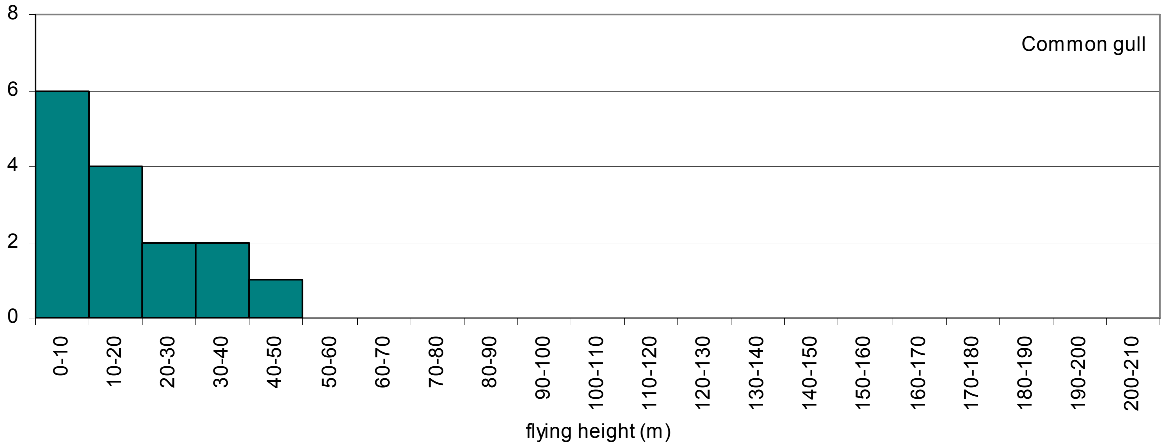


Figure 62. Frequency distribution of flying heights of Common gull.

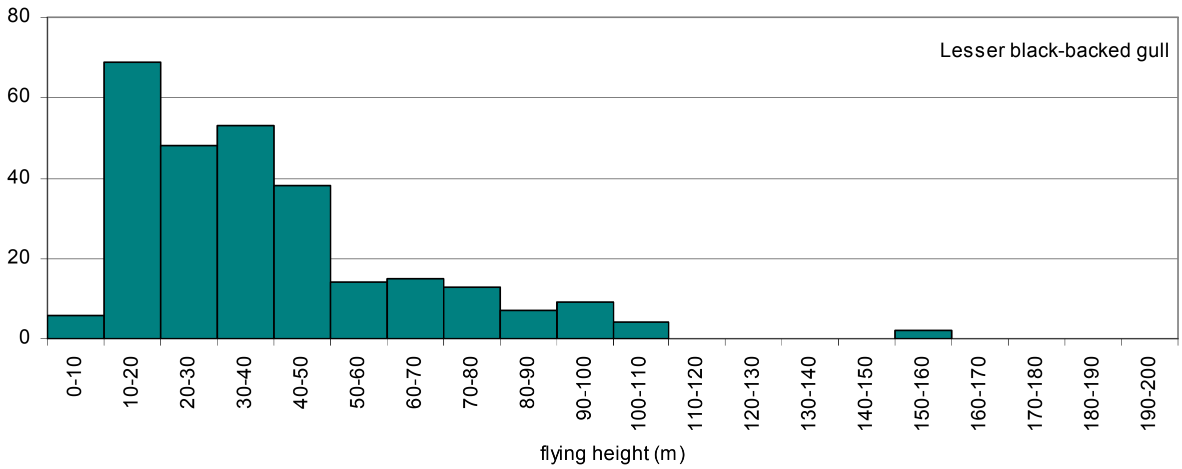


Figure 63. Frequency distribution of flying heights of Lesser black-backed gull.

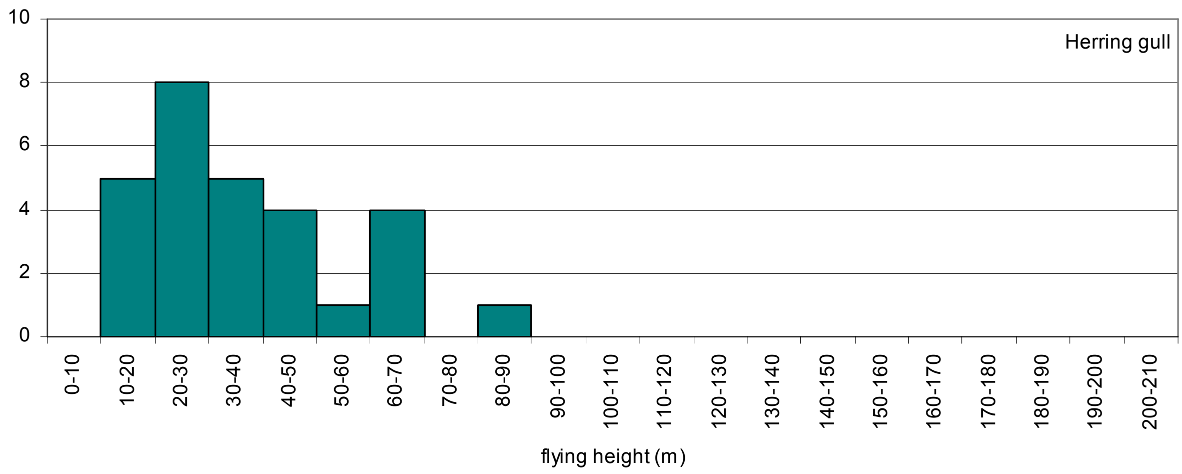


Figure 64. Frequency distribution of flying heights of Herring gull.

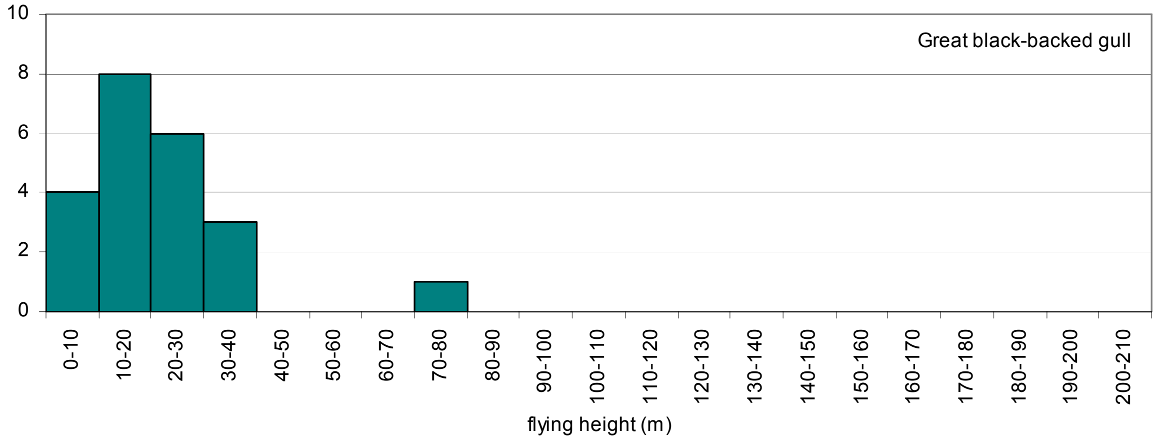


Figure 65. Frequency distribution of flying heights of Great black-backed gull.

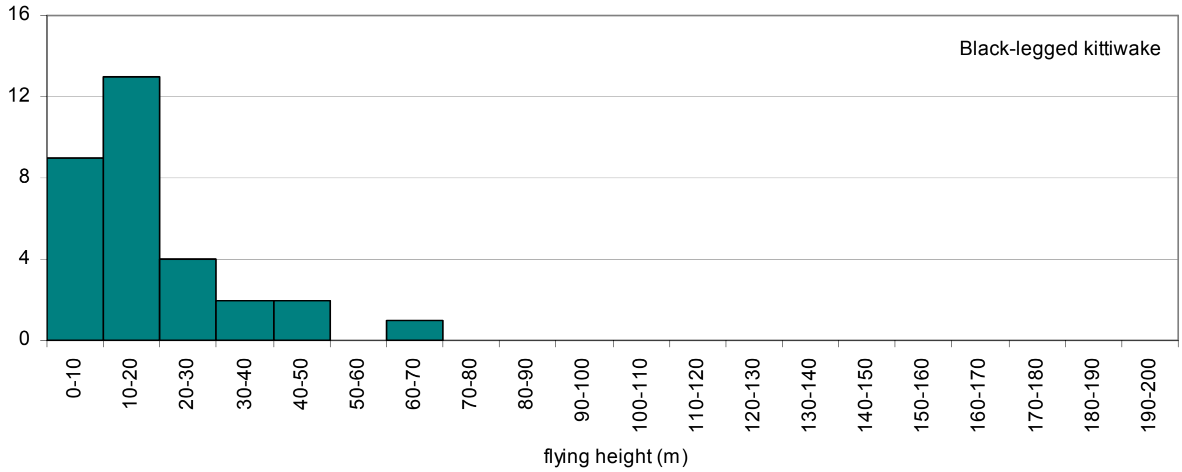


Figure 66. Frequency distribution of flying heights of Black-legged kittiwake.

8.7.1.2.3. Comparison results of visual assessment and assessment using a clinometer

Simultaneously with the clinometer assessments, it was visually estimated whether the birds flew beneath (<31m) or through the rotor sweep area (31-157m). This allows us to compare our visual assessment of flying height (higher or lower than 31m) with the flying heights obtained through measurements with the clinometer.

Only 3% of the visual height assessments did not correspond to the assessment using a clinometer, which is a very low percentage. However, there is a large 'grey' zone due to the categorical distance estimation. The grey zone comprises of no less than 28% of all observations.

Table 10. Comparison of the results of visual flying height assessment with assessment using clinometer.

Visual	Clinometer		
	<31m	31-157m	????
< 31 m	199	2	59
31-157 m	12	81	58

8.7.2. Bird flux in the Thorntonbank wind farm area

8.7.2.1. Methodology

During the migration periods April-May and September-October we performed so-called 'flux counts' to estimate the number of flight movements occurring in the WFA-TTB (Table 11). In contrast to the standardized seabird counts, these counts were made from a stationed ship. At each of 4 fixed locations (Figure 67), all birds passing an imaginary transect line oriented NW-SE (perpendicular to the supposed migration direction) were counted during one hour. The birds' flight direction was determined making use of a compass. Meanwhile we assessed flying heights as explained in the previous paragraph §8.7.1.2.

Table 11
Overview of flux counts.

Season	Date	Number of locations	Time counted
Spring	21/04/2008	4	3h53'
	27/05/2008	2	2h00'
	28/05/2008	2	2h00'
Autumn	18/09/2008	4	3h55'
	30/10/2008	4	3h46'

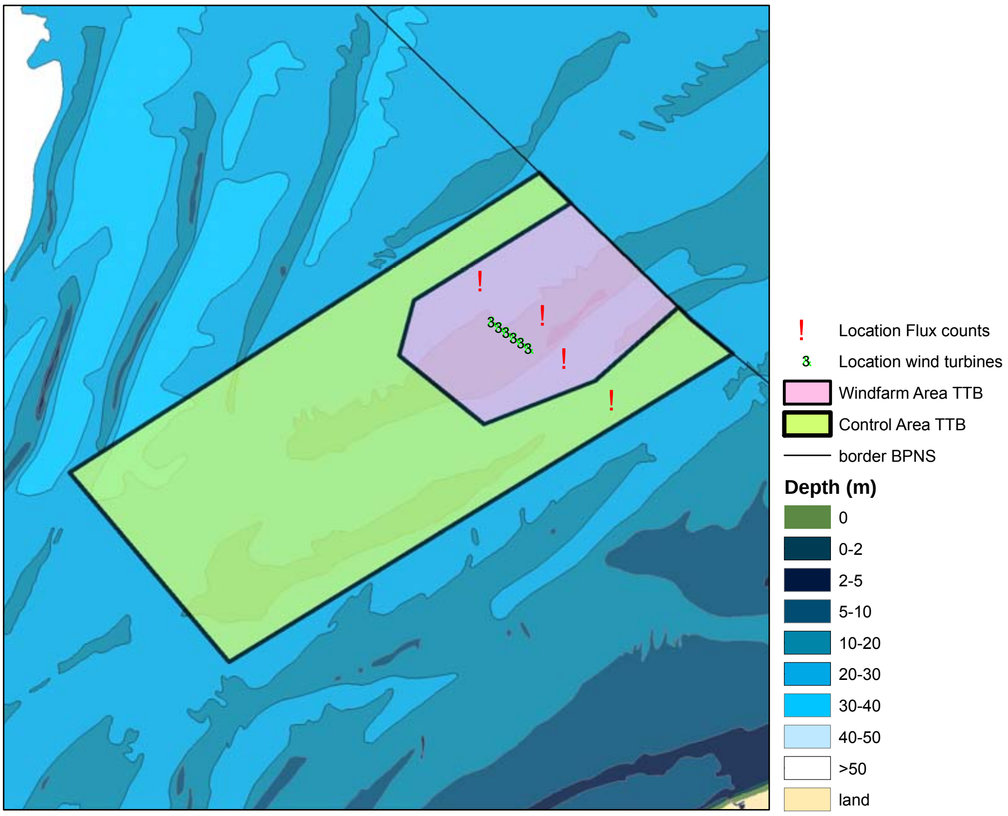


Figure 67. Locations of flux counts.

8.7.2.2. Results: Flight directions

During autumn and spring, respectively 997 and 1507 flying birds were counted. As expected there was a clear north-eastern component in the flight directions observed during spring, and a clear south-western component in flight directions during autumn (Figure 68). According to the output of the Bolker-model (Figure 82), these are the most unfavourable flight directions with regard to collision risk.

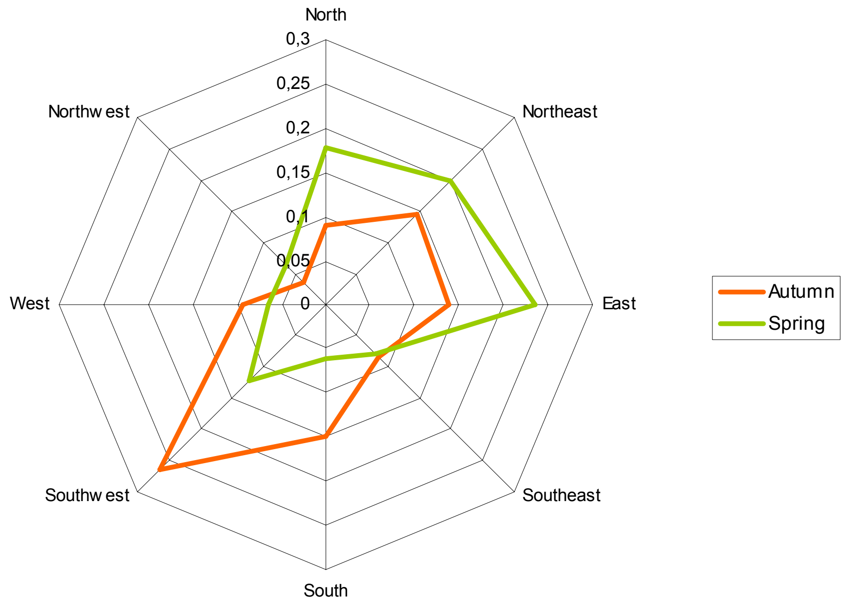


Figure 68. Proportional flight directions observed during flux counts in spring and autumn of the year 2008.

8.7.2.3. Results: Flux

All birds flying closer than 100m (spring) or 200m (autumn) were withheld for flux calculation. Hence, for each flight direction, the observed numbers could be converted into a flux, expressed in number of birds flying through the smallest 'containing circle' of the future wind farm per hour (diameter = 8.7km) (see Figure 69 & Figure 70).

During autumn, up to 1,800 flight movements cross the wind farm area each daylight hour, mostly oriented east (21%) and south (18%). In contrast to what we see in Figure 68, the south-western component in flight directions is no longer apparent in Figure 69. This is probably due to the fact that the most observed species are gulls, which mainly reside in the area rather than migrating through.

During April and May, the WFA-TTB is crossed by an estimated number of 1,820 flight movements each daylight hour. 29% of this flux has a north-eastern orientation.

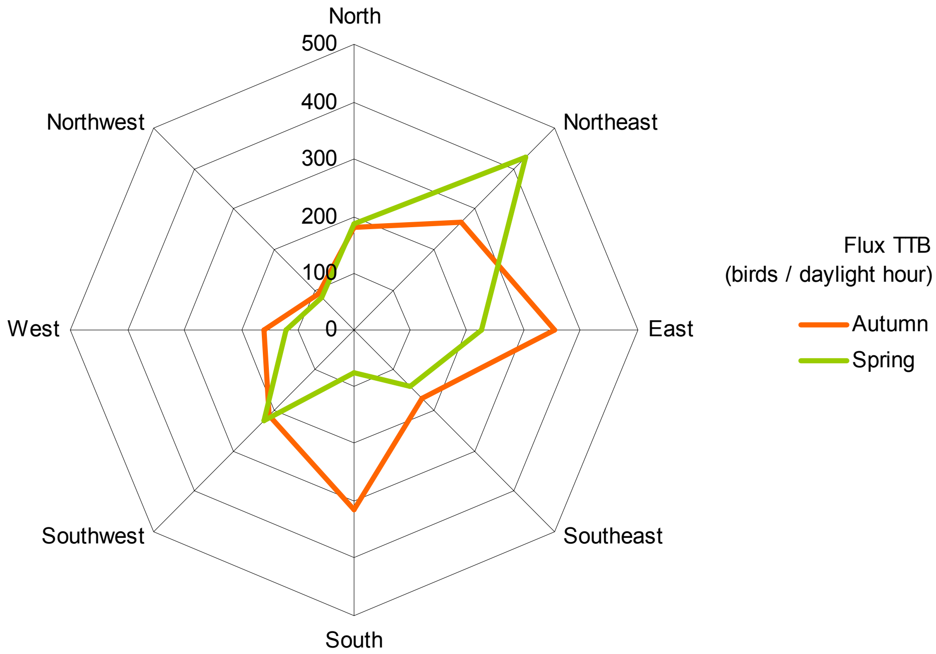


Figure 69. Flux of birds (ind./ hour) flying through the smallest containing circle (diameter = 8.7km), based on flux counts in spring and autumn 2008.

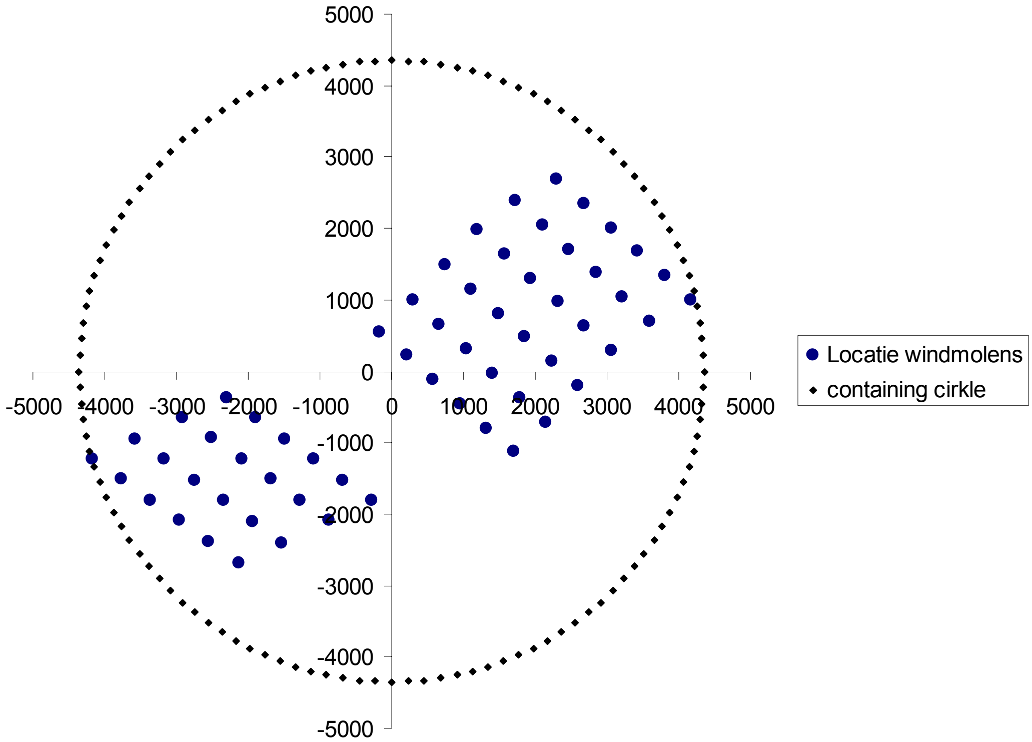


Figure 70. Position of the turbines in the Thorntonbank wind farm with indication of the smallest 'containing circle' with radius 4,352m.

8.7.2.4. Results: species composition

In spring, the most common species were Lesser black-backed gull (58%) and Northern fulmar (28%). We counted only low numbers of Annex I species Little gull (1.5%), Common tern (1.8%) and Sandwich tern (1.8%).

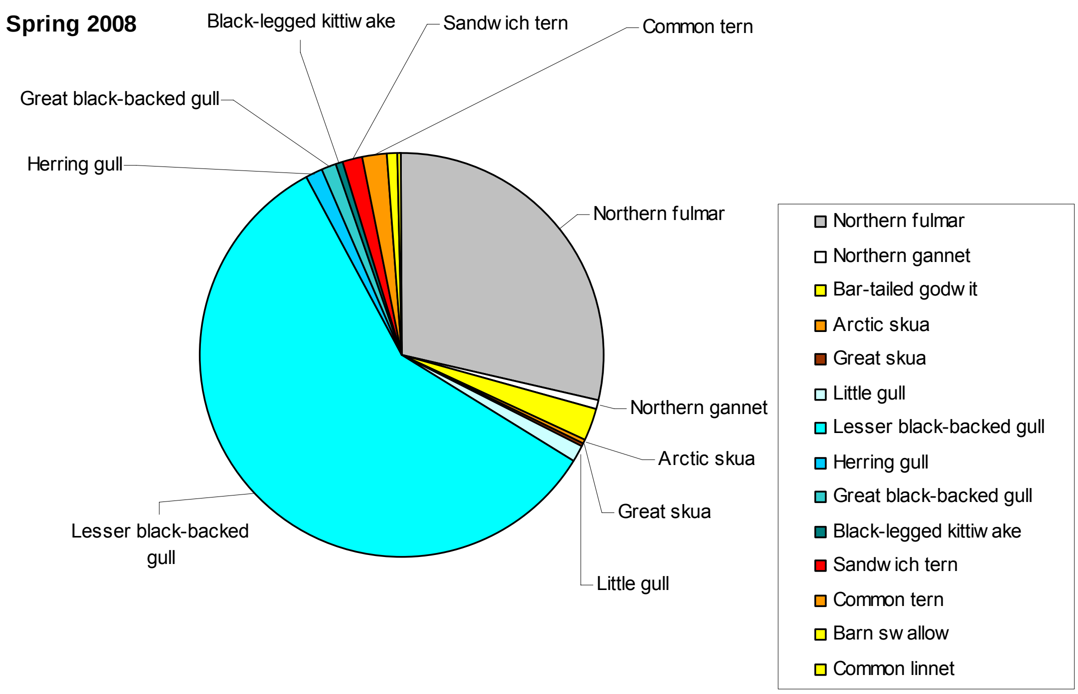


Figure 71. Proportion of bird species observed during spring flux counts (birds flying within 100m).

Species composition in autumn was made up of gulls (70%), Northern gannets (10%) and passerines migrating over sea (20%). As in spring, Lesser black-backed gull was the most observed species (44%). An unexpected result was the migration of Black-headed gulls this far at sea (7.7%). Annex I species Little gull and Sandwich tern were observed in very low numbers (<1%).

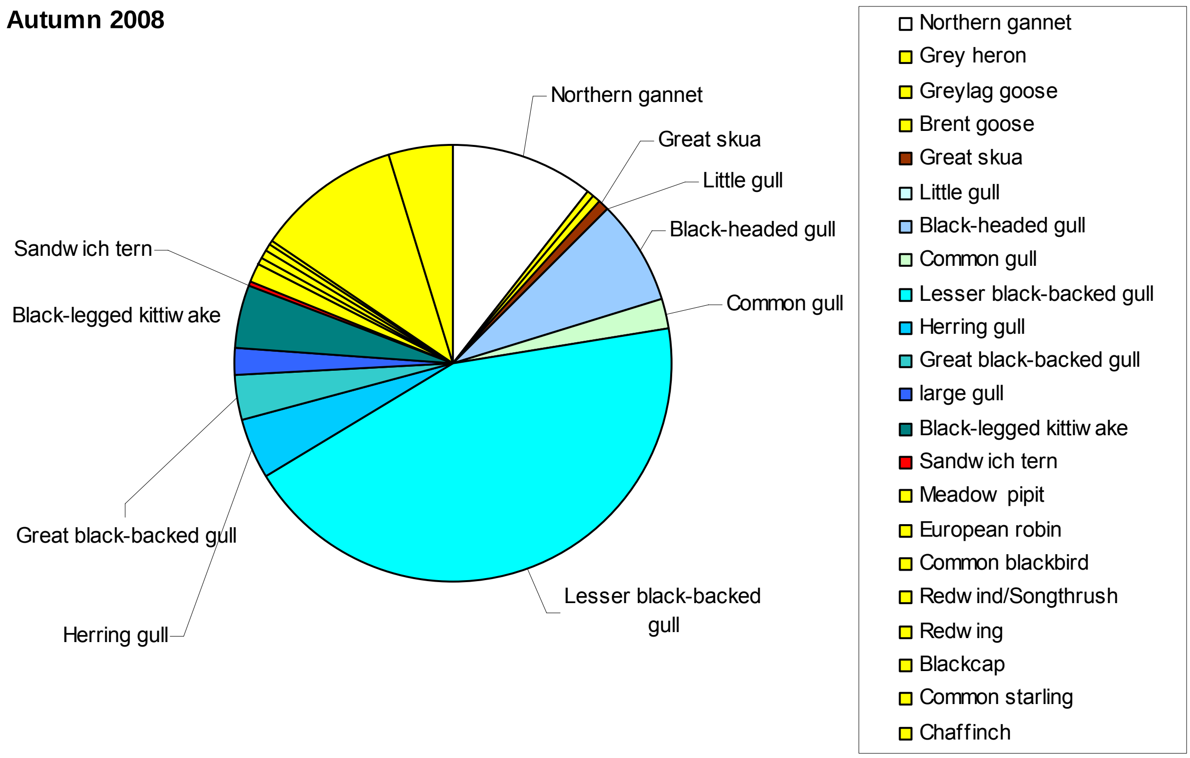


Figure 72. Proportion of bird species observed during autumn flux counts (birds flying within 200m).

Table 12 shows the measured bird fluxes for all observed species. For each species, the observed numbers were extrapolated to a transect of 8.7km long, equalling the diameter of the smallest containing circle of the WFA-TTB (Figure 70). Fluxes of more than 100 birds/h were observed for Northern fulmar, Northern gannet, Black-headed gull and Lesser black-backed gull. Lower numbers were noted for the Annex I species Little gull, Sandwich tern and Common tern, who still showed moderately high fluxes of around 30 birds/h. During one of the observation days in autumn, there was massive migration of passerines, which is translated in high fluxes of Common starling and Chaffinch. All of these species (marked bold in Table 12) will be discussed in detail in §8.7.2.5.

Table 12
Summary of measured bird fluxes through the WFA-TTB (number of birds per daylight hour).

Species	Spring	Autumn
Northern Fulmar	518.9	0.0
Northern Gannet	16.6	188.9
Grey Heron	0.0	2.8
Greylag Goose	0.0	5.6
Brent Goose	0.0	11.3
Bar-tailed Godwit	44.2	0.0
Arctic Skua	5.5	0.0
Great Skua	5.5	14.1
Little Gull	27.6	2.8
Black-headed Gull	0.0	138.2
Common Gull	0.0	42.3
Lesser Black-backed Gull	1059.9	786.7
Herring Gull	27.6	79.0
Great Black-backed Gull	22.1	62.0
large gull	0.0	31.0
Black-legged Kittiwake	5.5	87.4
Sandwich Tern	33.1	5.6
Common Tern	33.1	0.0
Barn Swallow	16.6	0.0
Meadow Pipit	0.0	22.6
European Robin	0.0	2.8
Common Blackbird	0.0	8.5
T. philomelos / iliacus	0.0	11.3
Redwing	0.0	11.3
Blackcap	0.0	2.8
Common Starling	0.0	194.6
Chaffinch	0.0	84.6
Common Linnet	5.5	0.0

8.7.2.5. Species discussion

Northern fulmar (*Fulmaris glacialis*)

During spring large numbers of Northern fulmar were observed during the flux counts, resulting in a calculated flux of more than 500 individuals per daylight hour, most birds heading northeast. In contrast, not one single Northern fulmar was observed during autumn. At the BPNS, an influx of Northern fulmars took place in the spring of 2008, which is quite unusual, since highest densities are normally observed during November-January. However, there is no need for concern regarding this species since it was never observed flying at rotor height.

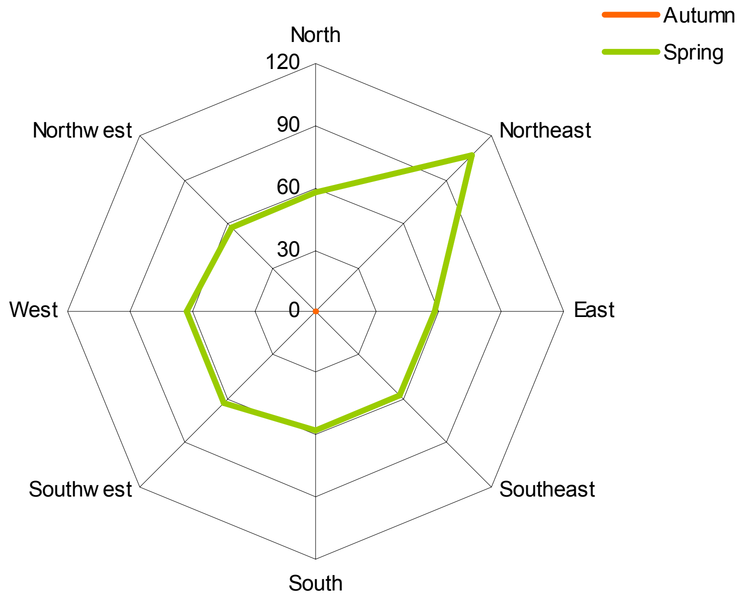


Figure 73. Flux of Northern fulmar through the Thorntonbank wind farm area (n birds / daylight hour).

Northern gannet (*Morus bassanus*)

As expected, the number of flight movements of Northern gannet was highest during autumn (190 birds per daylight hour), when large numbers are present at the BPNS. Flight orientation had a clear southern to western component (resp. 42 and 44 birds per daylight hour). During spring most birds flew in a north and north-easterly direction (resp. 6 and 11 birds per daylight hour). Considering this high flux, combined with the relatively high collision risk (Table 13), there is strong reason to believe there will be many collision fatalities among Northern gannets.

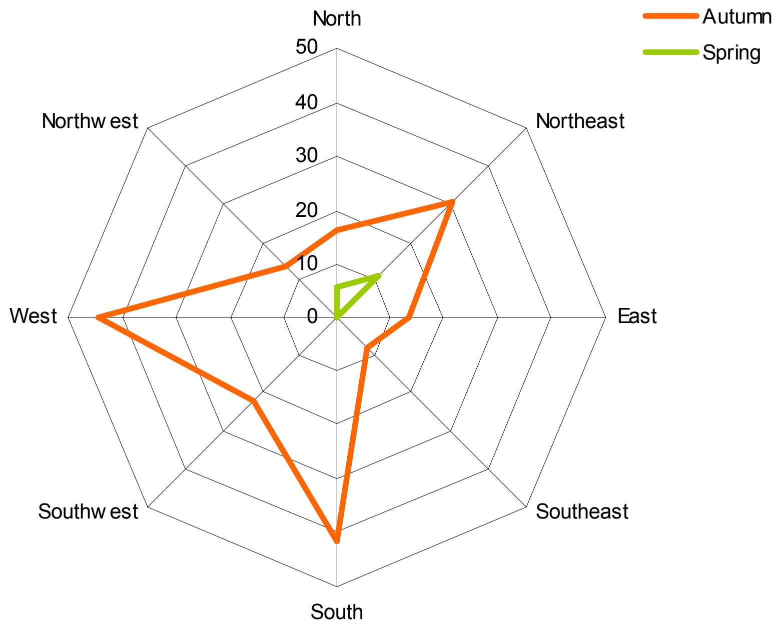


Figure 74. Flux of Northern gannet through the Thorntonbank wind farm area (n birds / daylight hour).

Little gull (*Larus minutus*)

Little gulls were observed solely during spring, with a total flux of 28 birds per daylight hour, mainly heading north (17 birds per daylight hour).

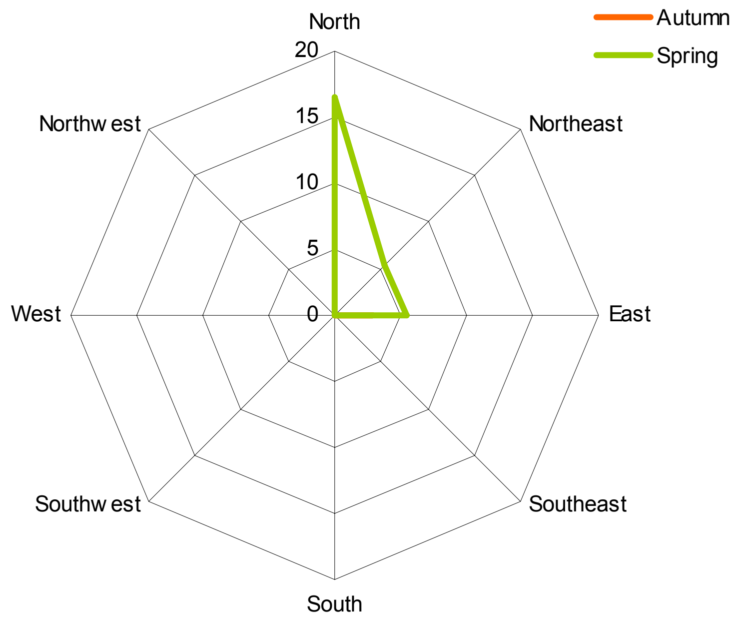


Figure 75. Flux of Little gull through the Thorntonbank wind farm area (n birds / daylight hour).

Black-headed gull (*Larus ridibundus*)

In general, this is a coastal bound species, but during autumn several groups of Black-headed gulls were observed migrating through the WFA-TTB. This resulted in a high flux of 138 birds per daylight hour, flying south and southeast.

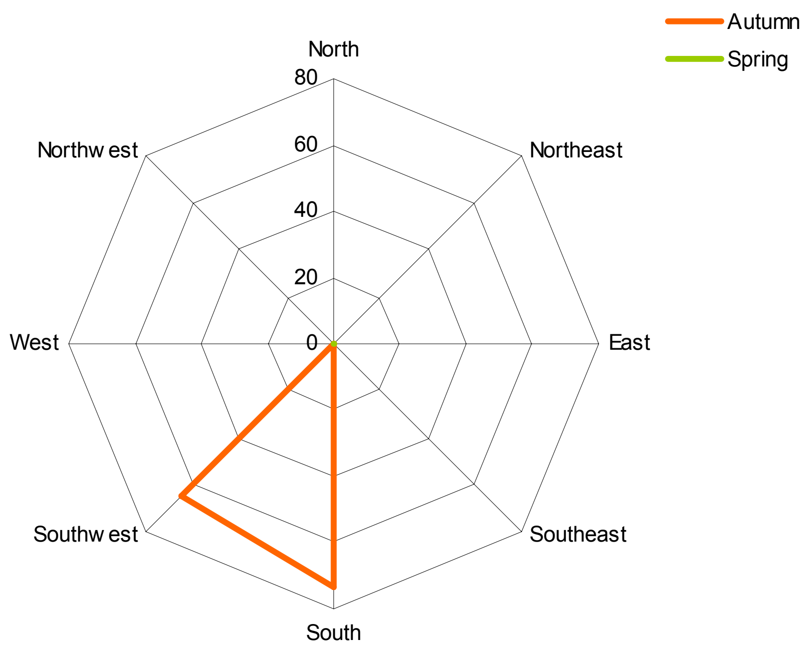


Figure 76. Flux of Black-headed gull through the Thorntonbank wind farm area (n birds / daylight hour).

Lesser black-backed gull (*Larus fuscus*)

This was the most commonly observed species during spring and autumn (resp. 1,060 and 790 birds per daylight hour). Movements occurred scattered over all directions, but with a clear north-eastern aspect during both migration seasons. Probably most gulls reside in the area for foraging, rather than migrating through. These high fluxes combined with the high species-specific collision risk will inevitably result in high numbers of collision victims.

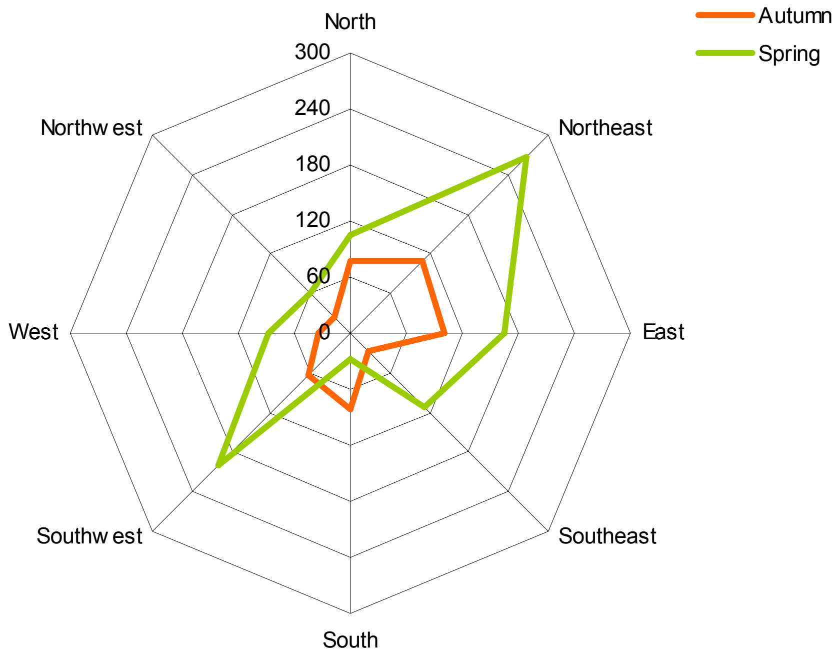


Figure 77. Flux of Lesser black-backed gull through the Thorntonbank wind farm area (n birds / daylight hour).

Sandwich tern (Sterna sandviscensis)

Most Sandwich terns were observed in spring with a resulting flux of 33 birds per daylight hour. This flux had a clear eastern component. Autumn saw far less Sandwich terns, with 2 observed individuals and a flux of 6 birds per daylight hour.

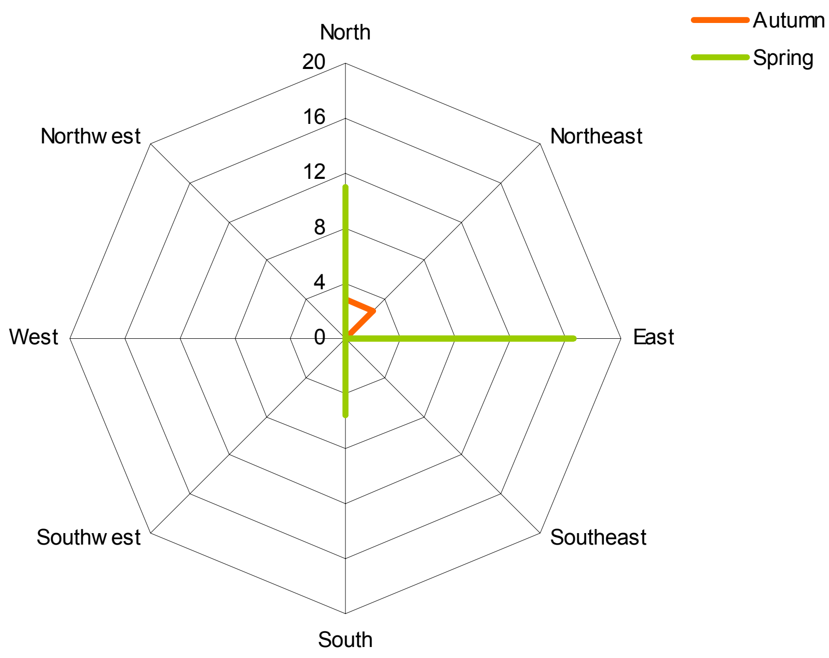


Figure 78. Flux of Sandwich tern through the Thorntonbank wind farm area (n birds / daylight hour).

Common tern (*Sterna hirundo*)

Common terns were exclusively observed in spring with a total flux of 33 birds per daylight hour. Most birds headed northeast (17 birds per daylight hour).

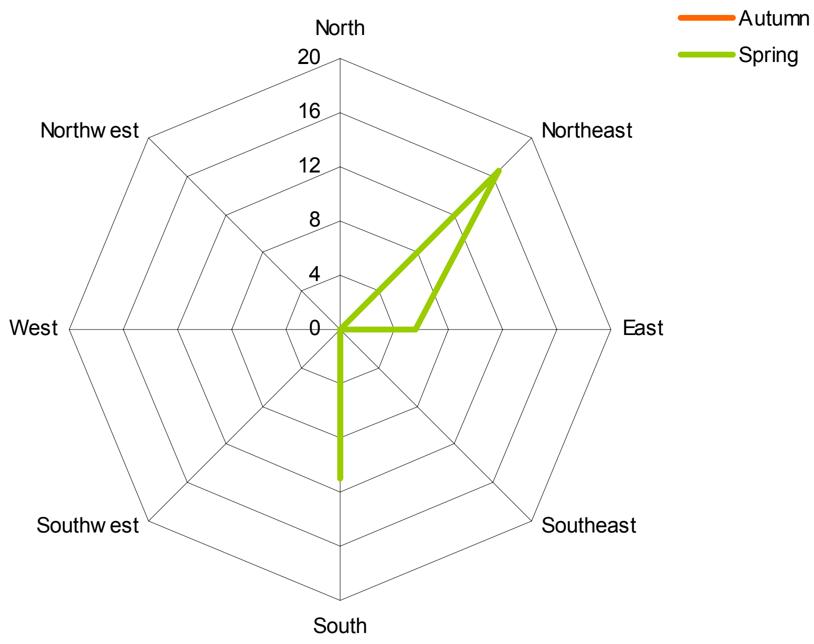


Figure 79. Flux of Common tern through the Thorntonbank wind farm area (n birds / daylight hour).

Chaffinch / Starling (Fringilla coelebs / Sturnus vulgaris)

On 30 October 2008, there was massive migration of passerines above the Belgian part of the North Sea. Strikingly, the migrating passerines mainly flew in east to south-eastern directions, straight towards land. Except for small numbers of thrushes, most passerines however were flying below rotor height.

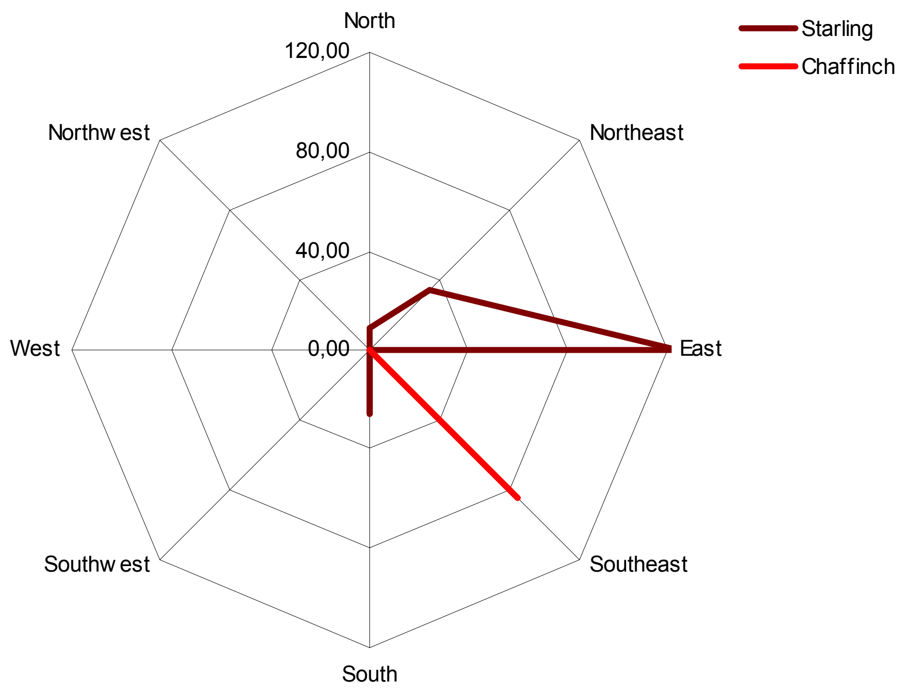


Figure 80. Autumn migration flux of passerines through the Thorntonbank wind farm area (n birds / daylight hour).

8.7.3. Collision risk assessment

In this chapter we make a preliminary estimation of the expected collision risk of migrating seabirds. Based on the results discussed in Chapters 2 & 5, the estimation is done for nine species or species groups: Northern gannet, Great skua, Little gull, Common gull, large gulls, Black-legged kittiwake, Sandwich tern, Common tern and auks.

8.7.3.1. Collision risk assessment: methodology

Step 1: assessment of the number of bird movements through the wind farm (1)

In a first step we need to assess how many birds will fly through the wind farm at rotor height, for which three input parameters are needed:

- Flux **F**: Number of bird movements per time unit;
- Correction for flying height **Cfh** (%): Percentage of birds flying at rotor height (§8.7.1);
- Correction for macro-avoidance **Cma** (%): Birds flying towards the wind farm may deflect their flight path to fly around the wind farm. This value represents the fraction of birds avoiding the wind farm as a whole.

→ (1) = **F** x **Cfh** x **Cma**

Step 2: assessment of the collision risk for birds flying through the wind farm (2)

In a second step we assess the collision risk for birds flying through the wind farm at rotor height. This value is deducted from two mathematical models. Again, three input parameters are needed:

- Average number of turbines encountered **Nt**: This value can be calculated using the geometrical Bolker-model (Bolker *et al.* 2006). In this mathematical model it is assumed that birds fly in straight lines through the wind farm, without taking any avoidance action. Moreover, it assumed that the rotor plain is oriented perpendicular to the flight direction. Input parameters include height of turbine centre, rotor length and turbine positions;

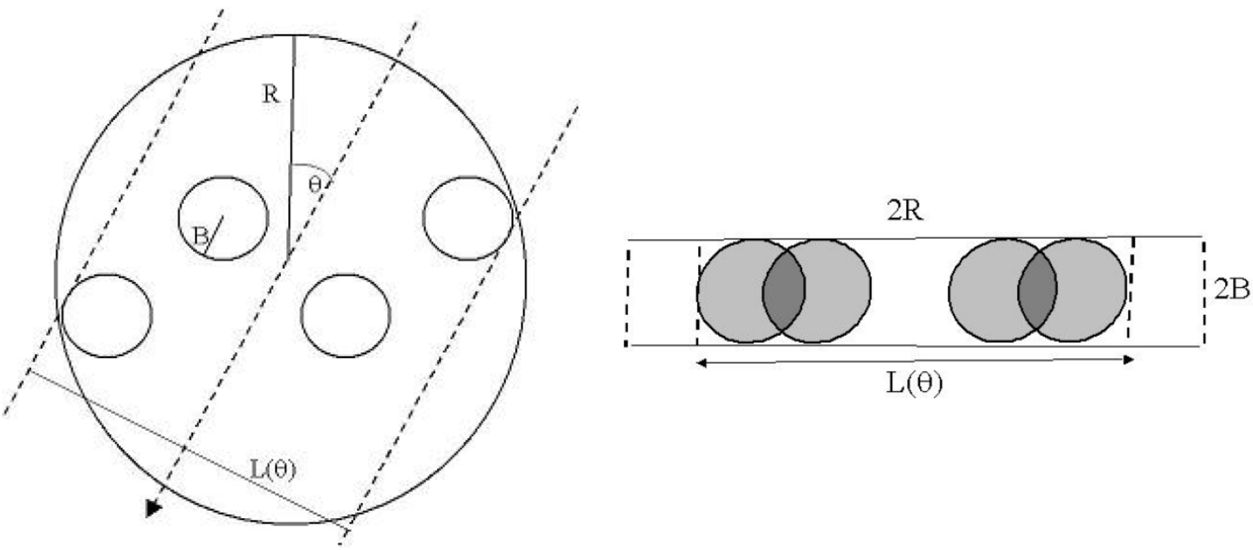
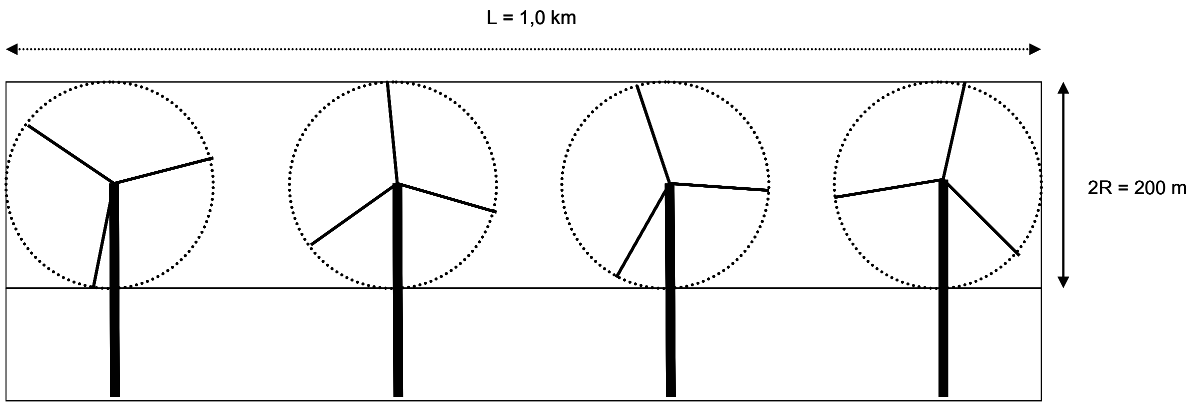


Figure 81. The Bolker model: top view of an imaginary wind farm, and side view for birds arriving from an angle Θ, with the rotor plane perpendicular to the birds' flight direction (Bolker *et al.* 2006).

Example:



Imagine a wind farm of 4 turbines with rotor blade length R placed in one line as in the figure above. Assuming that all birds fly perpendicular to the turbine alignment, then the Bolker model calculates the 'average amount of turbines' these birds will encounter. We already corrected for flying height in step (1), so this equals the ratio of the total rotor surface area to the vertical area available at rotor height ($[4\prod R^2] / [2RL] = 0.63$). Hence, birds flying at rotor height perpendicular to the turbine alignment will encounter less than one turbine on average. Alternatively, birds flying in line with the turbines will encounter more than 3 turbines on average ($[4\prod R^2] / [2R]^2 = 3.14$). Obviously, in case of a two-dimensional configurated wind farm these calculations are much more complicated, but the results are easily obtained using the Bolker Excell-spreadsheet.

- No-avoidance collision risk **Cr**: This parameter is the probability of a bird being hit by a rotor blade when it flies through the rotor sweep zone, in the assumption that the bird takes no avoidance action at all. Therefore the mathematical Band-model and the accompanying Excell-spreadsheet is used. The collision probability depends on the size of the bird, chord width and pitch angle of the turbine blade, rotation speed of the turbine and flight speed of the bird (Band *et al*. 2007);

- Correction for micro-avoidance **Cmi** (%): When birds fly into a wind farm they may choose to fly through the corridors to stay away from the rotating blades. Also, they may perform last-minute actions to avoid a collision. This behavioural aspect is compensated for through the micro-avoidance factor.

→ (2) = Nt x Cr x Cmi

Step 3: collision risk

→ Collision Risk = (1) x (2)

8.7.3.2. Collision risk assessment: results

8.7.3.2.1. Input parameters

All input parameters for collision risk calculation were chosen based on the worst case scenario principle. This means that we made the following assumptions:

Number of bird movements per time unit (Flux) **F**: this value is set to 100 birds/year and hence the modelled number of victims value may be considered as a collision risk, expressed in percent (%);

Correction for flying height **Cfh** (%): This value is species-specific. Based on our ship-based seabird observations we are able to deduct a percentage of birds flying at rotor height;

Correction for macro-avoidance **Cma** (%): This parameter is species and site specific. Up until now, there are few publications reporting on the macro-avoidance of seabirds towards offshore wind farms, and long term in situ research is needed for reliable determination. Compared to the pre-construction of the Nysted wind farm, a reduction of 46 - 78% of migrating waterfowl entering the wind farm area was found. Based on that research, we set this value is set to 0.5 (worst case scenario) (Kahlert *et al*. 2005, Desholm & Kahlert 2005);

Average number of turbines encountered **Nt**: The Bolker-model shows that the least favourable flight directions are 60° and 240°, at which birds should encounter 1.88 turbines per crossing. Calculations are based on the assumption that all birds fly in these directions;

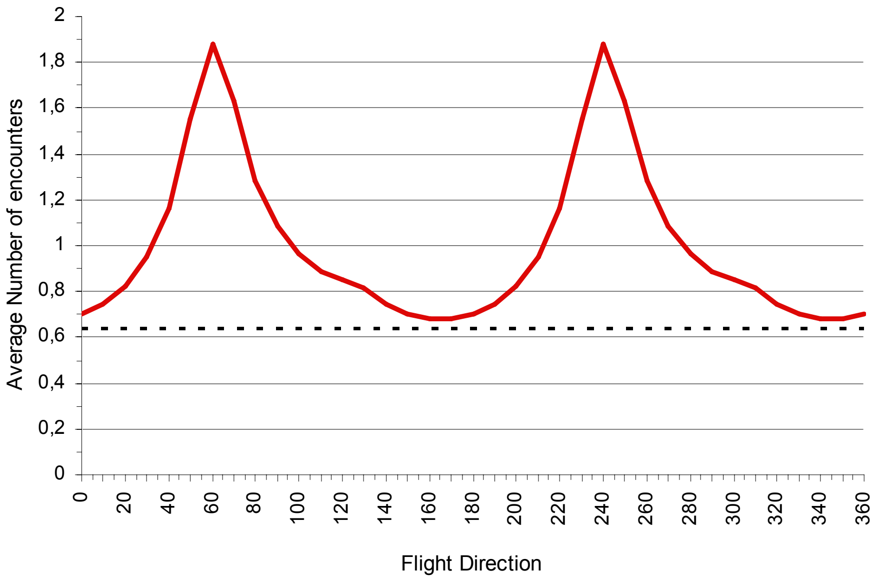


Figure 82. Average Number of Turbines Encountered per flight direction.

No-avoidance collision risk **Cr**: For the calculation of this parameter, maximum rotation speed, maximum bird length and maximum wingspan were used (Jonsson, 1997), as well as minimum flight speeds (Spear & Ainley, 1997). The turbine paramaters 'maximum chord width' and 'pitch angle' were estimated to be 8m and 30° respectively;

Correction for micro-avoidance **Cmi** (%): This value is extremely difficult to determine reliably. Moreover, Chamberlain *et al.* (2006) showed that only slight variations in this avoidance factor lead to large changes in mortality estimations. For most species this value is set to 0.95, which according to literature is likely to be a minimum value (Band *et al.* 2007, Chamberlain *et al.* 2006). For Sandwich and Common tern however, we followed a different path. We estimated this value by comparing modelled collision risk with actual collision risk, based on in situ data on bird flux and corpse searches by Everaert (2008) (analogous to Hatch & Brault, 2007). This resulted in a micro-avoidance of 0.992 and 0.985 for Sandwich and Common tern respectively.

8.7.3.2.2. Results

shows the calculated collision risks, sorted from low to high. Auks were never observed at rotor height and show a collision risk of zero. Collision risk for Annex I species Sandwich terns and Common tern is very small, due to their small size, generally low flying height and high micro-avoidance. In contrast, the risk for Little gull is much higher, with 1 victim each 7,000 flight movements. Black-legged kittiwake, Northern gannet, Great skua and Common gull all show intermediate collision risks of 1 to 10 victims per 10,000 flight movements. Large gulls appear to be most sensitive, with more than 2 collisions per 1,000 flight movements.

Table 13
Estimated collision risks for nine species or species groups at the Thorntonbank wind farm according to a worst case scenario (species marked with (*) are on the Annex I of the Birds Directive).

Species	Collisison risk (%)	Collision risk
auk sp.	0.0000	-
Sandwich tern*	0.0010	1 / 100,000
Common tern*	0.0010	1 / 100,000
Little gull*	0.0141	1 / 7,000
Black-legged kittiwake	0.0511	1 / 2,000
Northern Gannet	0.0668	1 / 1,500
Great skua	0.0717	1 / 1,400
Common gull	0.0883	1 / 1,100
large gull sp.	0.2153	1 / 500

8.7.4. Conclusion

Integrating above information we are able to calculate the expected number of collision victims. Be aware of the fact that these are preliminary results based on fairly limited research and according to a worst case scenario principle. Nevertheless, it makes clear that there will be relatively few victims among the protected Annex I species. In contrast, it appears that high numbers of collisions could occur among gulls and gannets.

It could well be possible that fluxes of gulls were overestimated due to attraction to the ship. In the future, radar research should give true and reliable insight in the bird flux through the wind farm area. These data should be supported by visual flux counts from the transformator platform, or even better, the wind turbines themselves. Also, we are largely ignorant regarding avoidance by birds, which remains one of the most crucial parameters to reliably estimate numbers of collision victims.

Table 14
Estimated number of collision victims in the future wind farm area at the Thorntonbank.

Species	Collision risk (%)	Spring flux (n ind. / (apr-may)	Autumn flux (n ind. / (sept-oct)	Number of victims (spring)	Number of victims (autumn)
auk sp.	0.0000	0	0	0.0	0.0
Sandwich tern	0.0010	23 760	0	0.2	0.0
Common tern	0.0010	23 760	4 320	0.2	0.0
Little gull	0.0141	19 440	0	2.7	0.0
Great skua	0.0717	4 320	10 080	3.1	7.2
Common gull	0.0883	0	30 240	0.0	26.7
Black-legged kittiwake	0.0511	4 320	62 640	2.2	32.0
Northern Gannet	0.0668	12 240	136 080	8.2	90.9
large gull sp.	0.2153	799 200	691 200	1 720.5	1 488.0

8.8. Acknowledgements

We first want to thank n.v. C-Power, n.v. Belwind and the Management Unit of the North Sea Mathematical Models (MUMM) for their financial input and assigning this research to INBO. MUMM staff members Robin Brabant and Steven Degraer are thanked for their guidance and critical comments on this report. We'd also like to thank our colleagues Marc, Hilbran & Wouter, and all volunteers who assisted on the seabird counts (especially Walter Wackenier, who joins us every month), as well as the crew of the research vessel 'Zeeleeuw', and not in the least the Flemish Institute for the Sea (VLIZ), without who's logistic support this research would never have been possible.

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Chapter 9. Research strategy and equipment for studying flying birds in wind farms in the Belgian part of the North Sea

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Photo Jan Haelters / RBINS

Table of contents

Abstract

The effects of offshore wind farms on flying birds are still uncertain at this time. Therefore it remains a necessity to study the impact of newly built wind farms on the flight movements of local and migrating birds. The biggest concern is the mortality risk due to collisions with the offshore constructions. This preliminary study aims to determine a research strategy and to select the right equipment to meet the long term research goals. According to De Groote & Roggeman (2006) the desired monitoring needs to be conducted with an Automated Radar System (ARS). The different ARS that were compared, in this study, are fit for purpose. In compliance with European legislation a public call for tender will be published and the received quotations will be evaluated on several criteria. The best suited ARS within the limits of the allocated budget will be purchased. The offshore high voltage stations seem to be the most appropriate locations for mounting the ARS. Before a platform is installed at sea it would be useful to install and test the ARS at an onshore location. This will give the researchers the ability to spend time with the system, which is not always possible offshore, and to get acquainted with the data. To estimate the mortality risk seems useful to calculate the number of collision victims with existing models. The data from the vertical scanning radar (fluxes, altitudes) will be used as input for the collision models. This is more reliable than results based on visual flux counts.

Samenvatting

De effecten van windmolenparken in zee op vogels zijn momenteel nog onzeker. Er is dus nood aan studies naar de impact van nieuwe windmolenparken op de vliegbewegeningen van lokale en migrerende vogels. De grootste bezorgdheid is de mortaliteit van vogels als gevolg van aanvaringen met de constructies. Deze voorstudie heeft tot doel om een onderzoeksstrategie op te stellen en de geschikte apparatuur te selecteren om de lange termijn doelstellingen te bereiken. Volgens De Groote & Roggeman (2006) is een automatisch radar systeem (ARS) het meest geschikt voor dergelijke monitoring. De verschillende ARS die in deze studie vergeleken werden zijn geschikt. Conform de Europese wetgeving zal een algemene offerteaanvraag gepubliceerd worden. De aangeboden offertes zullen geëvalueerd worden volgens verschillende criteria. Rekening houdend met het voorziene budget zal het meest geschikte systeem aangekocht worden. De offshore hoopspanningsplatformen zijn het best geschikt om het ARS te installeren. Vooraleer een platform in zee gebouwd is zou het nuttig zijn om het ARS aan wal te testen. Zo kunnen de onderzoekers veel tijd doorbrengen met het systeem en vertrouwd raken met de data. Om een schatting te maken van het mortaliteitsrisico kan het aantal aanvaringsslachtoffers berekend worden met bestaande modellen. De data van de verticale scanning radar (fluxen, hoogtes) zullen als input voor die modellen gebruikt worden. Dit is meer betrouwbaar dan de resultaten gebaseerd op visuele flux tellingen.

9.1. Introduction

The effects of offshore wind farms on flying birds are still uncertain at this time. Therefore it remains a necessity to study the impact of newly built wind farms on the flight movements of local and migrating birds. De Groote and Roggeman (2006) made a preliminary study of the possibilities to monitor flying birds at the Thorntonbank with a radar system. This report further elaborates on the findings of that study and presents the research strategy for the monitoring that is planned in the first five years of exploitation of the wind farms.

The research goals of the long term monitoring are:

- to study the avoidance behavior of flying birds in the vicinity of the wind farms by using a continuous monitoring strategy (with attention to temporal differences, different behavior by different species, differences during an operating wind farm and during a shut down, flight altitude, etc.);
- to quantify the flux of flight movements on site (with attention to diurnal differences of that flux and differences during varying weather conditions);
- to asses the number of collision victims and the impact of this mortality on the NW-European population of the concerned species.

The designated zone for the production of electricity from wind (figure 1) is far from the coast, with the nearest point at a distance of about 20 km. Vanermen *et al.* (2006) say that the species spectrum at the Thorntonbank, which is in that zone, is dominated by typical offshore birds such as guillemot, razorbill, kittiwake, lesser black-backed gull, etc. The near shore species great crested grebe, common scoter and divers are less frequent.

Every year, from one to 1.3 million birds pass through the Southern North Sea (Stienen *et al.*, 2007). The southern North Sea is funnel shaped, witch makes that a huge number of migrating birds are concentrated in the Channel. A lot of migration movements are happening over the sea, both at nighttime as at daytime. Sometimes the migration of, for instance, passerines is very intensive far at sea (Buurma, 1987; Alerstam, 1990). This was observed in the Belgian part of the North Sea by the Institute of Nature and Forest Research (INBO) and so this is also of importance for the zone for wind energy. The designated zone for wind energy is perpendicular to the dominant migration direction and if the zone becomes filled with wind turbines it could form a considerable barrier.

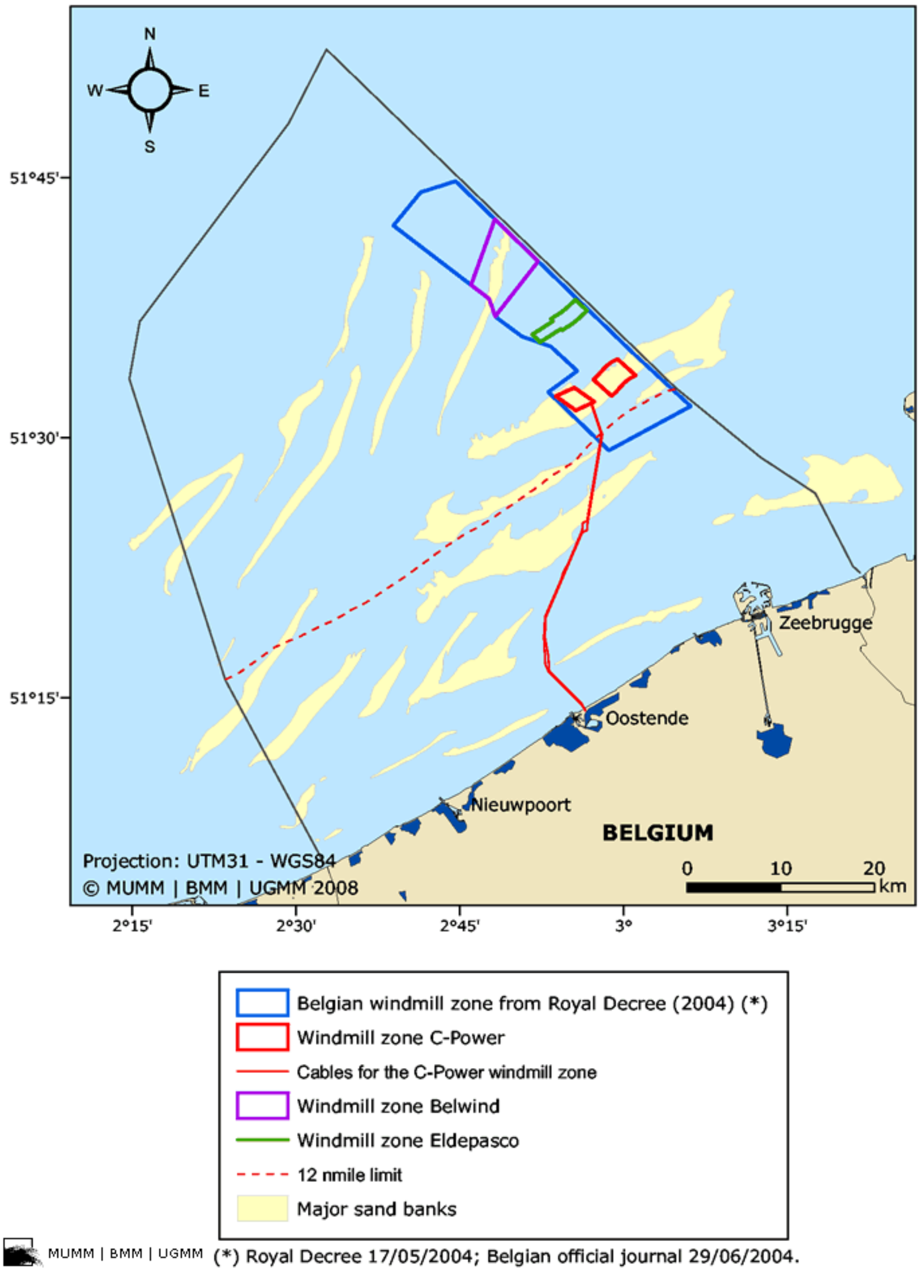

Figure 1. Map showing the designated zone for the production of electricity from wind, water or currents and currently approved wind farm projects.

This preliminary study aims to determine a research strategy and to select the right equipment to meet the long term research goals, and has the following objectives:

- to make a selection of existing radar systems taking into account the recommendations made by De Groote & Roggeman (2006);
- to define the method to determine the number of collision victims;
- to evaluate different location alternatives from which the research can be carried out (meteo mast, transformation platform, wind turbine);
- to investigate a possible collaboration with field ornithologists to validate the radar data with visual observations.

9.2. Method

9.2.1. Equipment to monitor flying birds

According to De Groote & Roggeman (2006) the desired monitoring needs to be conducted with an Automated Radar System (ARS) that meets the following requirements:

- The ARS needs to be an automatic system that registers data on a continuous basis without the presence of an observer. The data (track identifications or TID's) must be recorded automatically in a database.

- The system will use a dual radar configuration consisting of a horizontal surveillance radar (HSR) and a vertical scanning radar (VSR). The HSR scans in the horizontal plane providing x-y data 360 degrees around the research site and shows the spatial distribution of the birds. The VSR scans in the vertical plane providing y-z data from the ground level to a minimum altitude of 1.5 km. Figure 2 illustrates dual radar coverage with the VSR beam scanning from horizon to horizon and the HSR beam with 360 degree coverage.

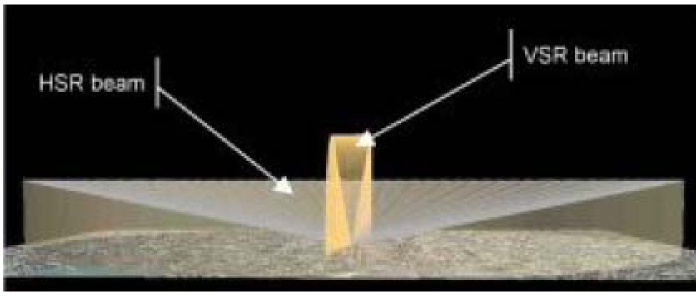

Figure 2. Illustration of the VSR (orange) and HSR (gray) beam coverage (DeTect).

- The system includes specialized sea-clutter suppression software to optimize bird target detection in an offshore environment.

In this study the available existing systems were examined by consulting the literature, by visiting radar research sites and by contacting external experts. Based on those results the best available system will be sought via a call for tender.

9.2.2. Monitoring collisions

The available methods (systems, models) to monitor collisions of birds with wind turbines were evaluated in a similar way as was done for the ARS.

9.2.3. Location

The wind farm area is located too far from the coast to be monitored with an ARS on land. To mount the ARS on a ship is less suited because the data need to be corrected with the movement of the ship and because a ship cannot be present at the research site continuously. De Groote & Roggeman (2006) advise to mount the ARS on an offshore platform in the vicinity of the wind farm.

To monitor the spring migration it would be best to mount the ARS on a platform located NW or SW of the wind farm, during autumn migration NE or SE is better to register the passing birds (De Groote & Roggeman, 2006).

The best available research location at sea will be looked for, taking into account the recommendations of De Groote & Roggeman (2006) and the practical hindrances that can be anticipated.

9.2.4. Visual observations

Visual observation and registration of birds are very important to validate the data delivered by the radar. They also give additional information that is not recorded by the ARS. A limitation of all available systems is that they are not species specific. To determine which species fly in the area, at what altitudes, how their behavior differs, etc., periodic visual observations are necessary.

De Groote & Roggeman (2006) propose some observation techniques. Those observations need to be made by researchers with thorough knowledge of field ornithology. The institutions that are eligible for such observations were contacted.

9.3. Results

9.3.1. ARS equipment

Information was gathered by consulting the internet, from accounts of research done abroad, and by contacting radar experts. The following systems were found to meet the recommendations made in 2.1:

- the Robin Lite system of the Dutch Organization for Applied Nature Scientific Research (TNO);
- the Merlin system of DeTect;
- the Mobile Avian Radar System (MARS) of Geo Marine Incorporated (GMI).

9.3.1.1. Robin Lite

We@sea, a consortium of the offshore wind energy sector contracted the research and development institute TNO to design an automatic bird radar system to assess the effects of offshore wind farms on birds. The result is the Robin Lite system, in witch ‘Robin’ stands for Radar Observation of Bird Intensity. The system consists of a horizontal X- or S-band[1] radar and a vertical X-band radar, a user console and specialized software. The choice for the X- or S-band horizontal radar depends on the study aims: for instance, the smaller wavelength of the X-band is more appropriate to track small birds like passerines, but it is also more sensitive to sea clutter.

The software does the signal and image processing and the automatic data storage. Clutter filtering is of great importance in the signal processing. TNO developed a sea clutter filter, called DEKODO, which improves the signal / noise ratio by filtering the sea wave induced clutter. Figure 3 shows an image with and without sea clutter filtering. In the picture on the right hand side the typical wave pattern is reduced by the sea clutter filter which makes it possible to track birds (yellow dots) in a high clutter environment.

[1] an X-band radar has a signal wavelength of 3 cm, the S-band a wavelength of 10 cm.

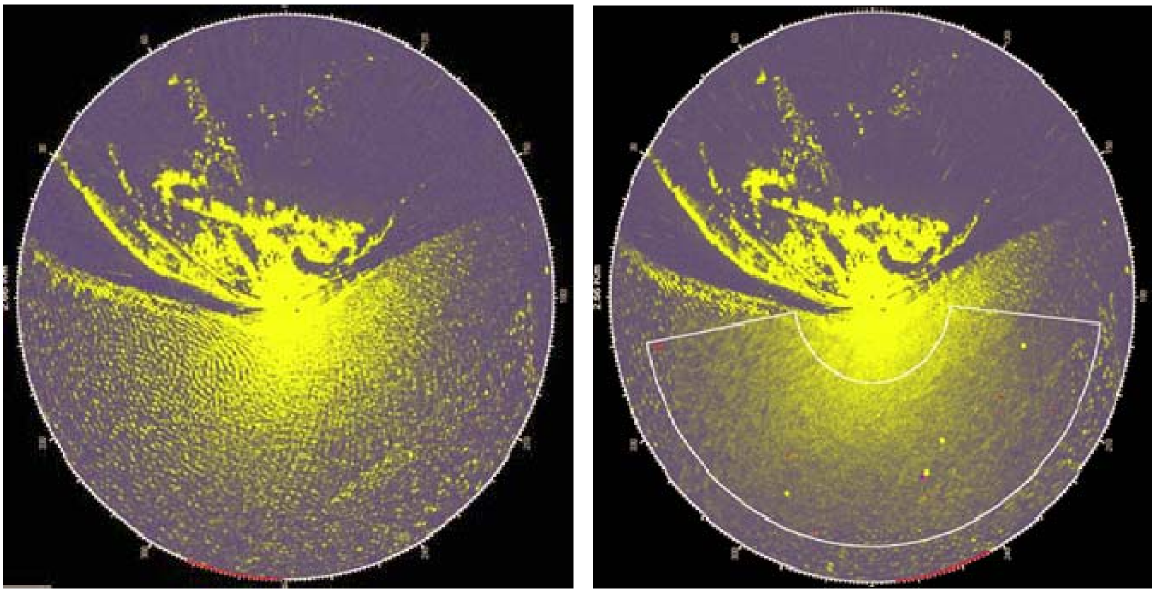

Figure 3. Reduction of sea wave induced clutter by the DEKODO filter (source TNO).

The recorded data are presented as bird tracks in a geographical information system and can, for example, be visualized in Google Earth where it is possible to zoom on individual tracks. This is shown in figure 4.

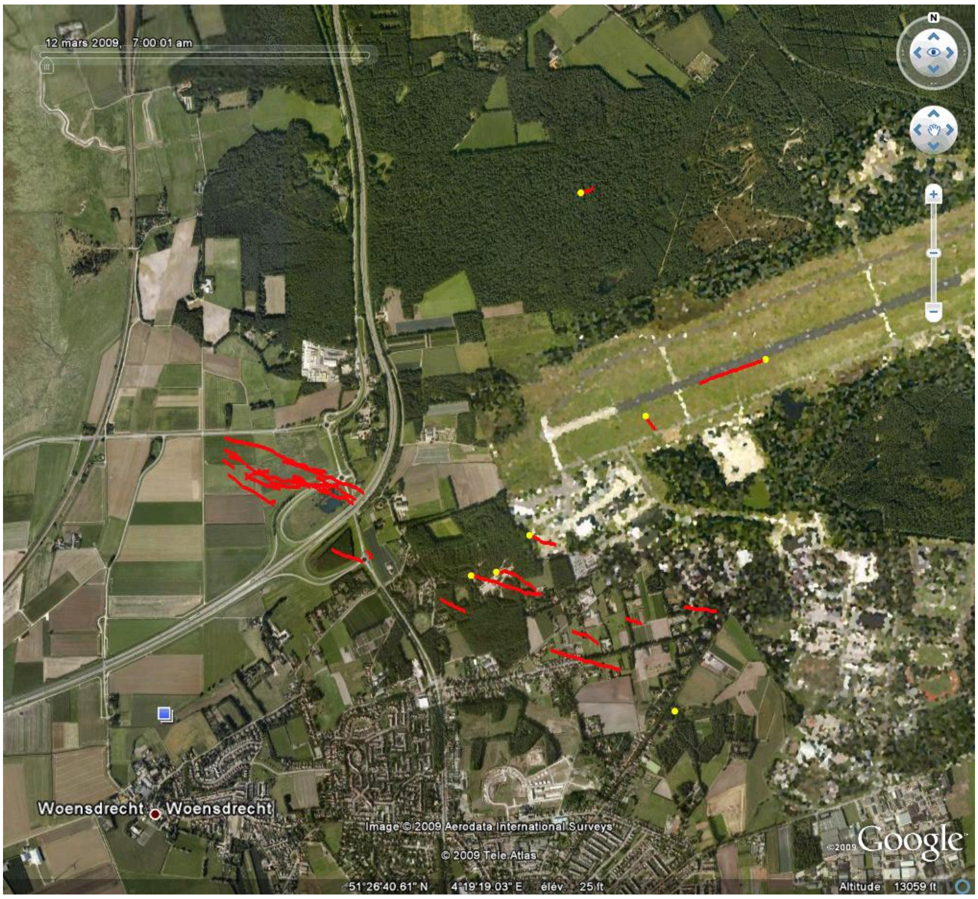

Figure 4. One-minute bird tracks (6.00 a.m. – 6.01 a.m.) recorded by the Robin Lite system on the military airport of Woensdrecht (The Netherlands; Source TNO). Every red line is one bird track.

In the database every bird echo is stored. Those data have a lot of different parameters (for example speed, size, direction, time, etc.) that can be consulted and can be post-processed.

The range of the VSR is from ground level up to 3.5 km, the HSR has a maximum range of 10 km for large birds and flocks of birds (A. Borst pers. comm.). Smaller birds can be detected up to 6 km.

The Robin Lite is being tested at a military airport in Woensdrecht (The Netherlands), the results of these tests are used to fine-tune the algorithms of the signal processing. On april 15, 2008 the site in Woensdrecht was visited. It was possible to see the system function and to simultaneously watch birds and see if the radar recorded them. Pigeons, crows and a hawk were visually spotted and also seen on the radar viewing system.

9.3.1.2. Merlin

The company DeTect (USA, Florida) developed the 'Merlin radar system' specifically for detection and tracking of birds and bats. The system is automated, can operate unattended and can be remotely controlled and data accessed via wireless and network connectivity. It is a dual radar system with an S-band HSR and an X-band VSR. The effective range of the VSR is 3 to 5 km and 5 to 7 km for the HSR. Merlin software processes, analyses and records the radar information. The top image in figure 5 shows a raw (unprocessed) radar screen image. The white spots are birds during heavy migration. The concentrated white is clutter. The bottom image is processed with the Merlin software. The bird targets are converted into clear symbols with history tracks (target trails).

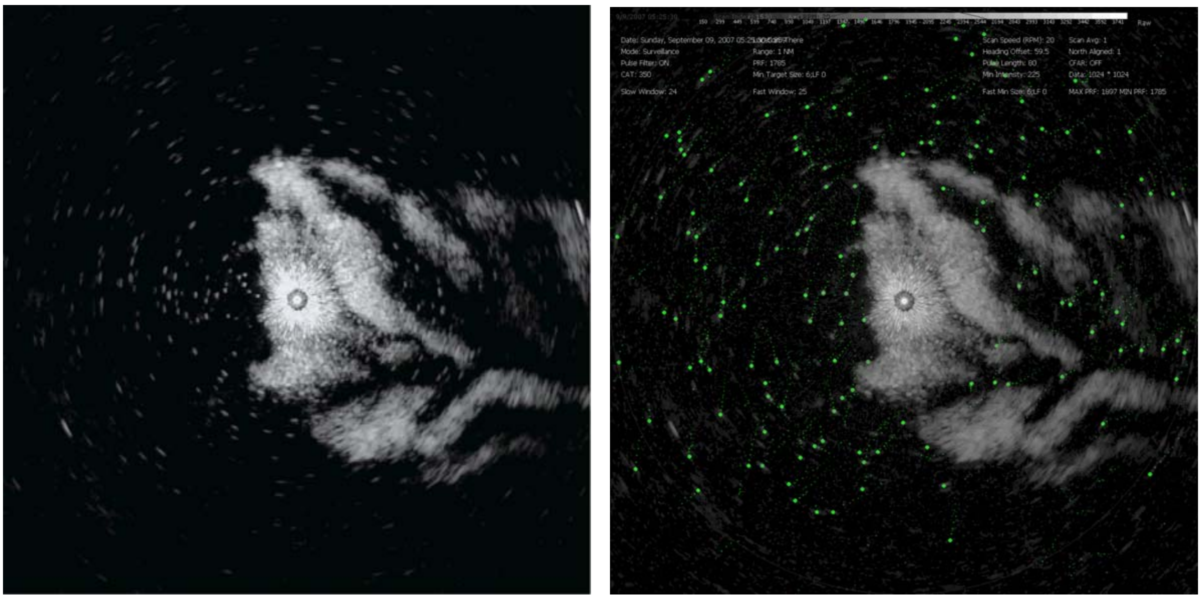

Figure 5. Heavy migration seen on horizontal radar; before and after processing by Merlin software (Source: DeTect).

The Merlin software has several clutter suppressing algorithms to improve bird detection in high clutter environments. In addition, several new clutter features will be available standard on 2009 Merlin radars. Furthermore, Detect is designing new adjustments to minimize sea clutter. For instance, a sea clutter filter is being designed that takes wave characteristics into account.

To validate the radar data and to collect additional information, the Merlin software has a bar in the interface in which you can assign a radar registration to a species in the list of the bar. Those links are directly recorded in the database. This technique is called 'flagging' (Krijgsveld *et al.*, 2005).

Data can also be displayed in real-time or exported to GIS and Google earth. The target records in the database can be queried and analyzed.

Additionally DeTect developed the *detect & deter* software as a controller system for high bird mortality risk projects. It is possible with this software to interconnect with the SCADA (Supervisory Control and Data Acquisition) software of the wind turbines in high risk conditions (ex. heavy migration) and automatically idle the turbines.

Merlin has been used to conduct offshore pre-construction surveys of proposed wind farm projects. In 2003 Bureau Waardenburg (BuWa) was contracted by Shell to assess the effects of offshore wind turbines on birds at the Near Shore Windpark Noordzeewind site (Egmond aan Zee, The Netherlands). BuWa tasked DeTect to design, construct, install, start-up and support a Merlin ARS. The pre-construction study started in September 2003, the post-construction survey in December 2006.

The radar hardware at the Noordzeewind site works well and has no problems with very high wind speeds. The VSR delivers a sound dataset with little clutter. Those data are very useful to know the altitude of the birds and to determine the flux in that area. The HSR data of the pre-construction were highly influenced by sea clutter. Those data were post-processed by DeTect and they provided additional clutter suppression algorithms and queries. The range of the HSR radar was set by BuWa at 3 nm (per. comm. K. Krijgsveld).

In the Beatrice Wind Farm (Scotland) the University of Aberdeen uses a Merlin ARS to do similar research as BuWa. The Central Science Laboratory (CSL) from the UK does on- and offshore research with two Merlin ARS.

9.3.1.3. Mobile Avian Radar System (MARS)

MARS is developed by GMI (Dallas, USA) and is a similar system to Merlin and Robin Lite. The producer never replied to the question if it would be applicable for an impact study of an offshore wind farm in the Belgian part of the North Sea. Therefore this system will not be described in this report.

9.3.2. Bird collisions

It is impossible to register bird collisions with an ARS (Desholm et al., 2006). The risk of birds colliding with turbines can be assessed with collision models or with specially designed devices. To carry out surveys underneath offshore wind turbines to find collision victims (possibly during heavy migration) is not realistic and will not deliver reliable data because of the loss of collision victims by sinking, drifting off and scavenging.

The Wind Turbine Bird system (WT Bird) was developed by the Energy Research Centre of the Netherlands (ECN) to register bird strikes on continuous remote operation. It is a combination of acoustic detection and video registration. The system consists of acoustic sensors that are placed on each blade. It registers the vibrations that are generated by the impact of a bird collision. The video runs continuously and registers the images just before and after the collision and makes species identification possible (Wiggelinkhuizen et al., 2006). Several prototypes were tested on onshore wind turbines with bird dummies. Tests on offshore turbines have not yet been done. The price for one WT Bird is in the order of 30.000 € (pers. comm. E. Wiggelinkhuizen).

Thermal Animal Detection System (TADS) is a remote technique for counting and estimating the number of bird collisions with a wind turbine based on infrared imaging (Desholm et al., 2006). The device creates pictures based on the heat energy emitted by objects. The advantage of these devices is that birds can be registered during the night and adverse bad weather conditions. When an object in the field of view exceeds a temperature threshold the video sequence is stored onto the hard disk. So not only colliding birds are recorded, also birds passing in the view of the camera are registered. TADS have been used in the Nysted offshore wind farm (Denmark) since 2003 on one turbine. To date no collisions have been registered (Desholm et al., 2006). The cost price of a TADS is in the order of 40.000 €.

In the wind farm on Smøla (Norway) a remote control camera and an infrared camera were mounted on a turbine. No collisions are reported to date.

9.3.3. Location

From several contacts with DeTect and TNO it is clear that the location for installing the ARS needs to comply with the following requirements:

- room on the top height[2] of the platform to install the radar antennas;
- power supply of 220 V AC;
- a data uplink to shore with a limited band width (the fiberoptic in the electrical cables of the windfarms can be used; 1 fiberoptic pair would be sufficient to transfer the data);
- a dry space to put an air conditioned computer cabinet;
- a room were two monitors can be placed and were two persons can work and stay for several days.

Practically there are three possibilities to install the ARS in or close to the wind farms that comply with the above mentioned requirements: namely the platform at the base of a turbine, an offshore high voltage station (OHVS) or a meteo mast.

The two already licensed wind farm projects chose not to install the ARS on a single turbine because of safety reasons and limited space. From radar technical point of view it is also not ideal because of the shadow effect of the turbine.

Every wind farm will install one or two OHVS. Those stations meet all requirements but are located inside the wind farm. According to Christensen & Hounisen (2004) the shadow effect of the surrounding turbines makes an OHVS inside a wind farm unsuited as a location for an ARS. But consultation with the ARS developers indicated that this is not a big problem: it just results in blind spots in the study area. The Robin Lite and Merlin software try to remedy that problem: when a bird is registered, then disappears behind an obstacle and then becomes registered again, the software will combine those registrations as one bird track. The ARS on Smøla (Norway) is set up in the middle of the wind farm and this gives no problems to register birds.

C-Power will build one OHVS, its location being shown in figure 6. Belwind will place two OHVS in the windfarm (figure 7). They will probably be built in 2010 and 2011.

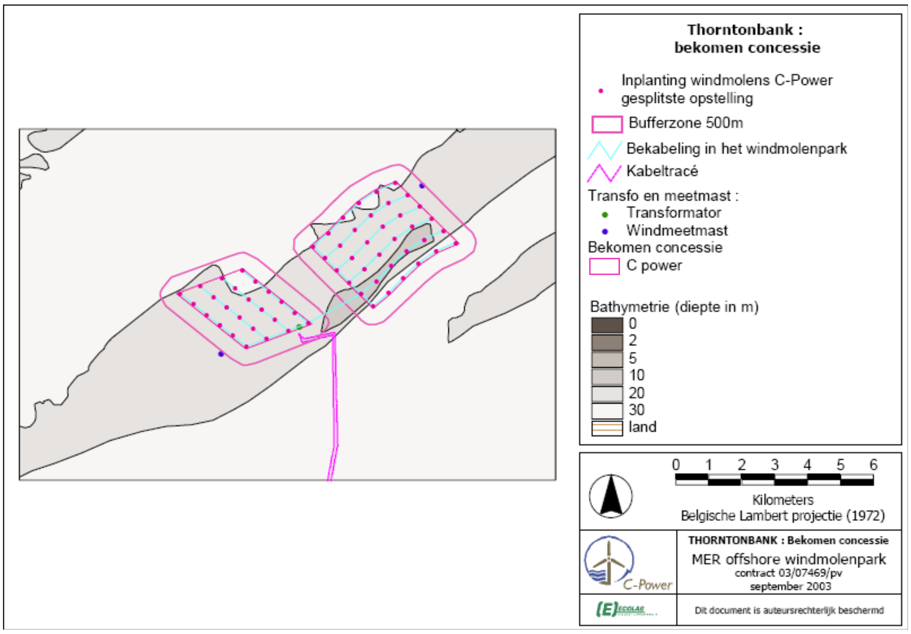

Figure 6 Location of the OHVS of C-Power (MER C-Power, Ecolas 2003).

[2] There is no health risk when you are at another height than the radar antenna. Therefore it would be ideal to mount the radar antennas on the top level of the platform. Long term exposion with radar signal at eye height is harmful. Therefore it is advised to put the antennas in stand-by when you are closer than 10m. This is the procedure that Bureau Waardenburg follows (pers. comm. A. Smith, DeTect).

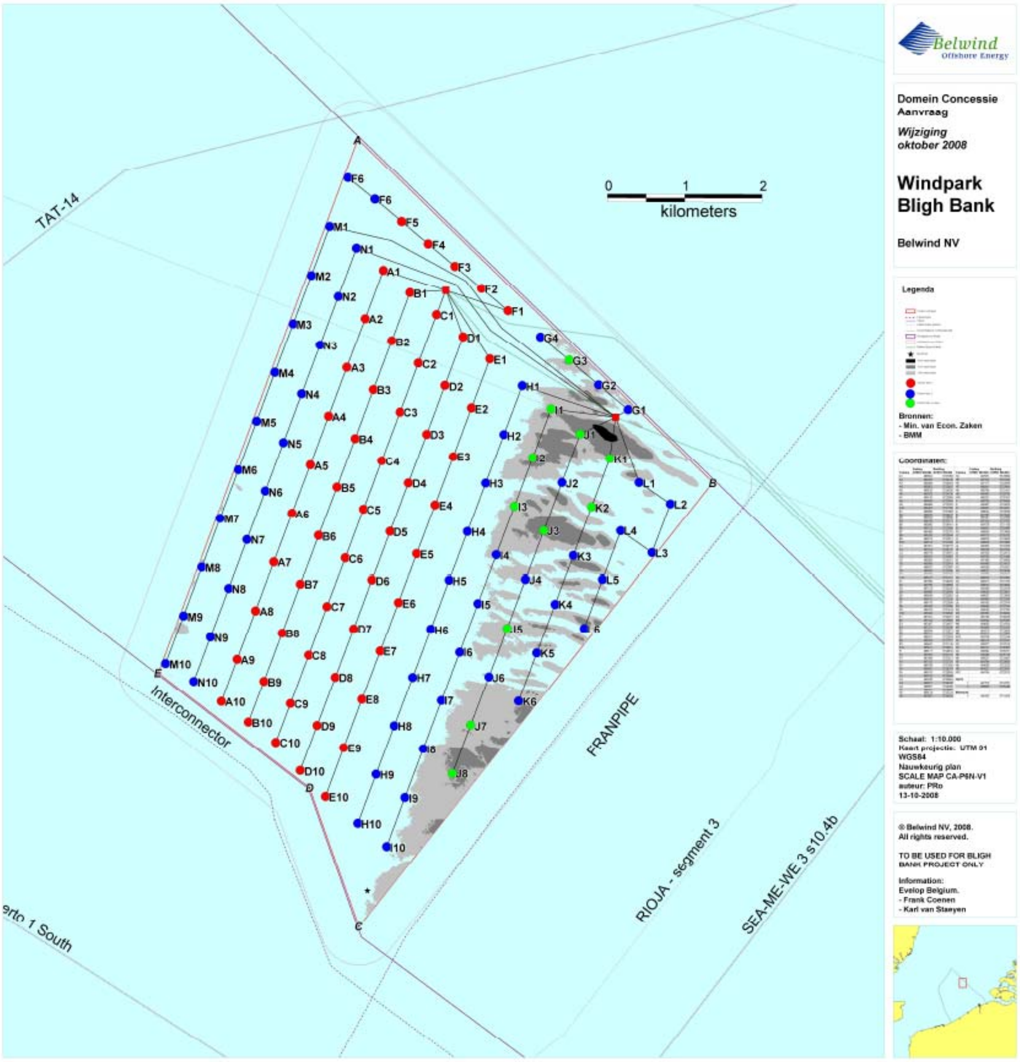

Figure 7. Location of the two OHVS (red squares) of Belwind (Royal Decree of 5 February 2009).

A meteo mast would also be suitable for the installation of an ARS. At this time the number of meteo masts and their location is not clear.

9.4. Discussion

The ARS that were described comply with the requirements made by De Groote & Roggeman (2006). They are basically very similar systems with the same abilities and limitations. Merlin, however, is the only system that has been used to conduct offshore surveys since 2003. DeTect has gained a lot of experience with the Merlin system in conditions similar to the Belgian part of the North Sea and has led to improvements of the system. Robin Lite has been intensively tested onshore, but not yet offshore. It must however be emphasized that TNO has developed a sea clutter filter (DEKODO) and that consequently Robin Lite is an operational system ready for offshore use. A third system (MARS) is available in the USA, but our enquiries there met with no success.

The Robin Lite system can be used with a X- or S-band HSR. However, for an offshore survey it would be best to work with an S-band radar. An X-band radar is better to register small birds like passerines, but it is more sensitive to clutter because the wavelength of the radar signal is shorter. Clutter will be the biggest problem in this research so it might be better to choose the option that is the less sensitive to clutter, with the disadvantage that it is less appropriate for registering small birds.

The currently available systems for registering collisions of birds with turbines do not seem useful at this stage of the monitoring.

There are several disadvantages with those systems:

- high cost price of individual system;
- WT Bird has not been tested on large turbines like the types used offshore;
- one or a few systems in a wind farm do not generate a large amount of data which makes it difficult to extrapolate the data to an entire wind farm and conclude what the effect is at te population level.

At this time it seems more useful to calculate the number of collision victims with existing models. In the framework of an existing contract between MUMM and INBO, INBO is measuring the flux of birds in the wind farm area on a monthly basis. INBO uses the results of those surveys to estimate the mortality risk using collision models. The data from the VSR (fluxes, altitudes) will be used as input for the collision models. This will calculate the mortality risk calculates more reliable than the results based on visual flux counts.

The different OHVS and the meteo masts seem to be the most appropriate locations for mounting the ARS as apposed to a single wind turbine. There will not be an OHVS installed at sea before 2010, so that before that time it would be useful to install and test the ARS at an onshore location. This will give the researchers the ability to spend time with the system, which is not always possible offshore, and to get acquainted with the data. The harbour of Zeebrugge seems a suitable location: there is intense bird activity, there are wind turbines on the jetty, the sea can be overviewed with the radar so the sea clutter filter can be tested and the data can contribute to research on the tern colony in the harbor.

MUMM has several scientists who would be able to do the flagging observations. But collaboration with INBO is a valid option because of their yearlong experience in monitoring birds in the Belgian part of the North Sea with standardized methods.

9.5. Conclusions

- The systems that were compared are both fit for purpose. In compliance with European legislation a public call for tender will be published and the received quotations will be evaluated on several criteria. The best suited ARS within the limits of the allocated budget will be purchased.

- The wind farms developers were asked to take the location requirements (3.3) into account in the design of their OHVS. So several locations will be suitable to mount the ARS. If needed, the ARS can be moved after a certain period to another platform. Before a OHVS is installed, the ARS will be mounted in the harbour of Zeebrugge.

- The bird mortality risk will be estimated by INBO with existing models based on visual and radar fluxes.

- The flagging and other visual techniques to validate the radar data and to gather species specific information (Krijgsveld *et al.*, 2005; De Groote & Roggeman, 2006) will be tested during the time that the ARS is installed onshore.

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Chapter 10. Monitoring of marine mammals in the framework of the construction and exploitation of offshore wind farms in Belgian marine water

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Photo's Jan Haelters / RBINS

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Abstract

For assessing the possible effects of the construction and exploitation of offshore windfarms on marine mammals, a monitoring plan was developed. This plan aims to both assess short-term and long-term effects, and requires a combination of different research methods. The monitoring results for 2008 can evidently not conclude about possible effects. Rather, 2008 was a year in which the monitoring programme was developed into detail, and in which methods were tested in the field. Given that the most abundant marine mammal in Belgian waters is the harbour porpoise *Phocoena phocoena*, research was focused at this species, although possible effects on other species are and will be assessed. The monitoring plan follows a BACI design: assessing the situation before, during and after the construction, and in both the impact zone as a control zone. The monitoring consists of the following disciplines: (1) aerial monitoring of porpoises to estimate ad hoc densities and distribution, using an internationally agreed methodology (line transect sampling); (2) use of static acoustic devices (PoDs) to determine presence of porpoises and dolphins at selected locations over a longer period of time; (3) assessment of other relevant data becoming available, such as originating from other monitoring activities around the windfarm areas (such as bird censuses) or from stranding schemes; (4) assessment of the possible impact of increased levels of underwater noise on marine mammals. The aerial surveys performed in 2008 yielded an estimation of 4,341 (2,630 – 7,167) porpoises present in Belgian waters at the beginning of April 2008, or a density of 1,21 (0.73-1.99) animals per km². A limited survey in May yielded lower numbers. The estimates are consistent with the data obtained from a large survey in 2005 (SCANS II). They confirm that at least up to 2008, fairly high densities of porpoises occurred in Belgian waters in spring until April. One of the conclusions of the analysis was that more surveys should be undertaken to be able to have more reliable estimates, and to be able to produce density surface models. At the end of 2008 four C-PoDs (porpoise detectors) were obtained. These static acoustic devices capable of demonstrating the presence of small cetaceans in the vicinity could not yet be deployed during 2008. Instead, a cost-efficient mooring system was designed, and mooring locations were selected. An analysis of

strandings data indicated that during 2008, a lower number of porpoises had washed ashore than in previous years. Also sightings from the coast have declined. Reasons for this are unknown, but it is clear porpoises remained further away from the coast, while still being present in large numbers further offshore in Belgian waters. The results of the underwater noise measurements during construction works on the Thornton Bank indicated levels similar those produced by merchant shipping. While it was possible that porpoises would avoid the area around the construction site, in a similar way as they usually avoid motorised vessels, this noise level was of little concern, given its level and duration. However, due to several circumstances the noise level of certain more relevant and specific construction activities potentially causing higher levels of underwater noise, such as the laying of the scour protection, could not be investigated during 2008.

Samenvatting

Om de mogelijke effecten van de constructie en exploitatie van offshore windparken op zeezoogdieren in te schatten werd een monitoringplan ontwikkeld. Dit plan heeft tot doel zowel korte- als langetermijneffecten vast te stellen, en maakt noodzakelijkerwijs gebruik van verschillende onderzoeksmethodes. De resultaten van het onderzoek uitgevoerd in 2008 kunnen vanzelfsprekend nog niet tot besluiten leiden over mogelijke effecten. De monitoring in 2008 was eerder gericht op het ontwikkelen van het plan en het uittesten van de methodologie in het veld. Het meest algemeen voorkomende zeezoogdier in Belgische wateren is de bruinvis *Phocoena phocoena*; vandaar dat het onderzoek zich vooral op deze soort richt heeft; waar mogelijk echter, worden ook effecten op andere soorten ingeschat. Het monitoring plan volgt een BACI ontwerp: onderzoek van de situatie voor en na de werken, in het projectgebied en controlegebieden. De volgende deelstudies worden onderscheiden: (1) de monitoring van bruinvissen vanuit de lucht door middel van een gestandaardiseerde methodologie (*line transect sampling*) voor het inschatten van aantallen en verspreiding; (2) het gebruik van statische akoestische toestellen (PoDs) om de aanwezigheid van bruinvissen en dolfijnen over een langere periode vast te stellen in geselecteerde locaties; (3) het onderzoek van andere beschikbare gegevens, zoals deze verzameld in het kader van de zeevogeltellingen of van het onderzoek van gestrande zeezoogdieren; (4) het inschatten van de mogelijke effecten op zeezoogdieren door de verhoging van het onderwatergeluid. Het onderzoek vanuit de lucht in april 2008 leverde een schatting op van 4.341 (2.630 – 7.167) bruinvissen in Belgische wateren, of een dichtheid van 1,21 (0,73-1,99) dieren per km². Een meer beperkte campagne in mei leverde een veel lagere schat op. De schattingen zijn in overeenstemming met een uitgebreid internationaal onderzoek uitgevoerd in 2005 (SCANS II). Ze bevestigen dat, ten minste tot 2008, tamelijk hoge dichtheden aan bruinvissen voorkwamen in Belgische wateren in het voorjaar tot april. Eén van de conclusies van het onderzoek is dat meer campagnes moeten uitgevoerd worden om meer nauwkeurige schattingen te kunnen maken en voor het samenstellen van een verspreidingsmodel. Eind 2008 werden 4 C-PoDs (Porpoise Detectors), akoestische toestellen die de aanwezigheid van bruinvissen en dolfijnen kunnen aantonen, bekomen; ze konden echter in 2008 nog niet ingezet worden. In 2008 werd het verankeringssysteem ontworpen, en er werd een keuze gemaakt van verankeringslocaties. Door analyse van strandingsgegevens bleek dat in 2008 minder bruinvissen aangespoeld waren dan de jaren daarvoor. Ook het aantal waarnemingen vanaf de kust bleek gedaald. De bruinvissen bleken in 2008 nog in tamelijk hoge aantallen aanwezig in Belgische wateren, maar bleven om nog onduidelijke redenen relatief verder van de kust weg dan voorheen. Het onderzoek van onderwatergeluid tijdens de constructiewerken op de Thorntonbank toonde aan dat de geluidsniveaus gelijkaardig waren als het geluidsniveau veroorzaakt door scheepvaart. Terwijl het mogelijk was dat bruinvissen de constructiesite vermeden, zoals ze gewoonlijk ook gemotoriseerde schepen vermijden, was dit geluid – gezien het niveau en de beperkte duur - geen reden tot bezorgdheid over effecten. Door omstandigheden kon in 2008 echter nog geen beschrijving gemaakt worden van het geluid veroorzaakt bij activiteiten typisch voor de constructie van offshore windparken, zoals het leggen van de erosiebescherming.

10.1. General introduction on marine mammal monitoring

The environmental impact assessment of the construction and exploitation of offshore windfarms in Belgian waters concluded that gaps in knowledge existed concerning their possible environmental effects on marine mammals, but that effects were possible. Consequently, a monitoring plan was developed. Monitoring the effect is a prerequisite for the validity of the construction permit and exploitation licence. All marine mammals are protected species, for which Belgium made commitments in international fora to avoid negative impacts as much as possible. Monitoring the effects of certain activities on these animals is also a legal obligation under international law, amongst which the Habitats Directive[1].

The most abundant marine mammal in Belgian waters is the harbour porpoise *Phocoena phocoena*. Other indigenous species which occur in the area are common seal *Phoca vitulina*, grey seal *Halichoerus grypus*, bottlenose dolphin *Tursiops truncatus* and white-beaked dolphin *Lagenorhynchus albirostris* (www.mumm.ac.be; Camphuysen & Peet, 2007; SCANS II, 2008; Haelters, 2007). Given that these other species are far less numerous, and some of them remain fairly coastal, monitoring of the effects of the construction and exploitation of offshore windfarms will focus on the harbour porpoise. It has been demonstrated that seasonally relatively high densities of this species can occur in Belgian waters (Depestele *et al*., 2008; Haelters & Camphuysen, 2009). Moreover, this is a species which is particularly sensitive to disturbance, amongst others originating from underwater noise (MUMM, 2004; MUMM, 2007). However, any information on marine mammals other than porpoises becoming available will be reported.

Through the monitoring we will aim at assessing the short-term and long-term effects of the construction and exploitation of offshore windfarms on marine mammals. The monitoring programme aims at finding out whether these activities have a measurable effect on porpoises and possibly also on other marine mammals. Given the changes in marine mammal populations we have observed in the last years (Haelters & Camphuysen, 2009), and the difficulties in studying marine mammals in the wild, this is a very challenging task, requiring a suite of methods.

This document reports on the preparatory activities for the monitoring, and on the results of the monitoring in 2008. There is a steep learning curve for the different monitoring disciplines, and more detailed investigations will be conducted over the years to come. Some of the monitoring, such as the one with passive acoustic devices, needs to be started in the field in 2009. Although this monitoring is predominantly of a long-term nature, the possibility of acute impacts should not be excluded, especially during the construction phases of the projects.

It is clear that the monitoring results presented here are preliminary, and cannot yet conclude about effects. Rather they should be considered as a description of the monitoring programme which will be continued over the following years. We will only be able to present more elaborated conclusions on the impacts on marine mammals after several years.

Given the subject of this report, the wide-ranging nature of marine mammals, and the initial development of only one of the windfarms in 2008, it has not been possible to subdivide every part of this report into sections for each of the windfarm areas separately. Moreover, the inaccuracy of our knowledge on that matter makes (and will make) such a spatial segregation in many cases very difficult.

10.2. Development of a monitoring programme

Assessing the effects of the construction and exploitation of offshore windfarms on marine mammals is not straightforward. A monitoring programme should be developed to obtain data before and during the construction phase, and during the exploitation phase, both within and outside the windfarm area (BACI design: before-after, control-impact zone). Moreover, to be able to identify cause-effect relationships, data should be collected not only on porpoises and other marine mammals, but also on relevant physical and biological changes occurring in the marine environment due to the construction and exploitation of the wind turbines.

[1] European Directive EC/92/43

Such a monitoring programme is clearly multidisciplinary and different techniques need to be used. In 2008, the first phase mainly consisted of the development of the monitoring strategy and of the development and fine-tuning of the methodology. In many cases the monitoring methods have been developed only recently. The different disciplines of the monitoring programme can be summarised as follows. They are dealt with in detail in the following chapters of this report.

1) Aerial monitoring of porpoises (and other marine mammals): regular assessment of numbers and densities over a large area, including the windfarm areas; in combination with density surface modelling, distribution maps will be prepared – these can only give an ad hoc impression of local densities and distribution of marine mammals in Belgian waters.
2) Monitoring of porpoises and dolphins with passive, static acoustic devices (porpoise detectors or PoDs), complementary to aerial surveys: estimation of the relative abundance of porpoises over a longer period, in the windfarm areas and in adjacent areas.
3) Other monitoring activities, such as bird surveys in and around wind farms, or the assessment of strandings data, can yield additional information on marine mammals.
4) The investigations of the underwater noise level during the construction and exploitation phases (see Chapter 3), together with the results of the research described above and the consultation of literature, can lead to the identification of possible short-term and long-term effects.

Prior to the execution of the monitoring programme, detailed protocols, which are similar to the protocols used in neighboring countries, were prepared for disciplines 1, 2 and 4 (MUMM, 2008a; b; c). Subsequently the field work was started. Where necessary the protocols will be adjusted – therefore these should be considered as *dynamic documents*.

Individually and in combination the results of the studies described in this report can provide qualitative and quantitative information of the effects on marine mammals, and especially on harbour porpoises. Consequently, they will provide a basis for the possible adjustment of activities in relation to the construction and exploitation of windfarms, and the establishment of relevant preventive actions and mitigation measures. Such measures can consist of alternative foundations to be used in the future, or the use of systems limiting underwater noise.

10.3. Aerial monitoring of harbour porpoises and other marine mammals

10.3.1. Introduction

Different methods to assess the population size, density and distribution of marine mammals exist. A cost-efficient means is the aerial monitoring through standardised *line-transect surveys* (SCANS II, 2008). In a protocol (MUMM, 2008a) the basic principles of line transect surveys are described, together with technical details on the monitoring itself and on the data analysis. A summary of the protocol is presented below.

10.3.2. Material and methods

10.3.2.1. Aerial line transect sampling

Aerial surveys have important advantages over other types of survey, such as ship-based surveys. Compared to ship-based surveys, an aerial survey can cover a much larger area in a similar stretch of time, and is independent of water depths or restricted shipping areas.

In executing aerial monitoring flights, it is important to use a methodology that can be repeated, that yields data that can be analysed in a standardised way, and that is internationally accepted. The theoretical background of the methodology used is *line transect sampling* (Buckland *et al*., 2001).

This background was used for the methodology of the aerial monitoring in the 2005 SCANS II project, in which numbers and distribution of small cetaceans in the North Sea and the adjacent Atlantic Ocean were assessed (SCANS II, 2008). The SCANS protocol had to be simplified for this monitoring programme, due to technical and budgetary limitations.

In aerial line transect sampling (figure 1), a series of independent tracks (line transects) are flown, during which sightings are recorded at non-predefined distances from the track line. The length of each transect is carefully recorded, together with the distances of sighted animals from the track line.

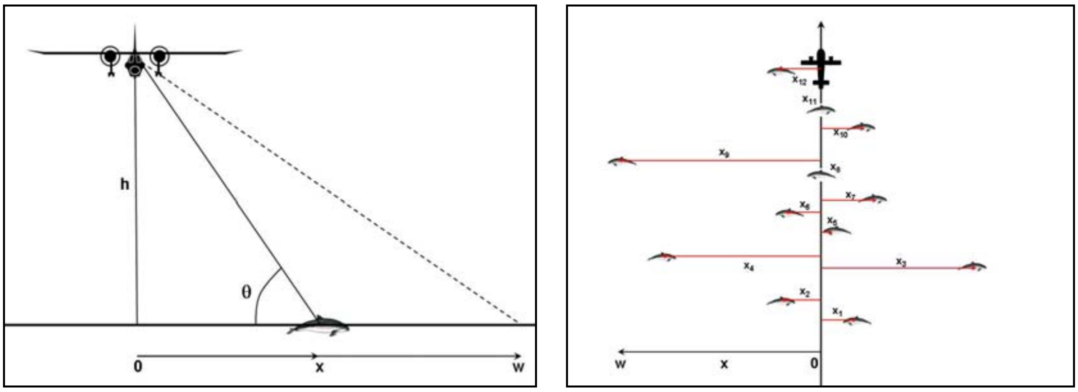

Figure 1. The principle of line transect sampling: determining perpendicular distances from the aircraft.

To determine the perpendicular distance to the trackline, the altitude is recorded, and the angle θ between the horizon and the perpendicular line to the animal(s) is measured. The perpendicular distance x is then given by:

$$x = h \times \tan(90° - \theta)$$

The largest observation distances may differ at the left and right side of the aircraft. Therefore all observation distances are made *positive*, as if they were made on one side of the aircraft (all observations at the *negative* side are *folded* over the trackline) – as such, we obtain only one value for the largest observation distance presented by w. The fraction of the survey area covered by observers at the left and right side of the aircraft is $2wL$, in which L indicates the total survey length and w the largest detection distance.

Not all animals are detected between distance 0 (underneath the aircraft) and w, even if we assume that all are at the surface. The probability of detection decreases with the increase in distance between the trackline and the animal(s). If enough observations are made in a survey, the probability of detecting a porpoise or a group of porpoises at a given distance x from the trackline can be described with a detection probability function g(x), in which we assume that g(0)=1 and $0 \leq g(x) \leq 1$ (figure 2). This function can be used to estimate the proportion of animals missed.

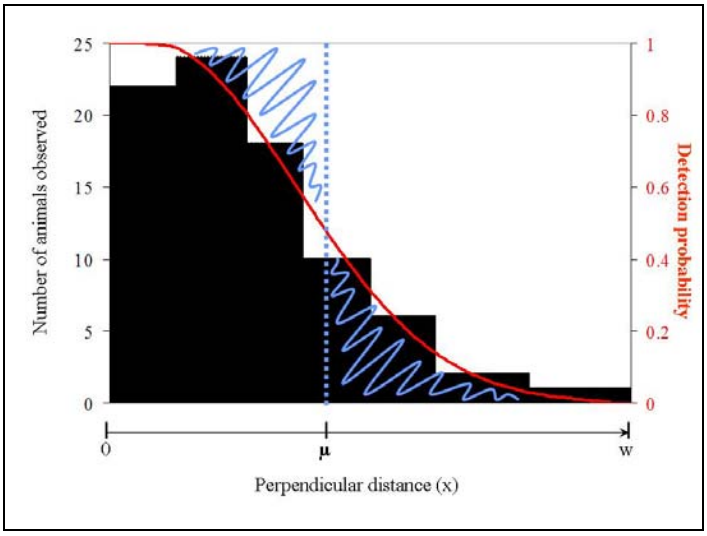

Figure 2. Illustration of the theoretical background of line transect sampling (simulated data): number of animals counted per distance interval (black boxes, left y-axis), detection probability function (red line, right y-axis); the detection probability function g(*x*) is forced through 1, and is strictly declining. The areas marked in blue have the same surface (see text).

The probability $\hat{P}_a$ of detecting an animal would then be described as:

$$\hat{P}_a = \frac{surface\ under\ curve}{surface\ under\ rectangle} = \frac{\int_0^w g(x)dx}{1 \cdot w} \qquad (1)$$

We define the *effective half strip width* μ (ESW) as the theoretical width of the track in which as many animals are not detected, as are detected outside this width (figure 2). For the ESW μ we can write:

$$1 \cdot \mu = \int_0^w g(x)d(x) \qquad (2)$$

Equation (1) thus becomes:

$$\hat{P}_a = \frac{\mu}{w} \qquad (3)$$

And the fraction of the survey area covered can be written as:

$$2wL = \frac{2\mu L}{P_a} \quad \text{or} \quad 2wLP_a = 2\mu L \qquad (4)$$

In figure 2 and in the above equations we presumed that g(0)=1. This is not correct, as some visible animals on the track are missed by the observers - therefore g(0) will be smaller than 1. This deviation from g(0)=1 will be influenced by many factors, including the experience of the observer, and the length of time since the start of the flight (Southwell *et al*., 2007). Secondly, other animals are missed because they were not visible from above (e.g. diving). Therefore a second correction factor needs to be considered for g(0), which will be dependent on weather and monitoring conditions.

Taking account of g(0), and the above equations, the total number of animals $\hat{N}$ in the survey area *A* can be estimated as follows, with *n* as the total number of animals observed:

$$\hat{N} = \frac{nA}{2\mu L} \frac{1}{g(0)} \qquad (5)$$

The density can be estimated accordingly. We assume that the detection probability of a group of porpoises and of a solitary porpoise are equal, and that the detection function is independent of the density of animals, their position in the survey area, and their activity.

Although a double-observer line transect, in which two observers work independently at the same side of the aircraft, would be able to indicate the level of deviation from g(0)=1 for animals missed by observers, this would not be possible during the monitoring described here for technical reasons, and this bias is not further taken account of. The limited monitoring programme did not allow for an assessment of g(0) for animals missed given they were not visible from above: this would need a survey with two aircraft, or the systematic return to each sighted animal on the trackline.

10.3.2.2. Aerial platform

The aircraft we used for the aerial surveys is the surveillance aircraft of MUMM (figure 3). This Britten Norman Islander is equipped with a bubble window (figure 4) and a computer connected to a GPS system to record tracks and positions. Flight altitude and ground speed were kept as stable as possible at respectively 600 ft and 100 kts.

As the surveillance aircraft of MUMM was equipped with only one bubble window during 2008, it was assumed that only the observations at this side would be useful for calculating densities and abundance. This was tested during the 2008 pilot surveys with two observers, one at the bubble window, the other one at a regular window; the results are given below.

Figure 3. Surveillance aircraft used during the marine mammal surveys (photo: Thierry Hubin / RBINS).

Figure 4. In 2008 the surveillance aircraft was equipped with one bubble window, allowing for observations underneath the aircraft (photo Jan Haelters / RBINS).

10.3.2.3. Survey tracks and collection of data

To obtain a general picture of the distribution of porpoises in Belgian waters, and to be able to detect changes due to the construction and exploitation of wind turbines, a larger area than the windfarm area needs to be monitored. For practical considerations, the survey design covers the larger part of Belgian waters (figure 5). The tracks are 5 km apart and follow a direction of 314°. This distance was large enough to avoid double counts, and to allow for a sufficient coverage of Belgian waters within a reasonable time frame. The tracks were fixed between waypoints, but were considered as *ad random*, even if they were repeated during different surveys and were pooled afterwards to obtain a better estimate of abundance (this can only be done if the surveys are performed within a short timeframe of at the most a couple of days; the repeated tracks are then considered as *new tracks*, as if they were at a different location). This simplification was especially made given aspects of flight control and aircraft GPS settings, but was considered also acceptable given the similarities of seabed features between tracks and the mobility of marine mammals. The choice of the direction of 314° was made to cross a potential inshore-offshore gradient, thus avoiding a bias which could occur if both inshore and offshore tracks would have been chosen.

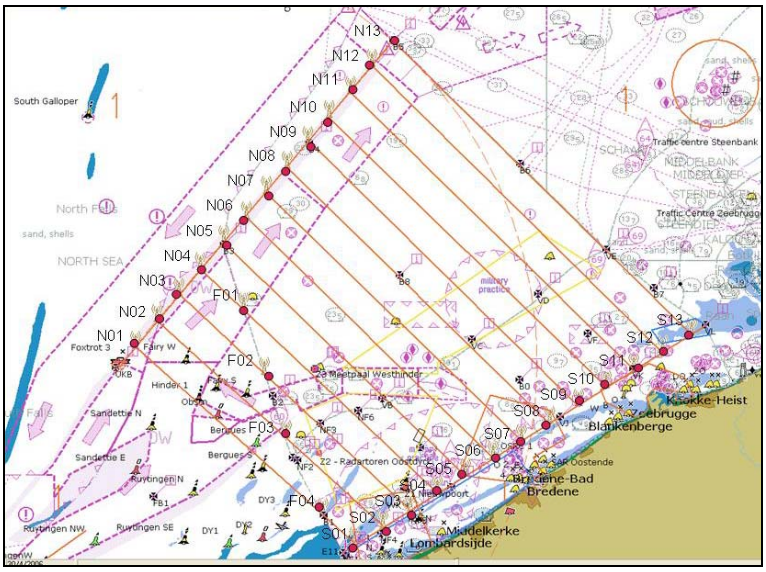

Figure 5. Survey design (orange tracks) for the aerial surveys of marine mammals. The delimitation of Belgian marine waters is indicated (grey dotted line); TRESCO map. For flight-technical reasons waypoints were not chosen on the coastline, but at a slight distance.

Monitoring flights were tentatively only performed during good weather conditions (seastate ≤ 2 and visibility > 2 km). This should allow for an optimal utilisation of efforts, the possibility to compare data gathered during different flights, to use only one g(0), and to pool data for establishing an appropriate detection probability function in case of only few observations during a survey. During flight, changes in seastate, glare, cloudiness and turbidity of the water column were noted, together with a subjective assessment of observation conditions for each observer, ranging from good to moderate and poor.

For each observation the following information was recorded and analysed: position (GPS event), species, number (cluster or group size) and perpendicular angle. The perpendicular angle was measured with a clinometer SUUNTO PM-5/360PC. Additional information gathered was presence of calves, cue (nature of the first observation, e.g. a splash), activity of the animals and their direction of movement relative to the course of the aircraft. This additional information was not analysed further at this stage of the monitoring programme, but it could prove to be useful in future.

10.3.2.4. Data analysis

For analysing the collected data, the software programme DISTANCE version 5.0 (Thomas *et al.*, 2006) was used. With this software the most suitable detection model can be chosen on the basis of the data obtained during the surveys. The analysis results in an estimate of the following parameters, together with their variance:

- Effective (half) strip width (ESW) μ of the survey;
- Average group or cluster size $\widehat{E}$;
- Density of porpoises in the survey area $\widehat{D}$;
- Total number of porpoises in the survey area $\widehat{N}$.

The analysis does not allow for the assessment of distribution patterns, although a first glance at a map with the observations on the tracks can give an idea, given a regular distribution of track lines. To estimate the spatial distribution of marine mammals within the study area, the development of a density surface model (DSM) is needed.

10.3.2.5. Defining a Density Surface Model (DSM)

An analysis in DISTANCE only gives an estimation of abundance and density over the predefined survey area. It would be useful however to use data gathered during line transect surveys for creating distribution maps. The availability of distribution maps would possibly allow for relating densities to static and dynamic spatio-temporal covariates (biotic and abiotic factors, human activities), estimating abundance in subareas of the survey area, or indicating changes in the distribution between surveys.

To obtain a representative coverage of the spatial distribution maps, tracklines need to be sufficiently spread over the survey area. They should also be considered as having been placed ad random with regard to the location of the animals. If tracklines are subdivided in sufficiently small contiguous segments of (by preference) equal length l_y, a local density D_l can be estimated in theory as:

$$D_l = \frac{n_l}{2\mu \cdot l_y} \frac{1}{g(0)}$$

in which n_l is the number of animals detected in the segment concerned.

The local densities over the survey tracks can be used for creating maps presenting the spatial structure of the population, for instance with kriging. This is a geostatistical technique in which values at an unvisited location are interpolated from observations made at nearby locations, independent of environmental predictors such as depth, distance from the coast or human presence.

Given the few number of surveys conducted during 2008, a spatial density model for analysing the line transect data has not been developed yet.

10.3.2.6. Assessment of trends

DISTANCE does not allow for the assessment of trends between two surveys. For estimating the number of surveys necessary for allowing an estimation of trends in a regularly surveyed area, a power analysis needs to be performed, e.g. through the aid of the programme TRENDS (Gerodette, 1993)[2]. Given the currently limited number of surveys, an estimation of the number of surveys needed to be able to allow for a statistically validated trend, will be performed after the spring 2009 surveys.

[2] TRENDS is a programme designed to carry out a power analysis of linear regression, particularly in the context of environmental monitoring. TRENDS summarizes the power analysis in 5 parameters: duration of study, rate of change, precision of estimates, alpha (type 1 error rate), and power (1-beta, where beta is the type 2 error rate). The value of any one of these can be estimated if the other 4 are specified. TRENDS is designed to help answer such questions as: how many years are required to detect a trend, how large is the rate of change that can be detected, and what is the probability of detecting a trend (that is, of getting a significant slope to the regression line)?

10.3.3. Results

10.3.3.1. Surveys

During 2008, five surveys were performed. At that moment some construction works were already ongoing on the Thornton Bank (the first foundation was placed on the seabed on 26 April 2008). These surveys should be considered as pilot surveys, in which it was important to test techniques, and if necessary adjust the protocol. An overview of the 2008 surveys is given in table 1.

Table 1
Overview of the 2008 aerial surveys for marine mammals. Time is given in UTC.

Flight number	Date	Take-off	Start survey	Stop survey	Landing	Total flight time	Total survey time
08077	8 Apr 2008	14:46	14:59	16:57	17:06	2:20	1:58
08079	9 Apr 2008	7:05	7:10	9:02	9:17	2:12	1:52
08095	5 May 2008	13:13	13:46	15:16	15:27	2:14	1:30
08098	7 May 2008	12:18	12:34	13:48	14:19	2:01	1:14
08157	29 Jul 2008	13:25	13:39	14:41	15:10	1:45	1:02

Table 2 presents the sighting conditions during these surveys (see protocol). Wind speed and direction were recorded during take-off and landing, as communicated by Ostend flight control. The visibility was assessed at one point at sea, and concerns a subjective estimate of the almost horizontal distance in which the coastline or ships are still visible with the naked eye. Cloud coverage is expressed as oktas: 8 oktas concern a completely covered sky, while a completely open sky has 0 oktas. Subjective sighting conditions were assessed by each observer independently. These can be considered as an integration of all factors influencing sighting conditions (glare, seastate, …), of which the individual assessments would not allow for expressing how good conditions were for observing porpoises.

Table 2
Flight conditions during the 2008 surveys.

Date	Seastate	Wind speed (kts) – take off/landing	Wind direction – take off/landing	visibility (km)	Cloud coverage (above/below)	Subjective sighting conditions
8 april	1-2	8/7	350°/020°	+10	4-0/0	Good
9 april	0-1	0	-	+10	0/0	Good
5 May	2-3	14	070°	+10	1/0	Good to average
7 May	2-3	9/10	030°	5-10	5/0	Average to poor
29 July	2-3	6	360°/310°	+10	0/0	Average

During the surveys of 7 May (flight 08098) and 29 July (flight 08157) the number of observed porpoises was very low (1 animal during each survey). While sighting conditions were good on 8 and 9 April, and good to average on 5 May, they were average to poor on 7 May and 29 July. Given the number of sightings and the sighting conditions, it is not possible to analyse the data gathered during these two surveys. In the framework of the monitoring of the effects of offshore windfarms, a conclusion indicating a very low number of animals present, is of major importance. In this case however, caution is necessary for concluding on densities of porpoises, given the average to poor flying conditions. The surveys of 8 and 9 April are considered further as one survey: the time gap between the surveys was very small, and the area surveyed was complementary.

Table 3 presents the tracks of the surveys on 8-9 April and 5 May. The deviation from the predefined track line was tested in two ways. First of all the track line as mapped was compared to the predefined track line, and secondly the theoretical speed (distance between start- and endpoints of the predefined track line versus the time that was needed to cover the distance) was put against the average ground speed, as measured and recorded by the GPS. In case of large deviations between the predefined track length and the covered track length, the covered track length was used in the analysis of data. The only deviations occurred during tracks 12 and 13 of the flight on 9 April. The deviation in track 12 was caused by performing a turn of 360° for the identification of a group of dolphins. Given that during this turn no porpoises were observed, and the track line was resumed afterwards, the length of the predefined track line is retained for the analysis. The deviation of more than 2% between theoretical (shortest) and actual track length in track 13, although still acceptable, was taken into account; the track distance was corrected to 6.8 nm.

Track 13 of the survey on 9 April and track 6 of the survey on 5 May were not predefined, but were additional tracks *of opportunity*. These were performed *en route* to surveillance tasks or upon return to the airfield. The data gathered on track 13 of the survey on 9 April were not considered for analysing density and abundance, due to the deviating length of the track (see table 3). They were used however to refine the detection probability function to estimate the average cluster size. It should be noted that locally a relatively high density of porpoises was observed on track 13: 7 animals were observed over a distance of 6.8 nm.

Table 3
Overview of the tracks per survey, with predefined track length, average ground speed and covered track length.

Date	Track	Track length (nm)	Survey duration	Predefined length vs. survey duration (kts)	Average ground speed measured (kts)
8 April	Track 1	33.52	0:19:52	101.2	101.4
	Track 2	33.04	0:18:49	105.4	106.0
	Track 3	32.00	0:18:34	103.4	103.5
	Track 4	31.32	0:17:25	107.9	108.2
	Track 5	30.04	0:17:16	104.4	104.3
	Track 6	29.66	0:16:49	105.8	105.5
9 April	Track 7	28.76	0:16:32	104.4	104.7
	Track 8	27.79	0:16:36	100.4	100.6
	Track 9	26.84	0:15:26	104.3	104.4
	Track 10	25.59	0:15:09	101.3	101.5
	Track 11	24.99	0:14:23	104.2	104.2
	Track 12	24.61	0:16:48	87.9	101.8
	Track 13	6.65	0:03:54	102.3	104.6
5 May	Track 1	20.53	0:12:14	100.7	100.8
	Track 2	22.27	0:13:14	101.0	101.0
	Track 3	22.46	0:11:24	118.2	118.2
	Track 4	25.83	0:14:42	105.4	105.2
	Track 5	24.50	0:13:06	112.2	112.8
	Track 6	27.69	0:15:15	109.0	109.0

10.3.3.2. Observations

Figures 6 and 7 present the tracks of the surveys of 8 and 9 April, and 5 May, and include the observations of porpoises, which are also given in table 5. Next to the animals observed on the tracks by the observer on the left side of the aircraft, also the sightings made by the observer right and the observations made off effort between tracks are put on the map, although these were not further used in the statistical analysis.

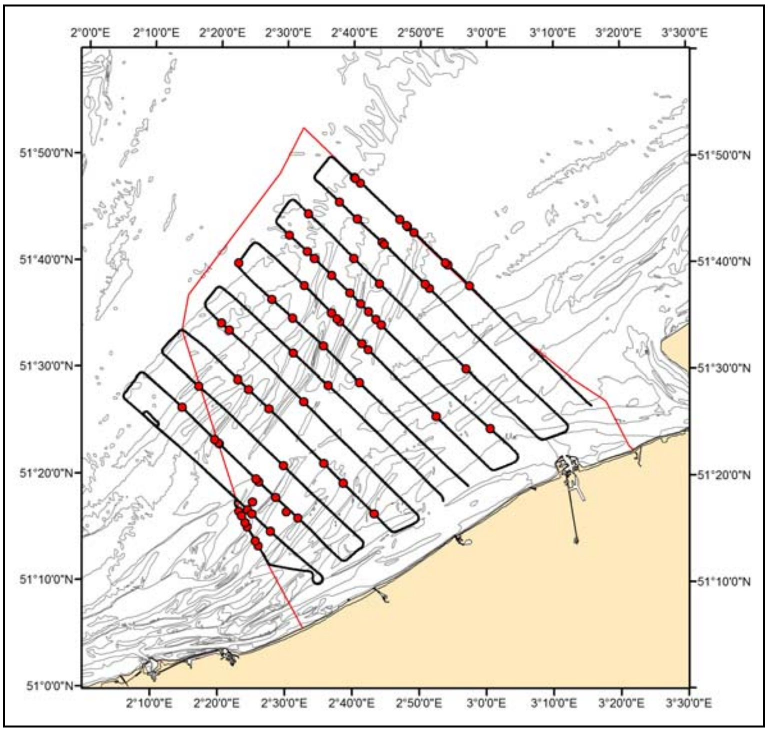

Figure 6. Tracks (black lines) and observations (red dots) as in the surveys on 8 and 9 April. The delimitation of Belgian marine waters is indicated with a red line (projection: WGS84).

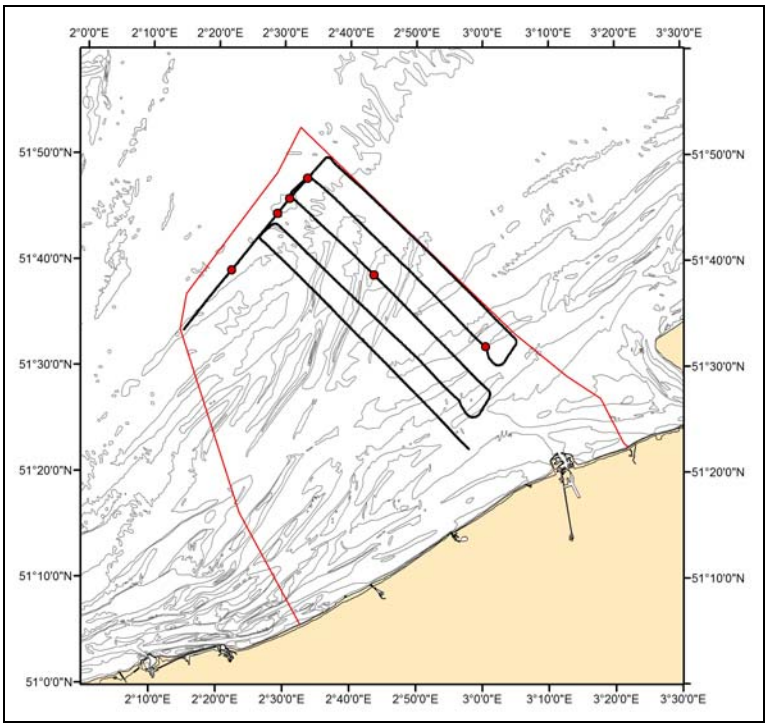

Figure 7. Tracks (black lines) and observations (red dots) as in the survey on 5 May. The delimitation of Belgian marine waters is indicated with a red line (projection: WGS84).

Table 4
The number of sightings of groups of porpoises and the number of porpoises observed by observer (L left and R right).

Date	Number of sightings of groups on effort		Number of observed animals on effort		Number of animals observed off effort	Total number of animals observed
	L	R	L	R		
8 April	25	17	27	22	1	50
9 April	20	10	23	10	3	36
5 May	5	1	5	1	0	6

10.3.3.3. Analysis of the observations

The largest number of sightings was made, as could be expected, at the left side of the aircraft, which is the side with the bubble window. Figure 8 presents the (relative) number of detections (in distance intervals) vs. distance from the trackline for the observers left and right. Different models were fitted to the probability of detection for the observations at the left side of the aircraft; a half normal distribution (cosine adjusted) was chosen on the basis of the analysis in DISTANCE, and is presented in figure 8. Only the probability detection function for the observer left is presented. For the observations made at the right side of the aircraft no useful detection model can be fitted that would correspond with the theoretical background of line transect sampling. As a focus of observations is required near the trackline, no useful detection probability function g(*x*) can be fitted to these data in which g(0)=1 (with g(0) uncorrected for animals missed). Therefore the observations made by the observer on the right were not further analysed.

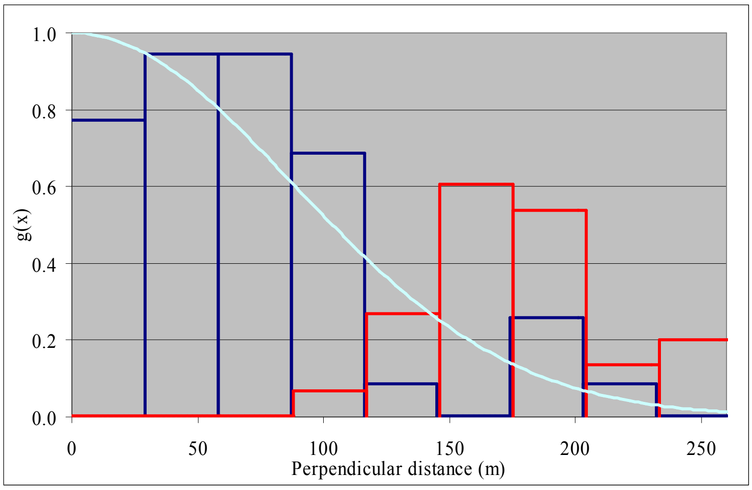

Figure 8. Detection probability function for the observer left (light blue line). The original data for establishing this function (observer left) are indicated as blue bars on the graph (without the exact numbers). Also the original distribution of the sightings by the observer at the right hand side of the aircraft are indicated (red bars); it is clear that no useful detection function, with g(0)=1 and strictly declining, can be produced with these data.

Fitting a useful detection probability function for the observations during the survey on 5 May is not possible, given the limited number of observations. Given that flying conditions were similar, the observations of the survey on 5 May were pooled with those of survey 8-9 April. With the pooled data a detection probability function, used to analyse the observations of the survey on 5 May, was calculated.

10.3.3.4. Density, abundance and average group size

The survey area as in the survey on 8-9 April overlaps for the larger part with the marine waters under Belgian jurisdiction. The size of the area between survey points S01-N01-N13-S13 is 3,216 km², which is approximately equivalent to the surface of Belgian marine waters (3,600 km²). Therefore the estimated abundance in Belgian waters in survey 8-9 April can be extrapolated from the estimated density in the survey area. The area covered in the survey on 5 May was set at 1,450 km². For the analysis, the parameters used, and the assumptions made, were the following:

- Extreme values were not eliminated;
- After testing a number of models, a half normal cosine adjusted model was chosen for the detection probability function; the adjustment was limited in order not to allow for an increase in the function;
- The detection probability function for the survey on 8-9 April was modelled independently of the survey on 5 May; the detection probability function for the survey on 5 May was prepared using the pooled data of the surveys of 8-9 April and 5 May; both detection probability functions will thus differ slightly, and consequently also the ESW values;
- As g(0) for good/average weather conditions we assumed a value of 0.45, which is the value calculated for similar surveys (porpoises, good conditions) by Hiby (2008). In practice this indicates that slightly more than half of the animals are missed on the trackline, most of these given they were at a depth beyond visibility. An additional simplification of the analysis of collected data concerns the application of g(0) without confidence intervals. As more exact values of g(0) might become available in the future, after more surveys, the data gathered may be revisited, and a more precise estimate of abundance might possibly be made.

The ESW and group sizes for the surveys on 8-9 April and 5 May are presented in table 5. The ESW for the survey on 5 May (151 m; pooled detection probability function) is larger than the one for the survey on 8-9 April (140 m). This is due to the relatively large distances from the track line of the few observations. No confidence values for the group size in the survey of 5 May are given: all observations concerned solitary animals.

For the analysis of data gathered in the survey of 5 May, a non-parametric bootstrap was used. In this analytical technique, the survey is resampled in which each resample has a number of transects of equal size as the original dataset, and is obtained by random sampling of the original dataset. The assumption is made that the transects are independent, and that the population is distributed fairly evenly. Each resample, numbering 999 in total, is analysed in a similar way as the original data. This technique yields detection function estimations and densities for each resampled dataset, and provides for estimates with a lower variance.

Table 5

Estimates of effective (half) strip width (ESW) and porpoise group size $\widehat{E}$ during the surveys on 8-9 April and 5 May, together with 90% confidence limits (% CV: coefficient of variation, or the standard deviation versus the estimate); nm: nautical miles.

Date	Survey length (nm)	ESW (m)			Group size		
		ESW (m)	% CV	90% Conf.-interval	$\widehat{E}$ (number of animals)	% CV	90% Conf.-interval
8-9 April	355	140	15.9	116-170	1.11	5.24	1.02-1.22
5 May	143	151	10.9	126-181	1	-	-

Table 6 presents the estimated density of porpoises in the survey area, and for the survey on 8-9 April an estimate of the total number of porpoises in Belgian waters. Given that the area covered in the survey on 5 May only consisted of part of the Belgian waters, a similar estimate was not made for this survey.

Table 6

Estimated density $\widehat{D}$ of porpoises in the survey area, and extrapolated number of animals $\widehat{N}$ in the survey areas (which have a different size), including 90% confidence intervals (% CV: coefficient of variation, or the standard deviation versus the estimate). The value of g(0) used was 0.45.

Date	Density			Survey area (km²)	Number of animals in the survey area		
	$\widehat{D}$ (n/km²)	% CV	90% Conf.-interval		$\widehat{N}$	% CV	90% Conf.-interval
8-9 April	1.21	29.5	0.73-1.99	3,600*	4.341	29.5	2,630-7,167
5 May	0.29	77.3	0.07-1.13	1,450	417	77.3	106-1,638

* The survey area covered 3.216 km², but the densities were extrapolated to 3,600 km² to obtain an abundance estimate for an area equivalent to the Belgian marine waters.

The density of porpoises estimated on the basis of the survey on 8-9 April (1.21 animals/km²) was much higher than on the basis of the survey on 5 May (0.29 animals/km²). However, confidence values are very large, especially for the survey of 5 May. This is due to the low number of observations and transects. Still, the data collected during the surveys proved to be useful for a first assessment of numbers of porpoises and densities in Belgian waters in general, and can be used as a baseline for future research. Given the highly migratory and mobile nature of porpoises, the results of each survey should be considered as an indication of the density and abundance at a given moment. In any case, with an estimated total number of animals of 4.341 animals on 8-9 April 2008, the porpoise can be considered as a common animal in Belgian marine waters.

Different values of g(0) have been calculated. Above the value of Hiby (2008) was used. In table 7 the estimates for density and abundance are given using different values for g(0): 0.5 (half of the animals are missed), 0.45 (Hiby, 2008) and 0.37 (estimate of g(0) in good conditions during similar porpoise surveys according to Scheidat *et al*., 2008).

Table 7
Estimates for density and abundance using different values of g(0); 90% confidence limits are given, and the analysis was done as for the data presented in table 7.

g(0)	Date	$\widehat{D}$ (n/km²)	$\widehat{N}$
0.37	8-9 April 2008	1.47 (0.89-2.42)	5,280 (3,198-8,717) (3,600 km²)
0.45	8-9 April 2008	1.21 (0.73-1.99)	4,341 (2,630-7,167) (3,600 km²)
0.5	8-9 April 2008	1.09 (0.66-1.79)	3,907 (2,367-6,450) (3,600 km²)
0.37	5 May 2008	0.36 (0.09-1.34)	517 (138-1,943) (1,450 km²)
0.45	5 May 2008	0.29 (0.07-1.13)	417 (106-1,638) (1,450 km²)
0.5	5 May 2008	0.25 (0.05-1.11)	363 (81-1,621) (1,450 km²)

10.3.4. Discussion

The survey design as tested in 2008 proved to be appropriate, and should be used in future surveys. An important lesson learned was that a strong focus of observers needs to be put on the track line. This might lower the ESW, but would provide for a more precise estimation of g(x), crucial for estimating abundance (see also Southwell *et al*., 2007).

The harbour porpoise was a common species during spring 2008 in Belgian waters, including in the areas where wind turbines are being constructed or are planned. A survey on 8-9 April 2008 yielded a number of 4,341 (2,630-7,167) porpoises, or a density of 1.21 (0.73-1.99) animals/km². A more limited survey on 5 May 2008 yielded much lower numbers, but also very large confidence limits. The findings are concurrent with the current knowledge of the occurrence of porpoises in coastal waters of the southern North Sea: they enter these waters in fairly large numbers from late autumn onwards, reach a peak in numbers between February and April, and have virtually left by May (Haelters & Camphuysen, 2009).

Although before this monitoring project an absolute number of porpoises in Belgian waters had never been estimated with a standardised method and statistical tools, the data reported here confirm the general pattern of occurrence as in the ad hoc observations at sea reported to MUMM (database MUMM, unpublished), the observations at sea made by the Research Institute for Nature and Forest (INBO), some aerial observations made in the past by MUMM, and the strandings pattern on the shorelines of Belgium and The Netherlands (Camphuysen & Peet, 2006; Haelters & Camphuysen, 2009; Depestele *et al*., 2008; Haelters & Jacques, 2006). Previous '*guesstimates*' on the basis of aerial surveys (without using standardised methods or statistical analyses) ranged from 0.2-0.4 animals/km² on 11 March 2004 and 0.3-0.6 animals/km² on 22 April 2004 (aerial surveys by MUMM, in Haelters & Jacques, 2006) to *2,000-5,000 animals at the most* in Belgian waters (ship-based surveys by INBO, reported in Haelters & Jacques, 2006).

10.3.5. Conclusions and recommendations for future research and preparatory work

For monitoring marine mammals at sea, aerial line transect surveys proved to be a very cost-efficient method. This is confirmed by the extensive assessments made in the SCANS II survey report, published in 2008 (SCANS II, 2008). The methodology of gathering and analysing data is standardised, and has a strong theoretical basis. The statistical analysis is made possible with dedicated software (DISTANCE 5.0.), widely used in line transect surveys.

In the analysis a number of assumptions are made, which make the estimates less reliable. An important assumption is to use g(0)=0.45, and applying it without confidence intervals. Within the current monitoring programme, estimating a value for g(0) in different weather conditions and for different observers was not feasible from a technical and budgetary point of view. In order to be able to compare results, aerial monitoring should only be executed during good observer conditions in future surveys. A '*flexible*' availability of a suitable aircraft is necessary for this.

We have demonstrated that bubble windows are a prerequisite for acquiring useful data: a detection probability function necessary for analysing data could only be obtained on the basis of the data gathered at the bubble window. As a consequence, administrative steps are being taken to equip the aircraft with a second bubble window (at the right hand side of the aircraft) in 2009.

Although in theory the total survey length should not affect the estimate of abundance, more aerial surveys should be undertaken to obtain smaller confidence limits for abundance, density and groups size. Surveys should aim at covering the whole of the Belgian waters, given that the number of transects is close to a minimum still useful for statistical analysis. This is also necessary for developing density surface models, which may reveal areas where porpoises aggregate, or may reveal inshore–offshore gradients or habitat preferences. Density surface models will be necessary to create distribution maps, which will yield information about the variability in the distribution of porpoises in space and time. Density distribution maps, together with the results obtained from the other disciplines, will provide for the basis for the assessment of possible effects of the construction and operation of offshore wind farms. A weakness is that the area of concern is very open, with 'uncontrolled' inflows and outflows of animals.

In future the collected data might be re-analysed, for instance when a better detection function would be made on the on the basis of more observations, with a better estimate of g(0), or with new analysis software being available.

10.4. Monitoring of porpoises and other small cetaceans with PoDs

10.4.1. Introduction

A Porpoise Detector (PoD) is an autonomous, static and passive device used for monitoring ultrasound originating from cetaceans (see protocol: MUMM, 2008b). Porpoise sounds can be distinguished from other noise or sounds from other animals, while with the devices available in 2008, dolphins cannot be identified up to the species level. Due to technical innovations and an increased ease of use, these systems are being used ever more frequently for long-term monitoring of selected populations of small cetaceans, for instance in the framework of environmental impact assessments (Carstensen *et al*., 2006; Leeney & Tregenza, 2006; Mellinger *et al*, 2007). Anchored PoDs can demonstrate the presence of porpoises and other toothed whales in a small area around the device during several months. The size of this area depends on the species of cetaceans, the type of PoD and the environment. While aerial surveys can give us an ad hoc image of the distribution and abundance of cetaceans over a large area, the use of PoDs provides for information over a longer period in a cost-efficient way (Depestele *et al*., 2008).

The information on PoDs given below is summarised from the information obtained from Chelonia Ltd., the company developing and manufacturing PoDs (http://www.chelonia.co.uk/). It proved not feasible to deploy PoDs in 2008 for monitoring the effects of the construction and exploitation of offshore windfarms in Belgian waters. In 2009 and during the following years a newly developed type of PoD, available from January 2009 onwards, will be used. In 2008 the most cost-efficient method to anchor the PoDs in the framework of offshore windfarm monitoring was investigated, building on experience gained in the project WAKO (Depestele et al., 2008).

10.4.2. Material and methods

10.4.2.1. T-PoDs and C-PoDs

A PoD consists of a hydrophone, a processor, batteries and a digital timing and logging system. These are put together in a watertight tube (PVC or polypropylene) of around 60 cms in length. PoDs are moored at sea for a period of days to months.

PoDs analyse ambient noise in real-time, and log clicks resembling those originating from small cetaceans. Such '*clicks*' can also originate from sand movement, boat sonar, crustaceans or rain. The repetition, duration and frequency of these clicks is analysed with dedicated software, and click sequences are categorised into different probabilities of origin: *cetacean*, *probably cetacean*, *unknown* and *boat sonar*. Cetacean click-trains indicate the presence of cetaceans, and can also provide some information about behaviour. Besides visualising information about detections (and pulse repetition frequency, interclick interval or click duration) for the whole period, the software allows for several export options, summarising information about a.o. total number of clicks, the number of detection positive minutes per day, the click intensity (number of clicks versus number of positive detection minutes), or the number of encounters per day.

The type of PoD that has been used most frequently for monitoring cetaceans in the North Sea is the T-PoD. T-PoDs are not available on the market anymore since the end of 2007. They are replaced by a technically improved version: the C-PoD. Data collected by T-PoDs cannot be compared easily to those collected by C-PoDs, given different technical specifications. C-PoDs have a number of technical advances over T-Pods, which include a better autonomy, a lower number of false detections, a memory card that can be replaced at sea, and a more limited need to enter specific settings. For these reasons C-PoDs are chosen for the monitoring of the effects of offshore windfarms on marine mammals for the duration of the monitoring projects. Given that in 2008 no C-PoDs were available on the market yet, no PoDs have been deployed in 2008. From 2009 onwards C-PoDs will be used. Data gathered by these PoDs will be used to optimise the C-PoD software by Chelonia Ltd. It will be possible to analyse gathered data retrospectively with updated versions of the software, and data used to optimise the software will remain confidential.

10.4.2.2. Technical specifications of C-PoDs

C-PoDs (will) have the following specifications (adapted from the information provided by Chelonia ltd.; www.chelonia.co.uk):

- Working depth up to at least 100 m;
- Powered by 8 (or 10) alkaline D cells;
- Autonomy at least 3 months – to be verified;
- Length: 535 mm (8 alkaline D-cell version);
- Weight: 1.7 kg – 2.9 kg (without – with batteries);
- Buoyancy: 0.5 kg (8 alkaline D-cell version);
- Omnidirectional hydrophone, 20 kHz to 150 kHz;
- Removable Secure Digital (SD) memory card;
- Detection radius up to 300 m for porpoises (100 % detection within 70 to 100 m), and at least 1200 m for dolphins;
- Angle sensing: an angle sensor and PoD settings allow for the PoD to be set and transported (e.g. upside down) without logging; while logging the angle is recorded each minute;
- The temperature is recorded each minute.

10.4.2.3. Mooring system

Two systems for mooring PoDs that were used by MUMM in the past (Depestele *et al.*, 2008) are presented below (figures 9 and 10). In the system in figure 9 the PoD is attached to a *tripode*, a heavy pyramidal frame that is placed on the seafloor. Only one tripode is available to MUMM for the moment, and it is being used for other monitoring equipment. Usually it is moored for only one month at a time. The second system (figure 10) was a simple frame developed ad hoc by the Flemish Hydrography, and was moored very close to a fixed measuring platform at sea, where no interference with fisheries was likely. It was not indicated at the surface by an extensive buoying.

Figure 9. PoD vertically mounted on a tripode (image: J.Backers, MUMM).

Figure 10. PoD mounted on a system developed by the Hydrographic Service of the Flemish Community (image: Hydrographic Service).

Although it is likely that a tripod system may become available, it is not likely that this system will be available for dedicated long-term research of porpoises, given that the number of tripods available is too low, and the mooring of the tripod is fairly short (around 1 month). Therefore alternative and independent mooring systems for the PoDs were assessed during 2008. Also an estimate of the total cost of alternative systems was made. For these assessments, experts of MUMM were consulted, as well as experts of the Hydrographic Service and the Department Fleet (MDK) of the Flemish Community, and crew of the oceanographic vessel BELGICA.

The first possible system is given in figure 11. It consists of a heavy anchor and large buoy, equipped with light and radar reflector, connected to a smaller weight attached to the PoD. The smaller weight is held in place by a Danforth anchor. The position of the PoD is indicated by a surface marker buoy. The objective is that the PoD can be lifted from the water to be inspected and serviced from a small craft. In agreement with MDK, existing buoys could be used as the large marker buoys, and the PoD could be attached to these from the surface. After deliberation it became clear that only small buoys indicating underwater obstacles (*wreck buoys*) could be used for this kind of mooring.

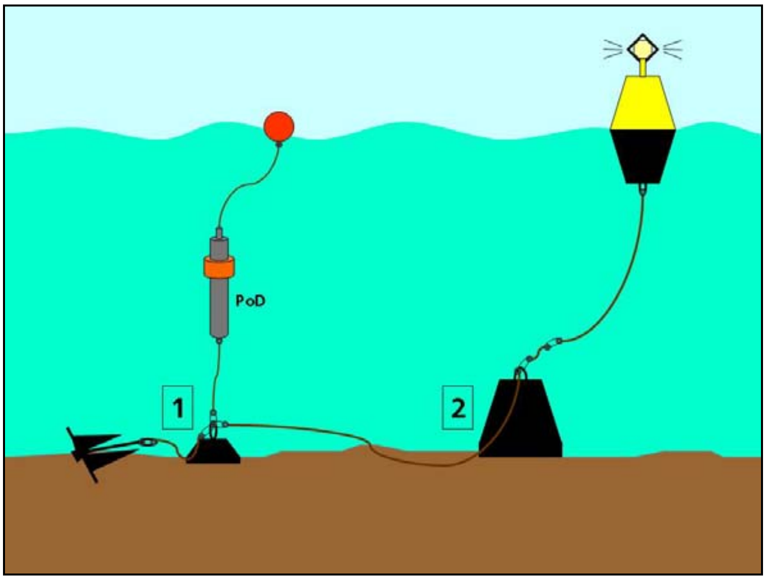

Figure 11. PoD mooring system combined with existing buoy (not to scale); 1: PoD anchorage with danforth anchor, anchor stone of around 25 kg and surface marker buoy; 2: existing marker or wreck buoy. The bottom rope is (stretched) around 100 m long.

The second system is similar to the one described above, and is given in figure 12. In this system an additional anchor stone is placed on the seabed, very near to an existing (mother-) buoy, which can be a large cardinal buoy used to indicate shipping lanes or sandbanks. Given the vicinity of the large buoy, equipped with radar reflector and light, the additional anchor stone can be marked with a simple blub. Alternatively, the simple blub can be eliminated to avoid vandalism or theft, commonly encountered with moorings in coastal waters. The PoD can then be recovered by dredging for the ground rope with a dredge anchor from a small craft.

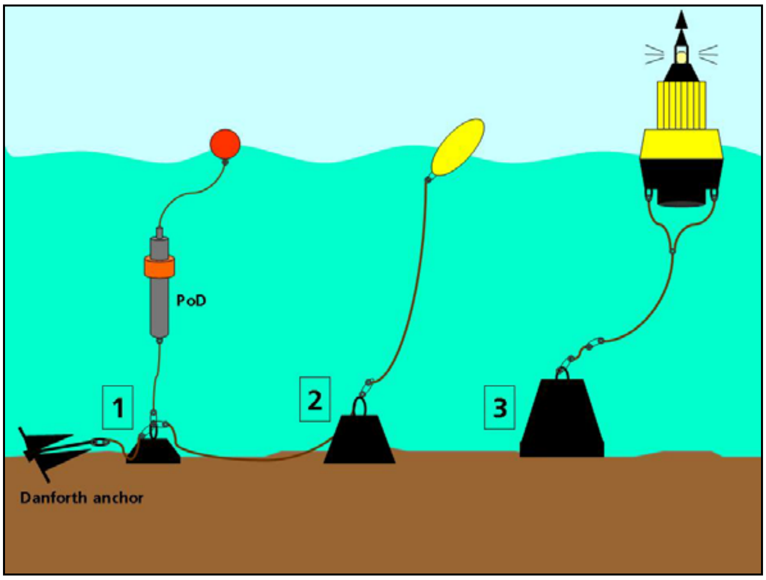

Figure 12. PoD mooring system in the vicinity of an existing buoy (not to scale); 1: PoD anchorage with danforth anchor, anchor stone of around 25 kg and surface marker buoy; 2: anchor stone of around 500 kg and surface marker buoy; the bottom rope is (stretched) around 50 m long; 3: '*mother buoy*' system: existing cardinal buoy or buoy marking shipping lane; the distance between the two large anchor stones depends on the length of the anchor chain of the mother buoy.

10.4.3. Mooring plan

The most suitable mooring locations in and outside the windfarm areas were chosen, and a tentative time-table for the years to come was set up. For the locations of the PoDs, the presence of buoys in or very near to the windfarm areas were looked at, and also reference areas were chosen. For the choice of the location of the reference mooring sites, the following were considered:

- Mooring in the vicinity of an existing buoy;
- Avoidance of areas with intense shipping;
- If possible at a location with a depth similar to depths at the windfarm sites;
- If possible at a similar distance from the coast as the windfarm sites;
- Sufficient distance from the windfarm site (at least 5 nautical miles);
- Possibility to retain the mooring site for future moorings.

The chosen locations are given in table 8 and in figure 13. These choices were made after consultations with MDK and with C-Power for the PoD at the C-Power site. As soon as a mooring will be made, MDK will be informed, as well as the hydrographic service, the MRCC (Maritime Rescue and Coordination centre) and C-Power. A notice to mariners, indicating the presence of monitoring devices, will be issued (BaZ – *Berichten aan Zeevarenden*).

Table 8
Mooring locations for 4 PoDs and information about the existing buoy; the chain length and water depth are important for calculating the minimal distance between the mother buoy and the PoD mooring.

Name of the location	**Description**	**Name of existing buoy**	**Position**		**Water depth**	**Chain length**
TB	PoD in windfarm C-Power	TB	51°34.38’N	002°59.02’E	21 m	60 m
BB	PoD near windfarm Belwind	[Track Ferry]	51°33.78’N	002°36.33’E	33 m	80 m
REF 1	First reference PoD	Goote Bank	51°26.95’N	002°52.72’E	26.5 m	80 m
REF 2	Second reference PoD	Oostdyck W	51°17.15’N	002°26.32’E	25.4 m	80 m

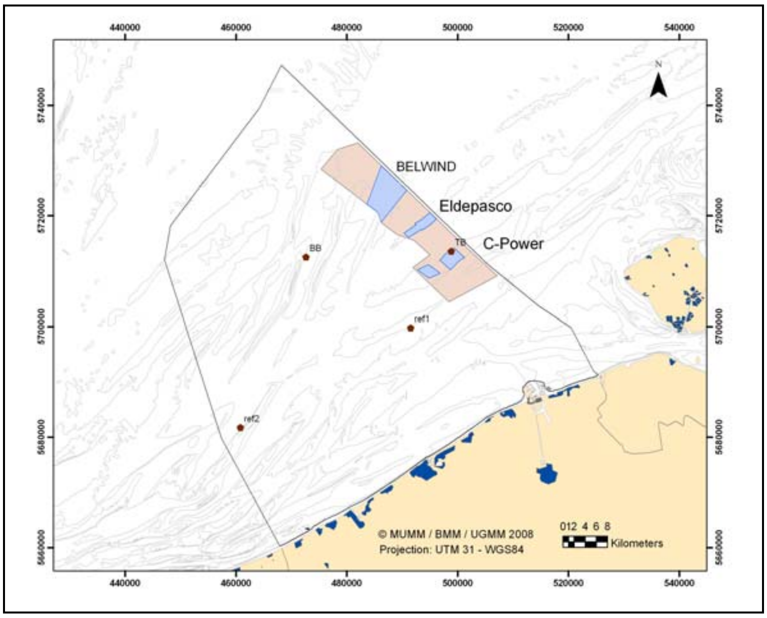

Figure 13. Planned location of the PoDs to be moored from 2009 onwards.

The location of the BB PoD – now at the Track Ferry Buoy, will be reviewed at the start of the construction works, when cardinal buoys will indicate the construction zone.

In table 9 the planning for the mooring and servicing of the PoDs in 2009 is presented. This planning is tentative, and it is clear that technical difficulties, adverse weather conditions and changes in the planning could interfere with it. PoDs will be moored as soon as possible in 2009 (weather permitting). All mooring equipment should be available by the beginning of January 2009.

Table 9
Planning of the mooring of PoDs during 2009 and indication of the ship that will be used (BELGICA: oceanographic vessel; TUIMELAAR: Rigid Inflatable Boat – RIB).

Late winter - spring 2009	Late winter -spring 2009	Late spring 2009	Summer 2009
Placement of 4 anchorage systems (TB, BB, REF 1, REF 2) – OV BELGICA	If placing of anchoring systems was successful, check of these systems, and placement of 4 PoDs (TB, BB, REF 1, REF 2) - TUIMELAAR	Depending on the success of the February campaigns: servicing of the PoDs: replacement of batteries and memory card, removal of fouling - TUIMELAAR	Depending on the success of the previous campaigns Retrieval of PoDs (TUIMELAAR – BELGICA)

If the PoDs are available by the end of January 2009, the placement of the anchorage system and the PoDs will be combined. Depending on the quality of the mooring system and the activities in the windfarm areas, it is possible that the PoDs will be left at sea for a longer period of time, and be serviced more often.

10.4.4. Conclusions

Using passive acoustic devices is considered as an elegant method for monitoring the effects of the construction and exploitation of offshore windfarms on marine mammals, given that marine mammals, and especially porpoises, are very difficult to monitor in the wild. During 2008, a mooring system was developed, in which existing buoys are used to reduce costs. A choice was made for the locations of the two windpark PoDs and the two reference PoDs that will be deployed from the beginning of 2009 onwards. Given that the existing buoys of choice are all large cardinal buoys or buoys marking shipping lanes, a mooring system as in figure 12 will tentatively be used. For the mooring, a very good coordination with MDK will be necessary. The experiences in 2009 should indicate whether this mooring system works in practice, or whether a mooring system used exclusively for marking the PoDs should be used instead. Given that loss of PoDs or vandalism cannot be excluded with this fairly modest mooring system, one or more spare PoDs should be obtained.

10.5. Collection of additional data

10.5.1. Introduction

Several additional sources of information on marine mammals in Belgian waters exist. These include strandings data, sightings data reported by the public, by authorities at sea or by the constructor of wind turbines, and sightings data collected by the Research Institute on Nature and Forest (INBO) during seabird censuses.

The strandings data reported here can be considered as effort-related, given that we believe that the majority of washed ashore porpoises are reported, and most are collected by MUMM for research purposes. The sightings data only concern ad hoc sightings reported by the public, and are not effort related. Given that the harbour porpoise has been common in spring during the last years, we suspect that they increasingly are perceived as of little interest, and that as such many of them are not reported anymore. The data collected by INBO are reported in the report of the monitoring of seabirds.

Also in this section an overview is given of strandings and sightings of other marine mammals.

10.5.2. Material and methods

All marine mammals are protected species, for which a specific legislation exists. Stranded animals need to be dealt with accordingly. To cope with the legislation, and in order to contribute to specific obligations of the Belgian authorities in the framework of international conventions, a network was established to organise the scientific research of stranded and bycaught animals. This network is coordinated by MUMM. In practice, MUMM takes care of the interventions in case of strandings and bycatches, and makes sure carcasses are recovered for scientific research. Trends in numbers of stranded animals can indicate trends in abundance at sea, and the investigation of the washed ashore animals can indicate problems the population is facing, such as bycatch in fishing gear.

Next to gathering strandings data, MUMM also maintains a database on sightings. These sightings are directly reported to MUMM, or indirectly through websites such as www.zeezoogdieren.org or www.waarnemingen.be. Also these ad hoc (non effort related) sightings can yield interesting information (Haelters & Camphuysen, 2009).

10.5.3. Results

10.5.3.1. The harbour porpoise

The harbour porpoise has not always been a common animal in Belgian waters. It was virtually absent from southern North Sea waters from the mid-1950s up to the early 1990s. In the early 1990s a gradual increase in strandings indicated a return of the species to these waters. Reasons for the decline and return are unclear, but certainly the return may have been caused by altered feeding conditions in the central and northern North Sea (Camphuysen, 2004; Haelters & Camphuysen, 2009).

Stranded animals

Since a peak in strandings in 2006, the yearly number of stranded porpoises has decreased (figure 14). It cannot be predicted whether this trend will continue in the years to come or not. However, even with the downward trend in strandings numbers, the porpoise remains a common animal in the southern North Sea.

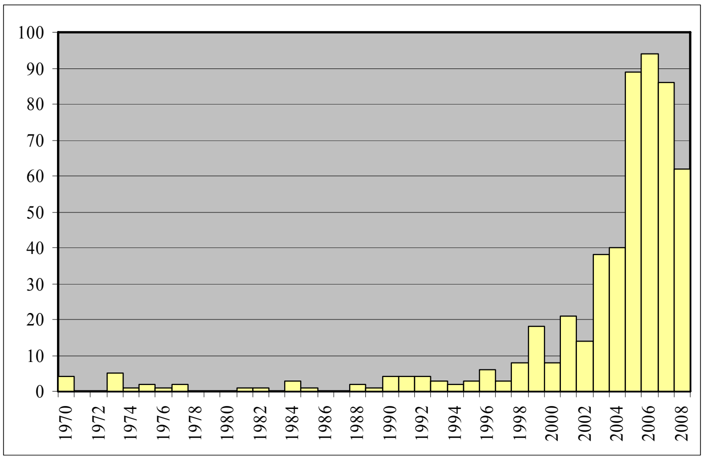

Figure 14. Total number of stranded porpoises in Belgium between 1970 and 2008 (data MUMM, partially unpublished).

The occurrence of the porpoise in coastal waters of the southern North Sea is clearly seasonal: the animal is most common from late autumn to early spring (Haelters & Camphuysen, 2009). Also the strandings pattern shows a seasonal trend, although this trend is somewhat different than the trend in sightings. Figure 15 demonstrates that during the 21st century the highest number of animals washed ashore from March to May, and in August.

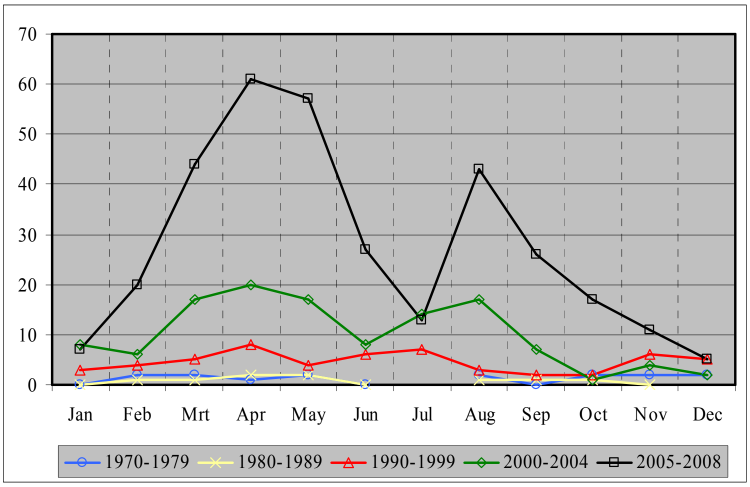

Figure 15. Total number of stranded porpoises per month during different periods between 1970 and 2008.

A bias in spring exists due to bycatch, especially during March and April. Up to 75% of the porpoises washing ashore on Belgian beaches during these months were found to have incidentally drowned in fishing gear (Haelters & Camphuysen, 2009). The gears responsible for most bycatches in the North Sea are passive: gillnets and tangle nets (CEC, 2002; Norhridge *et al.*, 2003; Vinther & Larsen, 2004). In early spring Dover sole *Solea solea* and other flatfish start their migration towards shallow (coastal) waters to spawn. There they are targeted by many fishermen, both professional and recreational; given these fish actively migrate, they are a fairly easy target for fishermen using passive fishing techniques.

Although the majority of porpoises have left the coastal waters of the southern North Sea by May, still fairly high numbers washed ashore during that month. This is partly due to a high number of decomposed carcasses, originating from animals that may have died already during April (Haelters *et al.*, 2006). The peak in strandings during August is for a large part due to animals of only days to weeks old. Porpoises are born from May to August, and a high mortality of very young animals is a natural phenomenon. Porpoises are rarely seen in Belgian waters during summer months, but strandings during August indicate a presence in higher numbers further offshore.

The stranding records in 2008 proved to be anomalous in relation to those from the previous years. Figure 16 compares the stranded number of porpoises in 2008 to the average monthly number stranded between 2005 and 2007. It indicates lower numbers from March to May and in August, and a relatively high number in October.

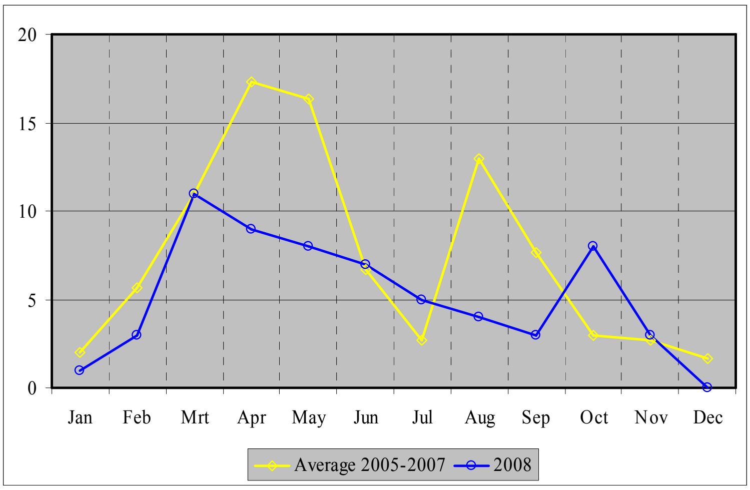

Figure 16. Strandings of porpoises per month in 2008 compared to the average numbers per month from 2005 to 2007 (data MUMM, partly unpublished).

Sightings of porpoises

MUMM's database contains 278 sightings of porpoises made between 1995 and 2007, excluding those made during dedicated aerial survey flights performed by MUMM. Mapping these sightings (figure 17; data up to June 2007, in total 272 sightings) makes clear that they are not distributed homogenously over Belgian waters. This might be to an irregular distribution of porpoises and to an irregular distribution of persons reporting sightings. The vast majority of sightings was reported between January and April, although the period with the highest human presence in coastal waters lies between May and August.

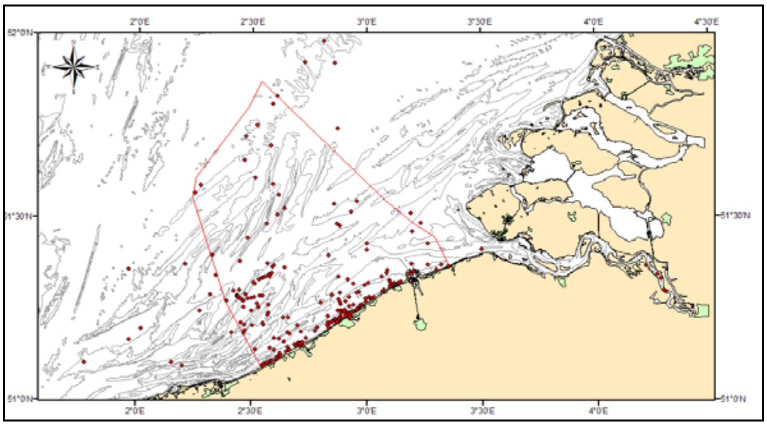

Figure 17. Sightings of groups of porpoises between 1995 and June 2007 as in MUMM's database, and reported in Depestele *et al*., 2008.

10.5.3.2. Other marine mammals

MUMM's sightings and strandings database contains, besides sightings of porpoises, also sightings of other marine mammals in 2008.

Common seal

Over 80 sightings of solitary common seals or small groups were reported. Especially at the end of 2008 common seals were frequently reported from apparently stable haul-out sites on the beach of Koksijde and in the port of Nieuwpoort, with together up to 16 animals. The vast majority of the reported sightings occurred in ports, on the beach or in the river Scheldt.

Figure 18. An unusual sight at the Belgian coast in 2008: in total 9 common seals hauled out in the port of Nieuwpoort on 21 December, at the same time when at the beach of nearby Koksijde 7 seals had hauled out – a higher number than ever recorded before at the Belgian coast during the last decennia (Photo Jan Haelters / RBINS).

Grey seal

Eight sightings of solitary grey seal were reported by the public, all from the coast. However, a number of seals had been released at Heist, and INBO reported one or a couple of seals hauling out on a daily basis on a tern breeding site in the port of Zeebrugge during several weeks.

White-beaked dolphin

As in previous years sightings of white-beaked dolphins were reported. In total 9 groups were reported, ranging from 1 to 7 animals. All sightings occurred offshore.

Bottlenose dolphin

Five sightings of bottlenose dolphins were reported, but some of these concern multiple sightings of the same animal for a period of weeks. Sightings probably concern only 1 individual, that was observed at the Belgian coast also in previous years. Sightings were reported off Nieuwpoort, in a well defined area of mussel culture, and off Ostend.

10.5.4. Discussion

The lower numbers of stranded porpoises in March and April 2008 than in previous years could have been caused by many factors. It might indicate that a lower number is being bycaught in recreational fishing gear, set from the beach. However, given that these fisheries have hardly changed over the last years, this is unlikely. The lower number of strandings, bycatches in recreational beach fisheries combined with the lower number of sightings from the coastline compared to previous years (data MUMM, unpublished), all indicate a lower number of porpoises in coastal waters, and the presence of the bulk of the population further offshore than in previous years.

Also the absence of a peak in strandings in August 2008 indicates that porpoises remained further offshore during 2008 than the years before. However, the peak in strandings in October 2008 is without precedent: while between 1995 and 2007 only eleven porpoise strandings were recorded for October months, eight were recorded during October 2008. Although this might have indicated an early autumn migration of porpoises from more northerly waters, numbers of stranded animals returned to average in November, and none washed ashore during December.

Other marine mammals are far less numerous in Belgian waters than the harbour porpoise.

10.5.5. Conclusions

Part of the offshore windfarm monitoring programme is dedicated to research on marine mammals. Next to the results of these investigations, the analysis of strandings and sightings data is also useful to understand spatial and temporal trends in the occurrence of porpoises in Belgian waters. Advantages of such analyses are that the raw data have been gathered for many years.

Since 2007 a downward trend has been observed in the number of porpoises washing ashore. The results of the investigations of stranded animals in years to come may confirm this trend, or might prove this was only a temporary phenomenon. The lower numbers of washed ashore porpoises is probably due to the presence of the bulk of the animals slightly further offshore compared to previous years, as sightings from the beach have declined while porpoises are still common in Belgian waters.

Most stranded porpoises were recorded during March and April. This coincides with the period when the animals are most common in the coastal waters of the southern North Sea, but also indicates the current major conservation problem for porpoises in this area: bycatch in fishing gear. A second peak in strandings occurs during summer months. These carcasses are in many cases decomposed, and many of them originate from very young animals. This indicates that animals occur further offshore, and that in the southern North Sea reproduction takes place. This is relevant information in the framework of the offshore windfarm monitoring programme.

Also ad hoc sightings, such as those reported by the public, are useful to obtain a better picture of the temporal and spatial distribution of porpoises and other marine mammals in Belgian waters.

Although the harbour porpoise is by far the most numerous marine mammal in Belgian waters, four other species were observed. While the reported observations of harbour seals were exclusively coastal, the irregular occurrence of this species in the windfarm areas is likely. The white-beaked dolphin is a very regular visitor to Belgian waters, and an assessment of numbers and spatial and temporal distribution would be useful.

10.6. Results of the monitoring of underwater noise relevant to marine mammals

The investigation of effects of increased underwater noise on biota is so complex, that it is impossible to undertake in the current monitoring programme. However, the results of the underwater noise monitoring programme can indicate a possible relevance for cetaceans.

The results of the underwater noise monitoring at the Thorntonbank construction site did not yield levels which would have potentially significant effects on porpoises or other marine mammals. The noise levels were comparable with those originating from shipping activities, already omnipresent in the area. It should not be expected that porpoises remain in the immediate vicinity of the construction works, as they usually avoid motorised vessels.

However, only a few underwater noise measurements were performed, and the noise level of some of the activities, including the placement of gravity foundations or scour protection, still needs to be measured. The objective is to perform such measurements during 2009 and consecutive years. For projects in which piles will be driven, the main objective is to measure the noise levels associated with this activity, and to assess potential impacts.

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Chapter 11. Seascape and socio economic study: preparatory year

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Abstract

There is a big concern on the impact on the seascape of the planned offshore wind farms in the Belgian part of the North Sea, This study describes the preparatory work done for the monitoring of the impact on the seascape. The main goals of the sociological landscape study is to see what people's opinions are on the existing wind farm with 6 wind turbines and their opinion on the planned extension of the wind farm and the completion of other wind farms. For achieving these goals an inquiry will be held amongst people regularly staying at the coast. The landscape imagery focuses on simulations of the planned wind farms, they are used in the inquiries. As a previous study is available on peoples opinion on renewables and wind energy it will be possible to compare peoples opinion of today (when the wind farm exist at sea) with that of some years ago (when the wind farm wasn't built yet).

Samenvatting

Er bestaat een grote bezorgdheid over de impact van de geplande windmolenparken in het Belgisch deel van de Noordzee op het bestaande zeezicht. Deze studie beschrijft het voorbereidende werk dat gedaan werd voor de monitoring van de impact op het zeezicht. Het doelstellingen van deze sociologische landschapsstudie is te weten komen wat de mening is van de bevolking over het bestaande windpark van 6 windturbines en over de geplande uitbreiding en de bouw van andere windmolenparken. Om dit te bereiken zal een ondervraging gebeuren van mensen die zich regelmatig aan de kust bevinden. Deze ondervraging gebeurt aan de hand van fotosimulaties van de geplande windmolenparken. Er zijn resultaten bekend over de mening van mensen over hernieuwbare energie en windenergie. Dit zal het mogelijk maken om de huidige mening van mensen te vergelijken met de opinie van de bevolking van een aantal jaar geleden (toen er nog geen windmolenpark in zee gebouwd was).

11.1. General

The monitoring of the seascape, as described in the environmental permits of C-Power and Belwind, was the basis for the tender on seascape and socio economic issues of offshore wind farms in the Belgian part of the North Sea. This tender was divided in 2 parts: a landscape imagery part and a sociological landscape part. For the landscape imagery part the tender provided the taking of a set of pictures that is to be used in the sociological landscape part were these pictures will be used to simulate viewings on the offshore wind farms in public interviews on the people’s opinion on offshore wind farms.

For the first part only one interested party send in a proposal. For the second part two parties were interested and send a proposal, a third party informed MUMM not to be interested. The final chosen methodology for both parts are described below.

11.1.1. Part 1: Landscape imagery

11.1.1.1. Photo simulation

11.1.1.1.1. Introduction

As a base layer a neutral sea picture will be used. On this base layer the wind turbines are added digitally to give an impression on how the situation would look like with real wind turbines. The created picture is called a “simulation picture”. Using this technique many different viewpoints and angles can be simulated. The relevance (for use during the inquiries) of the these different simulated pictures will be checked and a selection of pictures to be used during inquiry will be made.

11.1.1.1.2. Methodology

The picture simulations have an important function when evaluating the impact of the offshore wind farms on the seascape. The picture simulations will also be used in the second part of this study (the sociological landscape part) to search for effects the offshore wind farms could have on seascape according to the interviewed people. It is therefore of most importance that the simulations are made for the different building phases of the wind farms. Following arrangements will be used:

- six wind turbines of C-power project;
- complete C-power project (60 wind turbines, smallest distance to Zeebrugge coastline = 27 km);
- complete C-power wind farm + complete Belwind wind farm (60 windturbines,smallest distance to Zeebrugge coastline =27 km and 66 windturbines with smallest distance to Zeebrugge coastline = 42 km);
- complete C-power wind farm + complete Belwind wind farm + complete Eldepasco wind farm. For the Eldepasco project different farm layouts have been proposed. The layout with the biggest impact will be used for this simulation;
- complete C-power wind farm + complete Belwind wind farm + complete Eldepasco wind farm + complete implementation by wind turbines of the wind farm area as indicated by the royal decree dated 17/05/2004.

11.1.1.1.3. Viewpoints Coastline

Three different viewpoints will be taken at the east coast. Proposal is made for the following locations: Zeebrugge (location with the smallest distance wind farm/coast), Ostend (location at west end of the east coast, but where wind turbines are still visible), Knokke (location at east end of the east coast). To have a good insight in the difference of experience between people on the dike and people in their apartment the visualizations will be made at two different view heights. Proposal is to have a height of 15 and 35 meters as representative heights for these pictures. If these simulations will give a significant difference, both simulations will be relevant in the sociological landscape part of the study.

11.1.1.1.4. Viewpoints seaside

The three viewpoints at seaside will be taken near the corners of the Belgian wind farm area and such that all wind turbines can me mounted in the picture and that the closest wind turbine will be a 1 to 2 km distance. Eventually a distance of 500m can be taken used as this is the security distance for ships approaching the wind farm. It is proposed to choose two viewpoints in the land direction and one sea ward. This will give a good insight in the maximal impact of the wind farm for seagoing people. The view height at seaside is assumed to be 5m above sea level.

11.1.1.1.5. Assembling the simulations picture

The simulation of the wind turbine will be mounted in two neutral base layer photo's, with maximal visibility, which will be representative for the experience of the view on wind farms when looking from the Belgian coastline to open sea. The use of neutral base layer is important because the simulations will be used in the inquiries for the sociological landscape study and the evaluations made by the interviewed people may not be influence by casualties on the photo like e.g. passing ships, object on the beach, etc.

From all the available simulations pictures with maximal visibility, a selection (+/- 10) will be made for which a simulation in different weather conditions and night view would give additional relevant insight. For this a hazy and heavy cloudy sky base layer will be used as well as a night view. The nigh view will simulate the eventual effects of the wind farms lights. For practical reasons it is proposed to use only 5 to 6 simulation pictures during the inquiry.

11.1.1.1.6. Material

For the picture simulations the contractor will use the 3D visualization program WindPRO. The coordinates of the wind turbines, the coordinates of the viewpoints and the view angles are the input for the program. The diminishing visibility with distance and perspective issues will be taken into account. Photo's will be taken with a digital camera, a Nikon 20D with 10 megapixel resolution. No artificial lights will be used. The quality of the pictures has to be excellent as to be able to use them for poster printing.

11.1.1.1.7. Output

A total of 75 photo simulations are made:

- from the coastline: 5 arrangements x 3 viewpoints x 2 heights = 30 simulations
- from seaside: 5 arrangements x 3 viewpoints= 15 simulations
- additional other weather circumstances and night: (indicative) 10 x 3 (weather circumstances + night) = 30 simulations

The simulations will be ready at the beginning of the sociological landscape study.

11.1.1.2. Photomontage

11.1.1.2.1. Introduction

Goal of this part is to make pictures of the first 6 built wind turbines that will be used to evaluate the real effects of the 6 first built wind turbines. On top of the simulations made with the neutral base layer, also photomontages using the real situation at sea as the base layer will be made. On these last mentioned pictures the same technique will be applied to add the wind turbines. The final result of this photomontage will then be compared to the real situation at sea and to pictures of that real situation. This methodology will allow us to see if the photomontage gives a good impression of the real situation that is seen by people at the coast side.

11.1.1.2.2. Viewpoints

Pictures will be taken at three different viewpoints, at the east coast, at locations with the highest impact of the wind turbines. These pictures will be taken during sunny weather and good visibility, sunny weather and bad visibility and heavy cloudy dry weather. To evaluate the effect of the lights a night picture can be made at 1 of the three locations. The pictures will be taken on the beach and on the dike. If possible some pictures will be taken from a higher position (e.g. flat).

If needed pictures at the seaside of the 6 wind turbines can be made at three different locations, at two distances. It will be practically not possible to take pictures in different weather circumstances. A time period of two months is foreseen to be able to cover all the possible weather circumstances.

11.1.1.2.3. Timing

As the mounting of the photomontage will take some time it their availability for the inquiry can not be confirmed. It is therefore suggested to have the inquiries on the dike with the real time view on the wind turbines and to use the photo simulations with neutral base layer described at the beginning.

11.1.1.2.4. Output

Using the methodology of part A following pictures are taken and photomontages will be made:

- 12 pictures of 6 real built wind turbines on the Thorntonbank (from 3 locations at the east coast during 3 different weather conditions + night);
- 6 pictures of 6 real built wind turbines from seaside (from 3 locations at sea, during one weather condition (sunny-good visibility) + night);
- about 15 photomontage with actual view base layer from different viewpoints in weather conditions yet to be defined.

11.1.1.2.5. Material

The printed pictures will be in A4 format (29.7x21 cm). For the inquiry the pictures will be in A3 format. Every picture will be carefully annotated with all relevant parameters (locations, distance, and weather). Pictures will be burned on CD-R of DVD and delivered in JPEG format. Three digital and 1 analog copies will be delivered.

11.1.2. Part 2: sociological landscape study

11.1.2.1. Introduction

Primary goal of this study is to see what peoples opinion is on the existing wind farm with 6 wind turbines. Second goal would be to see how people feel about the impact of the planned extension of the wind farm and the completion of other wind farms in the wind farm area. As a previous study is available on peoples opinion on renewables and wind energy it will be possible to compare peoples opinion of today (when the wind farm exist at sea) with that of some year ago (when the wind farm wasn’t built yet).

11.1.2.2. Methodology

Four important steps can be distinguished in the methodology used:

- definition of the research population,
- the choice of sample survey,
- selection of the enquiry method,
- selection of the questions to be asked during inquiry.

The methodology will be tested with a group of 10-15 people before actually being used in the field. In this way the questionnaire can be still adopted before final use. The field inquiry will be done by the contractor.

The final report will have a detailed table reporting part with all frequency – and crossing tables, figures, graphs and the used statistical tests. The written part will focus on main conclusions.

11.1.2.2.1. Definition of the research population

Before starting the sample survey and inquiry a clear vision on the population that will be interviewed is needed. Previous survey indicated that the impression of landscape is strongly correlated with the frequency of landscape observation and with the involvement of the people.

Following targets groups are chosen:

- Local habitants ;
- Second residential people;
- Day tourists;
- Long stay tourists;
- People not living, but working at the coast side.

In all these target groups sailors will be included if possible.

As previous study showed that the frequency of observation is important, focuses for the first two groups will be on the local inhabitants and second residential people of Knokke-Heist and Zeebrugge (primary region) as the wind farm at sea will be most visible in those two places.

Day tourists are those tourists that visit the coast without haven an overnight, whereas long stay tourists have at least one overnight.

11.1.2.2.2. Sample survey choice

A representative sample survey has to be chosen out of the research population to come to confidential conclusions. This means that a spreading of the sample survey over the research population is of importance as is a spreading in time and space. Three regions are selected: Knokke-Heist + Zeebrugge is the primary region, Blankenberge, De Haan and Bredene is the secondary region 1 and Oostende is the secondary region 2.

The number of enquiries in the different segments has to be big enough to get statistically justified and reliable conclusions. To achieve these goals a quota sample survey in combination with criteria for each target group and region will be used. A quota sample survey defines in advance how many people from each target group and region have to be questioned, taking in considerations that the number of enquiries have to be big enough for each of the target groups and regions.

For each target group a number of 210 peoples is proposed. In total 1050 persons will be interviewed for this research or 350 a region. This distribution will able us to conclude on following levels:

- the total sample survey of 1050 enquiries will allow us to give significant and statistical reliable results for the coastal populations;
- a comparison of the different target groups is possible by having the same amount of people questioned in every group;
- a comparison of different regions is possible by having the same amount of people in each region;
- conclusions at region level can be made with a confidence level of 95% and error margin of 5%;
- conclusions on target group level can be made with a confidence level of 95% and error margin of maximum 7%;
- conclusions on target group region level can be made with a confidence level of 90% and error margin of maximum 10%;
- conclusions on the sailors group can be made with a confidence level of 90% and a error margin of 10%.

11.1.2.2.3. Selection of the enquiry method,

The presented enquiry method is the same for all target groups but the way the target groups will be approached can vary:

- Coastal inhabitants: face-to-face, oral interview door to door;
- Second residential people: face-to-face, oral interview door to door;
- Day tourists and long stay tourists: face-to-face interview on the dike;
- People working at the coast: face-to-face oral at work location on the dike or in the vicinity.

The used formulary will be in made using a teleformprogram. This program allows automatically scanning of the answer on the formulary and avoids mistakes in the dataset.

11.1.2.2.4. Selection of the question to be asked during inquiry

Questions used in the inquiry will be based on the previous study of 2001-2002. The questionnaire will have different parts:

- the first part of the questionnaire will sound the relation of the persons with the coast side, we need to know at which frequency the person is in contact with the view of wind farms at sea;
- the second part will examine the social relevance of the durable development by proposing assumptions on wind farms and wind energy in general; we want to know the peoples opinion in this matter and see if the peoples' opinion has changed according to the previous inquiry in 2001-2002;
- the third part will sound the experience of the actual wind farm, how the visual impact is judged from the dike, what is the impact of the turned wings, what is the impact of lights in bad weather conditions or at night;
- the fourth part of the questionnaire will sound the effects the wind farm has on the people;
- the fifth part will sound the cumulative impact of the second and third wind farm in the wind farm area; photo simulations will be used for this part;
- the last part will focus on socio demographic information of the people (age, education level,etc.).

Chapter 12. Recommendations for a future monitoring of wind farms in Belgium's marine waters

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Photo Jan Haelters / RBINS

12.1. Introduction

The future monitoring will continue to aim at the hypothesized impacts in the concession areas. As well as some changes within the technicalities and scientific designs of this monitoring (see Executive Summary), suggestions for fine-tuning the focus of the monitoring programme have been formulated in the different chapters. These recommendations are further complemented with suggestions drafted during several research-partner meetings early in 2009.

Given their importance for the future of the monitoring programme, this chapter provides an overview of these recommendations, with a view to implementing them in 2009 and/or the following years of monitoring.

12.2. Recommendations as taken from the monitoring results

Underwater noise

Future underwater noise monitoring activities will focus on pile driving and on those activities of which the noise characteristics are less well known and/or are expected to cause a significant increase in noise levels. Examples are the dumping of scour protection and cable laying.

Hard substrate epifauna and fish

1. Species richness, species-specific densities and biomass will be measured wherever possible.
2. Given their possibly high nursery capacities for invertebrates, as well as (commercial) vertebrates, special attention should be given to the habitat engineering effects of species, such as *Lanice conchilega*, *Sabellaria spinulosa*, *Tubularia* spp., *Electra* spp. and the alien *Crassostrea gigas*. ROV videoing is considered useful here.
3. Within and between sites replicated sampling is recommended in order to increase the reliability of the measurements.
4. The future monitoring of the hard substrate fauna will also include density and diversity, feeding behaviour and physiological condition of fish in the direct vicinity of the wind turbines.

Soft substrate macrobenthos

To evaluation the possible edge effects of the colonized hard substrates on the surrounding soft sediments, samples should be taken starting close to the wind turbines and at small spatial intervals away from them (i.e. small-scale study).

Soft substrate epibenthos and fish

No immediate fine-tuning of the monitoring focus required.

Seabirds

Since monitoring should also focus on displacement through avoidance behaviour, as well as migration flux and collision risk, seabird radar research will be implemented in the monitoring programme. The Automated Radar System will first be tested and calibrated onshore.

Marine mammals

1. Passive acoustic devices (i.e. Porpoise Detectors or PoDs) will be applied for the detection of harbour porpoises. PoD deployment is foreseen from the beginning of 2009 onwards.
2. More aerial surveys will be conducted to allow for the development of density surface models, revealing information on spatial and temporal variability. This is needed for the assessment of possible effects of the construction and operation of offshore wind farms.
3. Although less abundant than the harbour porpoise, attention will also be paid to the white-beaked dolphin, which is a very regular visitor to Belgian waters.

Seascape

To investigate the impact of the wind farms on the seascape a two-step approach will be used: a landscape imagery part will aim at simulating the seascape impact and is to be used in a sociological landscape part. The pictures will be used to evaluate the people's opinion on the seascape impact of offshore wind farms. The inquiry will be held among people regularly who are staying at the coast side.

12.3. Integrative monitoring

12.3.1. Integrating monitoring programmes

As both monitoring programmes (i.e. C-Power and Belwind) are strongly intertwined, most conclusions from the monitoring apply to both areas. This should be considered an advantage, rather than a disadvantage, as from a macro-environmental perspective these sites can be considered highly similar and hence (most probably) representative for the Belgian offshore water ecosystem. Both sites might thus be considered replicates, increasing the reliability and generality of any observed impact. The MUMM strategy therefore includes the integration of the monitoring exercises for the C-Power, Belwind and possible future concessions in the Belgian part of the North Sea.

12.3.2. Cause-effect relationships

While the first aim of this report was to provide an overview of (1) what has been done so far, (2) what the major conclusions regarding impact detection are at this point and (3) what would be the major lessons learned for future monitoring, this part of the monitoring only represents a first step within the monitoring programme. Whereas the current (baseline) monitoring design aims at an objective *a posteriori* evaluation of existing and possible resultant impacts of marine wind farms in Belgian waters, it is incapable to disentangle the processes behind an eventual impact. Since however knowledge of these processes help understanding the cause-effect relationships, an upgrade of the monitoring programme from a level of *a posteriori* phenomenon observation to a level of process understanding is needed. The capability to link environmental changes to an underlying cause-effect rationale (i.e. targeted monitoring) is not only a pre-requisite for effective regulatory application, but – as it provides baseline knowledge to comprehend impact processes – also permits (1) current and future impact mitigation, (2) better prediction of future impacts, as well as (3) moving away from site-specific observations to more generic knowledge.

Consequently, it is advised to feed the information taken from the baseline monitoring into the investigation of a selected set of hypothesized cause-effect relationships. Selection should here be based on the knowledge from and prioritization within the baseline monitoring and the Environmental Impact Study. Within the monitoring programme, it will hence be important to find an adequate effort and budgetary balance between baseline and targeted monitoring.

The process of selecting the priority cause-effect relationships for future monitoring in ongoing. Hereto, a close interaction between MUMM and its research-partners is ascertained so as to assure a relevant selection with a direct added value to the marine wind energy sector.

12.3.3. Evaluation of the overall impact based on environmental indicators

After the quantification of the differential impacts of the construction and exploitation of marine wind farms, as presented in this report, a next and most legitimate request would be to compare the overall impact of this anthropogenic activity with that of other activities (e.g. marine aggregate extraction). Such comparison would allow us to evaluate and/or scale the overall severeness of any anthropogenic activity. However, this exercise is not as simple as it might seem. Here below, we therefore introduce the background of the subject and formulate MUMM's intentions for future action.

To fully comprehend the impact of an anthropogenic activity on the marine ecosystem, impact evaluation should be framed within the Driver-Pressure-State-Impact-Response (DPSIR) model, of which especially the pressure, state and impact are relevant here. In this case, the pressure, being the overall pressure of the construction and exploitation of marine wind farms on the marine ecosystem, eventually combined with the exclusion of bottom trawling fisheries, is clearly delineated. The environmental state as a result of the pressure, however, cannot be covered by only one (or a limited number of) characters, given the multi-faceted and hence multivariate nature of the environmental state. Marine wind farms, for instance, are known or at least expected (1) to cause local changes in hydrodynamic conditions (with consequent alterations within the sediment grain size composition), (2) to cause visual disturbance due to the presence of above-water structures, (3) to add new hard substrate habitat to a formerly and naturally soft substrate marine environment or (4) to cause vibrations due to the construction and exploitation, adding to the natural background levels of underwater noise. In their turn, each of these altered environmental states influences the ecosystem, which is the environmental impact we would finally like to evaluate. Again this impact on the ecosystem is multi-faceted and hence multivariate by nature. Local changes in sediment grain size composition, for instance, will – or at least might – cause community shifts within the benthos, as exemplified by an altered community structure (e.g. diversity, density or biomass) or functioning (e.g. remineralization processes and predator-prey interactions). Each of these measures or response variables can be quantified, which is exactly the aim of this monitoring programme, i.e. to unravel and quantify the ecosystem impacts due to the construction and exploitation of marine wind farms. Ecosystem impact can now be defined as the deviation of each of the response variables[1] from its condition prior to the impact or relative to the reference area(s).

From this reasoning it is clear that the evaluation of the overall impact is not as straightforward as we would like it to be. As e.g. (1) the impacts themselves are multivariate, (2) some of the impacts might be positive, other negative, (3) some might be severe, other more moderate or (4) some only cover one ecosystem component (e.g. benthos), other cover several ecosystem components (e.g. altered bentho-pelagic coupling), an overall judgment on whether the overall impact is positive or negative, not to speak about how positive or negative the impact is, remains difficult.

Here, environmental indicators offer a solution. These indicators generally combine several assets of the ecosystem into an integrative measure of ecosystem quality. As such, they are considered quantitative proxies for ecosystem quality. This combination of assets is generally based on known or presumed cause-effect relationships and are hence (presumed to be) generically applicable. Several indicators have already been developed and testing and intercalibration exercises were performed mainly as a consequence of the European Water Framework Directive (WFD). They will further be developed within the European Marine Strategy Framework Directive (MSFD). The indicators used in coastal waters for WFD purposes can be grouped in three types: (1) the multi-metric indicators based on the AMBI principle (e.g. m-AMBI [Spain], IQI [UK]); (2) the multi-metric indicator Benthic Quality Index (BQI, Sweden), using an objective way to define sensitivity-tolerance of species ($ES50_{0.05}$); and (3) the multi-level Benthic Ecosystem Quality Index (BEQI) evaluating different aspects of the benthic habitat/ecosystem without predefined sensitive-tolerance classes for species. Given its suitability to evaluate the effects of multiple pressure types, the BEQI was adopted to evaluate the environmental status (ES) of benthic ecosystems in Belgium and the Netherlands.

As such, an array of well-challenged and intercalibrated indicators exists and will be used in the future to present an integrative view on the ecosystem quality change (*prior* versus *post hoc* or impact versus reference site) as a result of the construction and exploitation of marine wind farms. From this array it was advised to select not only one, but a suite of suitable indicators (Royal Commission on Environmental Pollution, 1998). The selection of this suite should be based on indicator performance, as quantified in the various WFD intercalibration exercises, and the availability of response variables from the monitoring programme. As an alternative to the latter, the monitoring programme could be

[1] The true size of the multivariate impact space is dependent on both the number of response variables considered and their cause-effect connectivity. Several variables are interconnected (e.g. a change in hydrodynamical regime will cause changes in the sediment's grain size distribution or a change in benthic community structure will cause changes within the food availability to benthos-eating fish) and should hence be considered dependent. The true size of the multivariate impact space and hence the number of relevant response variables is limited to only independent response variables.

partly redirected towards those response variables, relevant for the selected indicators. The use of such environmental indicator approach will hence not cause a proliferation of the monitoring effort or cost.

If the ecosystem quality change – based on environmental indicators – could be calculated for several anthropogenic activities, then a comparison of the change between the different activities would allow us to scale the activities along an impact severity gradient. As such, the MUMM intention is to integrate the results of other, existing monitoring initiatives (e.g. aggregate extraction, dredging and dredge sludge disposal) with those from the marine wind farm monitoring initiative. This exercise would significantly contribute to an objective evaluation of the impact of the construction and exploitation of marine wind farms. The exercise will further allow to scale the magnitude of the overall impact, relative to the ES categories, as defined in the WFD and to be defined in the MSFD. Here, an impact should only considered unacceptable if it causes a significant degradation within the GES categories perspective (e.g. from good ES to bad ES).

In conclusion, integrative monitoring is and will be narrowly intertwined with the ongoing monitoring programme. Herein, three priority items can be discerned:

Detailed observations of the Before-After/Control-Impact (BACI) changes of a selected set of response variables within each of the (main) ecosystem components (i.e. benthos, fish, seabirds and marine mammals) provide the knowledge necessary for impact detection and quantification (i.e. baseline monitoring). This selection should be based on the list of expected impacts as taken from the environmental impact study (EIS).

The information taken from the baseline monitoring should be exploited for a selected set of hypothesized cause-effect relationships in order to improve possible mitigation and prediction of (future) impacts. Selection should here be based on the knowledge from the baseline monitoring results and the EIS. The capability to link environmental changes to an underlying cause-effect rationale is not only a pre-requisite for effective regulatory application (Rees et al., 2006), but also provides the baseline knowledge to comprehend impact processes and, therefore, to permit current and future impact mitigation, as well as better prediction of future impacts.

A last priority item should cover the evaluation of the severeness of impact by (1) comparing the overall impact with those of other pressures and (2) scaling its magnitude according to the ES categories, using a suite of multimetric environmental indicators.

These items will be covered simultaneously as the information taken from both first priority items is directly fed into the third priority item.

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Chapter 13. Conclusions: the main messages…

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Photo Jan Haelters / RBINS

In this conclusive chapter a listing of the major conclusions from each of the main chapters is provided. Since it is anticipated that – based on this listing – the reader might want to get the full detail on certain conclusions, the items are listed for each chapter separate. For a more integrated view of the major outcome of the monitoring work done in 2008, one is referred to the Executive Summary.

13.1. Underwater noise

1. The background underwater noise level recorded at the Bligh Bank site was similar to the background noise levels recorded at the Thornton Bank site. The difference in level could be linked to slight differences in weather conditions at the time of the monitoring campaigns, differences in the sites themselves, differences linked to the season and water temperatures, differences in human-generated noise during the respective campaigns (e.g. shipping) and to a combination thereof.
2. The variations observed between the T_0 at the Thornton Bank and at the Bligh Bank (likely due to the proximity of pipelines at the former site) indicate that it is necessary to establish T_0 values for each site separately.
3. The increase in underwater noise levels recorded at the C-Power site during the monitoring campaigns of 2008 (i.e. during the construction phase) was minor and can be compared to general shipping noise as temporarily present over a large part of Belgium's marine waters and especially near ports and shipping lanes.
4. Although a need to fine-tune the underwater noise recording methodology was recognized, it proved very difficult to synchronize the monitoring campaigns with relevant, selected construction activities, due to repeated changes within the planning of the construction works in 2008. The fact that adverse weather conditions make sound recordings impractical places additional constraints on this monitoring and calls for maximal flexibility in planning and resource mobilization.
5. The location of sampling stations for noise measurements should be appropriately adapted in the future, for instance to measure point sources, such as originating from pile driving activities.
6. Future underwater noise monitoring activities will focus on pile driving and on those activities of which the noise characteristics are less well known and/or are expected to cause a significant increase in noise levels. Examples are the dumping of scour protection and cable laying.

13.2. Hard substrate epifauna and fish

1. One of the most direct and obvious impacts of the construction of six wind mills at the C-Power site, was the fast and intense colonization process by hard substrate epifauna. After 3.5 months already, a high species richness was found, with a dense Bryozoan (*Electra pilosa*) cover, with associated species, such as small crustaceans, polychaetes, blue mussel *Mytilus edulis* and queen scallop *Aequipecten opercularis*.
2. Three vertical zones can be distinguished: (1) an intertidal and splash zone characterized by the dominance of the chironomid *Telmatogeton japonicus* and the presence of four filamentous algae, (2) a shallow subtidal to low intertidal zone dominated by barnacles and the tube building amphipod *Jassa* and (3) a deeper subtidal zone with a dense *E. pilosa* turf. The continued monitoring of response variables, such as species richness, species-specific densities and biomass, will allow the continued investigation and documentation of (1) the successional transitions, (2) the different stages along the succession gradient and (3) the change of the impact of wind farms and as such the change within the ecosystem functioning due to the presence of the wind farm.
3. The presence of exotic *Balanus perforatus* and *Megabalanus coccopoma* in the barnacle zone exemplifies the opportunity offered by artificial hard substrates to southern and alien fouling species spreading into the North Sea. This stepping stone effect of artificial hard substrates, such as wind turbines, might be particularly relevant for species like *Jassa* spp. and *T. japonicus*, that lack planktonic larval stages.
4. As an alternative or complement to the destructive scrape sampling, it is advised to test and evaluate ROV videoing for e.g. the search for egg deposits, engineered habitat structure and size

quantification and counts of sheltering (small) fish. Furthermore, given their possibly high nursery capacities for invertebrates, as well as (commercially valuable) vertebrates, special (ROV) attention should be given to the habitat engineering effects of species, such as *Lanice conchilega*, *Sabellaria spinulosa*, *Tubularia* spp., *Electra* spp. or the alien *Crassostrea gigas*.

5. To evaluate the metapopulation dynamics one should not concentrate on only one pile, but should rather include several piles at various distances from each other. However, because of cost-effectiveness considerations, within- and between-site-replicated sampling could focus only on the barnacle-*Jassa* zone. The combined presence of the two sibling species *Jassa herdmani* and *J. marmorata* provides a good model for metapopulation dynamics here.
6. The monitoring of the hard substrate fauna will further also include density and diversity, feeding behaviour and physiological condition of fish in the direct vicinity of the wind turbines. These fish constitute an important link between the hard substrate and the soft substrate fauna.

13.3. Soft substrate macrobenthos

1. For future monitoring it will be important to re-evaluate the suitability of the Gootebank as a reference area for the Belwind concession area and/or to select those response variables that do not show any significant difference.
2. No large-scale impact of six wind turbines on the sediment characteristics and the macrobenthos of soft sediments in the first year after implementation of the C-Power wind farm (1st phase) was detected and any impact remained subordinate to seasonal and yearly variability. Small-scale impacts as well as impacts at a longer-term are yet to be determined.
3. Knowledge on the possible edge effects of the colonized hard substrates on the surrounding soft sediments (including their spatial spread) would largely contribute to the understanding of possible changes within the soft substrate benthos. Therefore samples should be taken starting close to the wind turbines and at small intervals away from them. Further off, the interval can be enlarged.
4. A smaller research vessel with a high maneuverability or other sampling strategies and techniques (e.g. diver-operated sampling or ROV observations) will be necessary in the future to reach stations in the close vicinity of the wind turbines. Alternatively, a careful reconsideration of monitoring locations at both the Belwind and C-Power site would be appropriate.
5. An increase in the number of sampling locations between the two concession areas of C-Power is recommended, as possible (large-scale) impacts of altered sediment transport are expected mainly in northeastern direction

13.4. Soft substrate epibenthos and fish

1. The reference sites for soft substrate epibenthos and fish monitoring at the Gootebank and the reference part of the Thorntonbank (for C-Power) and the Oosthinder (for Belwind) are considered appropriate. Perciforms and flatfish dominated throughout the years, supplemented by locally and seasonally high densities of clupeids and gadoids. The epibenthos was generally dominated by brown shrimp (*Crangon crangon*), two brittle star species (*Ophiura* spp.), hermit crab (*Pagurus bernhardus*), flying crab (*Liocarcinus holsatus*), lesser bobtail squid (*Sepiola atlantica*) and squid (*Loligo vulgaris* and *Todaropsis eblanae*).
2. Seasonality, interannual differences, and spatial differences (sandbank tops versus gullies) account for most of the observed variation in the epibenthos and fish assemblages. As such, significant differences due to the construction of the present six wind turbines have so far not been detected.
3. Sampling epifauna and demersal fish in the vicinity of wind turbines will present a future challenge, since cables and other structures on the seafloor prevent the completion of the beam trawl tracks. Consequently, adaptations of the sampling strategy (mainly a shortening of the tracks) should be implemented.
4. The impact monitoring of the C-Power wind farm will benefit from the establishment of a closed area within the sand extraction concession zone, so as to avoid interference with the effects of future sand extraction and to assure a better suited reference area.

13.5. Seabirds

1. The C-Power concession area is moderately valuable to northern gannet, common gull, lesser black-backed gull, great black-backed gull, black-legged kittiwake, common guillemot and razorbill and valuable for little gull, sandwich tern and common tern. For the Belwind concession area those species are northern gannet, lesser black-backed gull, black-legged kittiwake and common guillemot (moderately valuable) and great skua and little gull (valuable). Future monitoring will focus on these seabird species.
2. Based on the spatial distribution of ten seabird species, suitable for future monitoring of the C-Power site, the selected reference area for seabird monitoring was considered suitable. These ten species were further ranked according to their suitability for future monitoring. Auks, terns, northern gannet and little gull offered the highest suitability for future monitoring of the impacts at the C-Power site.
3. Based on the spatial distribution of six species, suitable for future monitoring of the Belwind site (i.e. northern gannet, great skua, little gull, lesser black-backed gull, black-legged kittiwake and common guillemot), a site including the Oosthinderbank and the Blighbank was selected as future reference site.
4. Compared to the C-Power reference area, densities of northern gannet in the concession area were almost halved, whereas densities of common terns drastically increased. Future monitoring will reveal whether both changes can be attributed to the presence of the wind turbines.
5. In terms of reliable monitoring, it is absolutely necessary that in coming years ship-based bird counts be allowed inside the wind farm.
6. To accurately assess the impact of the future wind farms, migration behaviour and occurrence of the respective birds in the various concession areas need to be investigated in detail. Monitoring should also focus on displacement through avoidance behaviour, as well as migration flux and collision risk.
7. Based on a collision risk assessment, a relatively low collision risk for species such as auks, terns and little gull, but a higher collision risk for gulls, great skua and gannets was demonstrated.
8. To reliably assess the real loss of seabirds due to collision with wind turbines, seabird radar research will help give true and reliable measure of the bird fluxes throughout the wind farm areas. Therefore, MUMM has recently launched a call for tender to purchase an Automated Radar System to investigate seabird fluxes through the wind farm areas in further detail.

13.6. Marine mammals

1. Aerial surveys provided a first global estimate of the density of harbour porpoises in the area of interest. In April 2008 the total population was estimated at 4300 individuals for the entire area under Belgium's jurisdiction, with a 90% confidence interval of 2600 to 7200 individuals.
2. More aerial surveys will need to be undertaken to obtain narrower confidence limits for abundance, density and group size estimates. Surveys will also aim at covering the whole of the Belgian waters, given that the number of transects is close to a minimum still useful for statistical analysis. This should allow the development of density surface models, yielding information on spatial and temporal variability. Such information is needed for the assessment of possible effects of the construction and operation of the offshore wind farms.
3. Due to technical and budgetary constraints within the current monitoring program, future estimation of marine mammal densities should only be executed during good observer conditions.
4. Because a detection probability function, necessary for analysing data, could only be obtained on the basis of data gathered from a single bubble window, MUMM has decided to equip the aircraft with a second bubble window.
5. As passive acoustic devices for the detection of harbour porpoises are considered useful for impact monitoring, a mooring system for Porpoise Detectors (PoDs), in which existing buoys are used to reduce costs, was developed. PoD deployment is foreseen from the beginning of 2009 onwards.
6. In addition to the results of aerial surveys, the analysis of strandings and sightings data are and will be used to understand spatial and temporal trends in the occurrence of porpoises in Belgian waters.

7. Although less abundant then the harbour porpoise, the white-beaked dolphin *Lagenorhynchus albirostris* is a very regular visitor to Belgian waters and an assessment of numbers and spatial and temporal distribution in relation to the wind farms will be useful.

13.7. Seascape

1. A methodology was developed to investigate the impact of the wind farms on the seascape. A two-step approach will be used: the landscape imagery part will aim at simulating the seascape impact with and without wind mills. This imagery will then be used in the sociological landscape part: these pictures will be used to evaluate the people's opinion on the seascape impact of offshore wind farms at the hand of standard questionnaires. The enquiries will be made with people regularly staying at the coast.
2. The imagery work and the enquiries will be carried out by specialized firms under contract in 2009.

13.8. Integrative monitoring

1. As both monitoring programs (i.e. C-Power and Belwind) are strongly intertwined with each other, most conclusions from the monitoring apply to both areas. This should be considered an advantage, rather than a disadvantage, as from a macro-environmental perspective both sites can be considered highly similar and hence (most probably) representative for the Belgian offshore marine ecosystem. Both sites might thus be considered replicates, increasing the reliability and generality of any observed impact. The MUMM strategy is therefore to integrate the monitoring exercises for the C-Power, Belwind and possible future concessions in the BPNS. This notwithstanding, different building techniques (pile driving, gravity base foundations) and configurations (concrete basements, tripode and jacket foundations), will require a specific approach and the spreading of the licensed activities over time will condition the planning of the monitoring campaigns.
2. The current (baseline) monitoring design aims at an objective evaluation of existing and possible resultant impacts of marine wind farms in Belgian waters. Targeted monitoring should now upgrade the monitoring programme from a level of *a posteriori* phenomenon observation to a level of process understanding by targeting a selected set of hypothesized cause-effect relationships highly relevant to the wind energy sector. This step is not only a pre-requisite for effective regulatory application, but also permits (1) current and future impact mitigation, (2) better prediction of future impacts, as well as (3) moving away from site-specific observations to more generic knowledge.
3. To compare the overall impact of marine wind farms with that of other activities (e.g. marine aggregate extraction) would allow us to evaluate and/or scale the overall severeness of any anthropogenic activity. However, since e.g. (1) the impacts themselves are multivariate, (2) some of the impacts might be positive, other negative, (3) some might be severe, other more moderate or (4) some cover one only ecosystem component, other cover several ecosystem components, a quantification of the overall impact remains difficult. Environmental indicators, combining several assets of the ecosystem into an integrative measure of ecosystem quality, might offer a solution here. As such, an array of well-challenged and intercalibrated indicators will be used to present an integrative view on the ecosystem quality change (*prior* versus *post hoc* or impact versus reference site) as a result of the construction and exploitation of marine wind farms. The MUMM intention is to integrate the results of other, existing monitoring initiatives (e.g. aggregate extraction, dredging and dredge sludge disposal) with those from the marine wind farm monitoring initiative and to allow comparison as such.

Annexes

Annex 1: Systematic species list of hard substrate epifauna and -flora

0	Ind./sample
1-100	Ind./sample
100-1000	Ind./sample
>1000	Ind./sample

N = number of individuals

	C-Power D5						
	subtidal				intertidal		
	1 (23,7m)	2 (20,1m)	3 (14,8m)	4 (5,2m)	low	high	remarks
PROTOCTISTA							
CILIOPHORA (Ciliata)							
Polyhymenophora							
Folliculinidae							epibiont on e.g. Pomatoceros tubes and Aequipecten opercularis
PLANTAE							
CHLOROPHYTA							
Ulvophyceae							
Ulva intestinalis or *U. Compressa*					A		
Blidingia minima (Nägeli ex Kützing) Kylin, 1947						X	
Ulothrix flacca (Dillwyn) Thuret in Le Jolis, 1863						A	fertile
RHODOPHYTA							
Bangiophyceae							
Bangia fuscopurpurea (Dillwyn) Lyngbye, 1819						A	fertile
ANIMALIA							
CNIDARIA							

Hydrozoa							
Leuckartiara octona (Fleming, 1823)							epibiont on Electra
Obelia longissima (Pallas, 1766)							
Anthozoa							
Sagartia troglodytes (Price in Johnston, 1847)							
ANNELIDA							
Polychaeta							
Gattyana cirrhosa (Pallas, 1766)							
Harmothoe impar (Johnston, 1839)							
Lanice conchilega (Pallas, 1766)							
Pomatoceros triqueter (Linneaus, 1758)							
Syllidae							
Myrianida (Autolytus) sp. (prolifera-edwardsi-brachycephalus complex*)*							stolonisation
MOLLUSCA							
Bivalvia							
Aequipecten opercularis (Linneaus, 1758)							juv (0,5 - 22 mm)
Heteranomia squamula (Linneaus, 1758)		1					
Mytilus edulis (Linneaus, 1758)		3					juv (2 - 8 mm)
Parvicardium spec.			1				juv (3 mm)
Spisula solida (Linneaus, 1758)		1					juv (11 mm)
Venerupis senegalensis (Gmelin, 1791)							juv (1- 6 mm)
Gastropoda							
Crepidula fornicata (Linneaus, 1758)	2	4	3				juv (2,5 - 17 mm)
Epitonium clathratulum (Kanmacher, 1798)							juv (0,5 - 2 mm)
Facelina bostoniensis (Couthouy, 1838)							
Nassarius incrassatus (Ström, 1768)			2				juv
Rissoidae							
Pusillina inconspicua (Alder, 1844)							
CRUSTACEA							
Cirripedia							

Elminius modestus Darwin, 1854							
Balanus crenatus Bruguiére, 1789			1				
Balanus perforatus Bruguiére, 1789					D		(1 - 15 mm)
Megabalanus coccopoma (Darwin, 1854)					1		juv (15 mm) more specimens seen
Amphipoda							
Amphilochus neapolitanus Della Valle, 1893							
Aora gracilis (Bate, 1857)							
Atylus swammerdami (Milne-Edwards, 1830)							
Corophium (Monocorophium) sextonae (Crawford, 1937)		1					
Iphimedia nexa Myers & McGrath, 1987	1						
Jassa herdmani (Walker, 1893)				D	D		
Jassa marmorata (Holmes, 1903)							
Phtisica marina Slabber, 1769							
Stenothoidae							
Stenothoe spec.							
Decapoda							
Hippolyte varians Leach, 1814		2	1				
Liocarcinus holsatus (Fabricius, 1775)							juv
Macropodia linaresi Forest & Zariquiey-Alvarez, 1964	2	3	1				
Necora puber (Linnaeus, 1767)							
Pagurus bernhardus (Linnaeus, 1758)							
Pilumnus hirtellus (Linnaeus, 1761)							
Pisidia longicornis (Linnaeus, 1767)							
Thoralus cranchii (Leach, 1817)	1		3				
Galathea intermedia Liljeborg, 1851	1						juv
Megalope larvae							
INSECTA							
Diptera							
Telmatogeton japonicus Tokunaga, 1933						D	
BRYOZOA							
Cyclostomatida							

Cheilostomatida							
Electra pilosa (Linnaeus, 1767)	D	D	D				
ECHINODERMATA							
Echinoidea							
Echinoida							
Psammechinus miliaris (Gmelin, 1778)							juv (0,5 - 2 mm)

Annex 2: Systematic species list soft substrate macrobenthos

Belwind

Phylum	Class	Order	Family	Species	Code
Annelida	Clitellata			*Oligochaeta sp.*	Oligspec
	Polychaeta	/	Orbiniidae	*Orbinia armandi*	Orbiarma
				Orbinia norvegica	Orbinorv
				Orbinia sertulata	Orbisert
		Capitellida	Capitellidae	*Capitellidae sp.*	Capispec
				Heteromastus filiformis	Hetefili
				Notomastus latericeus	Notolate
		Magelonida	Magelonidae	*Magelona equilamellae*	Mageequi
				Magelona johnstoni	Magejohn
				Magelona mirabilis	Magemira
		Opheliida	Opheliidae	*Euzonus flabelligerus*	Euzoflab
				Ophelia limacina	Ophelima
				Travisia forbesi	Travforb
		Oweniida	Oweniidae	*Owenia fusiformis*	Owenfusi
		Phyllodocida	Dorvilleidae	*Parougia eliasoni*	Paroelia
				Protodorvillea kefersteini	Protkefe
			Glyceridae	*Glycera alba*	Glycalba
				Glycera gigantea	Glycgiga
				Glycera lapidum	Glyclapi
			Goniadidae	*Glycinde nordmanni*	Glycnord
				Goniada maculata	Gonimacu
				Goniadella bobretzkii	Gonibobr
			Hesionidae	*Microphthalmus similis*	Micrsimi
			Lumbrineridae	*Lumbrineris latreilli*	Lumblatr
			Nephtyidae	*Nephtys caeca*	Nephcaec
				Nephtys cirrosa	Nephcirr
				Nephtys kersivalensis	Nephkers
				Nephtys longosetosa	Nephlong
			Nereididae	*Eunereis longissima*	Eunelong
			Pholoidae	*Pholoe minuta*	Pholminu
			Phyllodocidae	*Eteone longa*	Eteolong
				Eumida sanguinea	Eumisang
				Hesionura elongata	Hesielon
				Phyllodoce lineata	Phylline
				Phyllodoce maculata	Phylmacu
				Phyllodoce rosea	Phylrose
			Pisionidae	*Pisione remota*	Pisiremo
			Poecilochaetidae	*Poecilochaetus serpens*	Poecserp
			Polygordiidae	*Polygordius appendiculatus*	Polyappe
			Polynoidae	*Harmothoe fragilis*	Harmfrag
				Harmothoe nodosa	Harmnodo
				Harmothoe sp.	Harmspec
				Subadyte pellucida	Subapell

			Serpulidae	*Pomatoceros triqueter*	Pomatriq
			Syllidae	*Autolytus prolifer*	Autoprol
				Exogone hebes	Exoghebe
				Syllidae sp.	Syllspec
				Syllis gracilis	Syllgrac
		Spionida	Spionidae	*Aonides oxycephala*	Aonioxyc
				Aonides paucibranchiata	Aonipauc
Phylum	**Class**	**Order**	**Family**	**Species**	**Code**
				Malacoceros vulgaris	Malavulg
				Polydora sp.	Polyspec
				Scolelepis bonnieri	Scolbonn
				Scolelepis foliosa	Scolfoli
				Scolelepis squamata	Scolsqua
				Scoloplos armiger	Scolarmi
				Spio filicornis	Spiofili
				Spio goniocephala	Spiogoni
Annelida	Polychaeta	Spionida	Spionidae	*Spionida sp.*	Spiospec
				Spiophanes bombyx	Spiobomb
				Spiophanes kroyeri	Spiokroy
			Trochochaetidae	*Trochochaeta multisetosaa*	Trocmult
		Terebellida	Pectinaridae	*Pectinaria belgica*	Pectbelg
				Pectinaria koreni	Pectkore
				Pectinaria sp.	Pectspec
			Terebellidae	*Ampharetinae sp.*	Amphspec
				Eupolymnia nebulosa	Euponebu
				Hauchiella tribullata	Hauctrib
				Lanice conchilega	Laniconc
				Polycirrus medusa	Polymedu
				Terebellidae sp.	Terespec
				Thelepus cincinnatus	Thelcinc
Arthropoda -	Malacostraca	Amphipoda	Aoridae	*Lembos websteri*	Lembwebs
Crustacea			Atylidae	*Atylus falcatus*	Atylfalca
				Atylus swammerdami	Atylswam
				Atylus vedlomensis	Atylvedl
			Calliopiidae	*Calliopius laeviusculus*	Calllaev
			Corophiidae	*Corophium volutator*	Corovolu
			Eusiridae	*Apherusa jurinei*	Aphejuri
			Haustoriidae	*Haustorius arenarius*	Hausaren
			Ischyroceridae	*Jassa falcata*	Jassfalc
				Jassa marmorata	Jassmarm
			Leucothoidae	*Leucothoe incisa*	Leucinci
			Melitidae	*Melita dentata*	Melident
				Melita obtusata	Meliobtu
				Melita palmata	Melipalm
				Melitidae sp.	Melispec
			Melphidippidae	*Megaluropus agilis*	Megaagil
			Oedicerotidae	*Pontocrates altamarinus*	Pontalta
				Pontocrates arenarius	Pontaren
			Pariambidae	*Pariambus typicus*	Paritypi

			Pontoporeiidae	*Bathyporeia elegans*	Batheleg
				Bathyporeia gracilis	Bathgrac
				Bathyporeia guilliamsoniana	Bathguil
				Bathyporeia pelagica	Bathpela
				Bathyporeia pilosa	Bathpilo
				Bathyporeia sarsi	Bathsars
			Urothoidae	*Urothoe brevicornis*	Urotbrev
				Urothoe elegans	Uroteleg
				Urothoe poseidonis	Urotposei
				Urothoe pulchella	Urotpulc

Phylum	**Class**	**Order**	**Family**	**Species**	**Code**
Arthropoda -	Malacostraca	Callanoida	Temoridae	*Eurytemora velox*	Euryvelo
Crustacea		Cumacea	Bodotriidae	*Bodotria pulchella*	Bodopulc
				Bodotria scorpioides	Bodoscor
				Cumopsis goodsiri	Cumogood
				Diastylis laevis	Diaslaev
				Diastylis rathkei	Diasrath
				Diastylis rugosa	Diasrugo
			Pseudocumatidae	*Pseudocuma gilsoni*	Pseugils
				Pseudocuma longicornis	Pseulong
				Pseudocuma similis	Pseusimi
		Decapoda		*Decapoda juv.*	Decajuve
				Brachyura juv.	Bracjuve
				Brachyura sp.	Bracspec
			Callianassidae	*Callianassa tyrrhena*	Calltyrr
			Crangonidae	*Crangon crangon*	Crancran
			Paguridae	*Anapagurus hyndmanni*	Anaphynd
				Anapagurus laevis	Anaplaev
				Pagurus bernhardus	Pagubern
				Pagurus forbesii	Paguforb
				Pagurus pubescens	Pagupube
				Pagurus variabilis	Paguvari
			Portunidae	*Liocarcinus pusillus*	Liocpusi
				Liocarcinus sp.	Liocspec
			Processidae	*Processa edulis subsp. crassipes*	Procedul
				Processa modica	Procmodi
			Upogebiidae	*Upogebia deltaura*	Upogdelt
				Upogebia pusilla	Upogpusi
			Thiidae	*Thia scutellata*	Thiascut
		Isopoda	Cirolanidae	*Eurydice sp.*	Euryspec
		Mysida	Mysidae	*Gastrosaccus spinifer*	Gastspin
				Mesopodopsis slabberi	Mesoslab
				Neomysis integer	Neominte
Arthropoda	Insecta	Coleoptera	Caridae	*Caridae sp.*	Carispec
Bryozoa				*Bryozoa sp.*	Bryospec
Chordata				*Pisces sp.*	Piscspec

	Actinopterygii	Perciformes	Ammodytidae	*Ammodytes tobianus*	Ammotobi
			Callionymidae	*Callionymus lyra*	Calllyra
	Ascidiacea			*Ascidiacea sp.*	Ascispec
	Leptocardii		Branchiostomidae	*Branchiostoma lanceolatum*	Branlanc
Cnidaria	Anthozoa	Actinaria		*Actinaria sp.*	Actispec
				Anthozoa sp.	Anthspec
	Hydrozoa			*Hydrozoa sp.*	Hydrspec
		Hydroida	Hydractinidae	*Podocoryne borealis*	Podobore
		Leptothecatae	Campanulariidae	*Obelia bidentata*	Obelbide
Echino-	Echinoidea	Echinoida		*Echinoidea sp.*	Echisp.
dermata			Fibulariidae	*Echinocyamus pusillus*	Echipusi
			Spatangoidae	*Echinocardium cordatum*	Echicord
			Paechinidae	*Psammmechinus miliaris*	Psammili

Phylum	**Class**	**Order**	**Family**	**Species**	**Code**
Echino-	Ophiuroidea	Asteroidea	Asteriidae	*Asterias rubens*	Asterube
dermata		Ophiurida	Amphiuridae	*Amphipholis squamata*	Amphispec
			Ophiuridae	*Ophiura albida*	Ophialbi
				Ophiura ophiura	Ophiophi
				Ophiura robusta	Ophirobu
Echiura		Echiuroinea	Echiuridae	*Thalassema thalassemum*	Thalthal
Mollusca	Bivalvia	Arcoida	Arcidae	*Arca lactea*	Arcalact
				Arca tetragona	Arcatetr
		Ostreoida	Pectinidae	*Aequipecten opercularis*	Aequoper
		Veneroida	Mactridae	*Spisula elliptica*	Spiselli
				Spisula solida	Spissoli
				Spisula subtruncata	Spissubt
			Pharidae	*Phaxas pellucidus*	Phaxpell
			Semelidae	*Abra alba*	Abraalba
			Solenidae	*Ensis arcuatus*	Ensiarcu
			Tellinidae	*Angulus tenuis*	Angutenu
				Macoma baltica	Macobalt
				Tellina pygmaeus	Tellpygm
				Tellina tenuimana	Telltenu
				Tellina tenuis	Telltenui
	Gastropoda	Heterogastropoda	Epitoniidae	*Epitonium clathrus*	Epitclat
		Mesogastropoda	Naticidae	*Polinices montagui*	Polispec
Nematoda				*Nematode sp.*	Nemaspec
Nemertea				*Nemertea sp.*	Nemespec
	Anopla	Heteronemertea	Baseodiscidae	*Oxypolia beaumontiana*	Oxypbeau
			Lineidae	*Cerebratulus sp.*	Cerespec
		Palaeonemertea	Cephalothricidae	*Cephalothricidae sp.*	Cephspec
Porifera				*Porifera sp.*	Porispec
Sipuncula				*Sipuncula sp.*	Sipuspec

Rare species (all species occurring in less than 3 samples and with less than 2 individuals per sample) were not taken into account for the analyses.

C-Power

Phylum	**Class**	**Order**	**Family**	**Species**	**Code**
Annelida	Polychaeta	/	Orbiniidae	*Orbinia armandi*	Orbiarma
				Orbinia norvegica	Orbinorv
				Orbinia sertulata	Orbisert
				Orbinia sp.	Orbispec
		Capitellida	Capitellidae	*Capitellidae sp.*	Capispec
				Heteromastus filiformis	Hetefili
				Notomastus latericeus	Notolate
		Magelonida	Magelonidae	*Magelona equilamellae*	Mageequi
				Magelona johnstoni	Magejohn
				Magelona mirabilis	Magemira
		Opheliida	Opheliidae	*Ophelia limacina*	Ophelima
				Travisia forbesi	Travforb
		Oweniida	Oweniidae	*Owenia fusiformis*	Owenfusi
		Phyllodocida	Dorvilleidae	*Protodorvillea kefersteini*	Protkefe
			Glyceridae	*Glycera alba*	Glycalba
				Glycera lapidum	Glyclapi
				Glycera unicornis	Glycunic
			Goniadidae	*Glycinde nordmanni*	Glycnord
				Goniada maculata	Gonimacu
				Goniadella bobretzkii	Gonibobr
			Nephtyidae	*Nephtys caeca*	Nephcaec
				Nephtys cirrosa	Nephcirr
				Nephtys kersivalensis	Nephkers
				Nephtys longosetosa	Nephlong
			Nereididae	*Eunereis longissima*	Eunelong
			Phyllodocidae	*Eteone longa*	Eteolong
				Eumida sanguinea	Eumisang
				Phyllodoce lineata	Phylline
				Phyllodoce maculata	Phylmacu
				Phyllodoce rosea	Phylrose
			Poecilochaetidae	*Poecilochaetus serpens*	Poecserp
			Polygordiidae	*Polygordius appendiculatus*	Polyappe
			Polynoidae	*Harmothoe nodosa*	Harmnodo
				Harmothoe sp.	Harmsp.
			Serpulidae	*Pomatoceros triqueter*	Pomatriq
			Syllidae	*Autolytus prolifer*	Autoprol
				Syllis gracilis	Syllgrac
		Spionida	Spionidae	*Aonides oxycephala*	Aonioxyc
				Aonides paucibranchiata	Aonipauc
				Malacoceros vulgaris	Malavulg
				Polydora sp.	Polyspec
				Scolelepis bonnieri	Scolbonn
				Scolelepis foliosa	Scolfoli
				Scoloplos armiger	Scolarmi
Annelida	Polychaeta	Spionida	Spionidae	*Spio filicornis*	Spiofili

Phylum	Class	Order	Family	Species	Code
				Spio goniocephala	Spiogoni
				Spiophanes bombyx	Spiobomb
Phylum	**Class**	**Order**	**Family**	**Species**	**Code**
Annelida	Polychaeta	Terebellida	Pectinaridae	*Pectinaria belgica*	Pectbelg
				Pectinaria koreni	Pectkore
				Pectinaria sp.	Pectspec
			Terebellidae	*Ampharetinae sp.*	Amphspec
				Eupolymnia nebulosa	Euponebu
				Lanice conchilega	Laniconc
				Terebellidae sp.	Terespec
				Thelepus cincinnatus	Thelcinc
Arthropoda -	Malacostraca	Amphipoda	Atylidae	*Atylus falcatus*	Atylfalca
Crustacea				*Atylus swammerdami*	Atylswam
			Corophiidae	*Corophium volutator*	Corovolu
			Haustoriidae	*Haustorius arenarius*	Hausaren
			Ischyroceridae	*Jassa falcata*	Jassfalc
			Leucothoidae	*Leucothoe incisa*	Leucinci
			Lysianassoidae	*Nannonyx spinimanus*	Nannspin
			Melitidae	*Melita dentata*	Melident
				Melita obtusata	Meliobtu
				Melitidae sp.	Melispec
			Melphidippidae	*Megaluropus agilis*	Megaagil
			Oedicerotidae	*Perioculodes longimanus*	Perilong
				Pontocrates altamarinus	Pontalta
				Pontocrates arenarius	Pontaren
				Synchelidium maculatum	Syncmacu
			Pariambidae	*Pariambus typicus*	Paritypi
			Pontoporeiidae	*Bathyporeia elegans*	Batheleg
				Bathyporeia gracilis	Bathgrac
				Bathyporeia guilliamsoniana	Bathguil
				Bathyporeia pelagica	Bathpela
				Bathyporeia pilosa	Bathpilo
				Bathyporeia sarsi	Bathsars
			Urothoidae	*Urothoe brevicornis*	Urotbrev
				Urothoe elegans	Uroteleg
				Urothoe poseidonis	Urotposei
				Urothoe pulchella	Urotpulc
		Callanoida	Temoridae	*Eurytemora velox*	Euryvelo
		Cumacea	Bodotriidae	*Bodotria arenosa*	Bodoaren
				Bodotria pulchella	Bodopulc
				Bodotria scorpioides	Bodoscor
				Diastylis laevis	Diaslaev
				Diastylis rathkei	Diasrath
				Diastylis rugosa	Diasrugo
			Pseudocumatidae	*Pseudocuma gilsoni*	Pseugils
				Pseudocuma longicornis	Pseulong

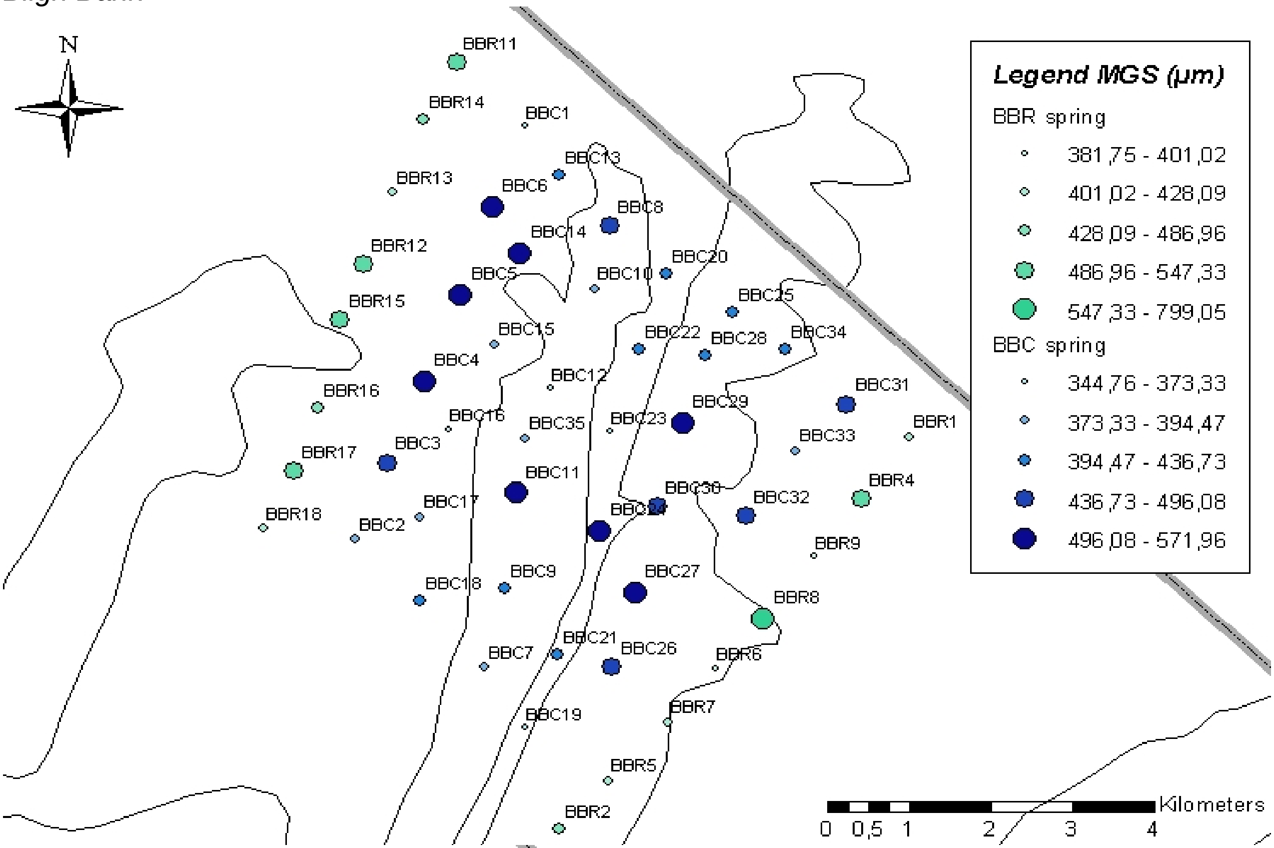
			Vaunthompsoniinae	*Vaunthompsonia cristata*	Vauncris

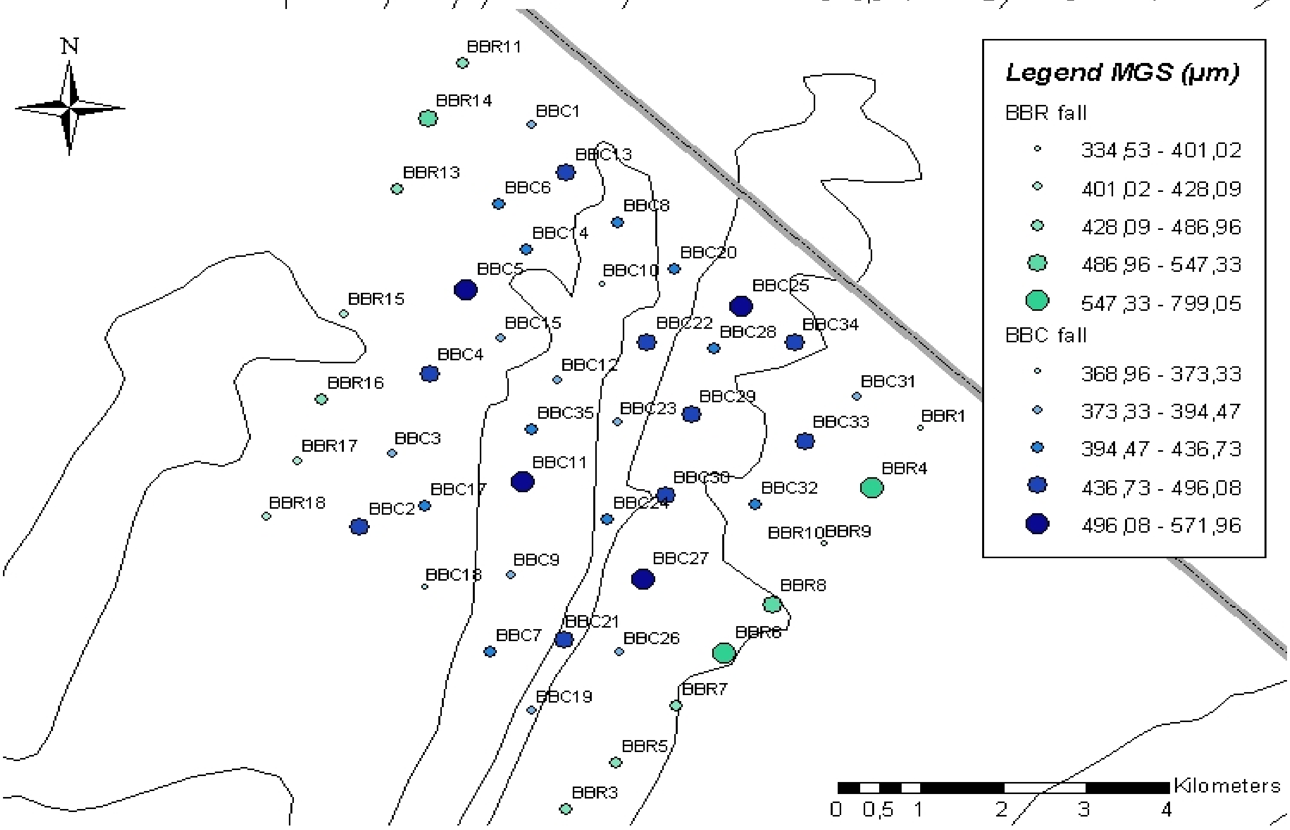
Phylum	**Class**	**Order**	**Family**	**Species**	**Code**
Arthropoda -	Malacostraca	Decapoda		*Decapoda juv.*	Decajuve
Crustacea				*Brachyura juv.*	Bracjuve
				Brachyura sp.	Bracspec
			Callianassidae	*Callianassa tyrrhena*	Calltyrr
			Crangonidae	*Crangon crangon*	Crancran
			Paguridae	*Anapagurus hyndmanni*	Anaphynd
				Anapagurus laevis	Anaplaev
				Pagurus bernhardus	Pagubern
			Portunidae	*Liocarcinus pusillus*	Liocpusi
			Processidae	*Processa edulis subsp. crassipes*	Procedul
				Processa modica	Procmodi
			Upogebiidae	*Upogebia deltaura*	Upogdelt
				Upogebia pusilla	Upogpusi
			Thiidae	*Thia scutellata*	Thiascut
				Thia scutellata larve	Thiascutlarv
		Isopoda	Cirolanidae	*Eurydice spinigera*	Euryspin
		Mysida	Mysidae	*Gastrosaccus spinifer*	Gastspin
Arthropoda	Insecta	Coleoptera	Caridae	*Caridae sp.*	Carispec
Bryozoa				*Bryozoa sp.*	Bryospec
Chordata	Actinopterygii	Perciformes	Ammodytidae	*Ammodytes tobianus*	Ammotobi
			Callionymidae	*Callionymus lyra*	Calllyra
		Pleuronectiformes	Bothidae	*Arnoglossus laterna*	Amoglate
	Leptocardii		Branchiostomidae	*Branchiostoma lanceolatum*	Branlanc
Cnidaria	Anthozoa	Actinaria		*Actinaria sp.*	Actispec
				Anthozoa sp.	Anthspec
			Edwardsiidae	*Edwardsiella sp.*	Edwaspec
	Hydrozoa			*Hydrozoa sp.*	Hydrspec
		Hydroida	Sertulariidae	*Abietinaria abietine*	Abieabie
		Leptothecatae	Phialellidae	*Phialella quadrata*	Phiaquad
Echino-	Echinoidea	Echinoida		*Echinoidea sp.*	Echispec
dermata			Fibulariidae	*Echinocyamus pusillus*	Echipusi
			Spatangoidae	*Echinocardium cordatum*	Echicord
			Paechinidae	*Psammmechinus miliaris*	Psammili
	Ophiuroidea	Asteroidea	Asteriidae	*Asterias rubens*	Asterube
		Ophiurida	Amphiuridae	*Amphipholis squamata*	Amphispec
			Ophiuridae	*Ophiura albida*	Ophialbi
				Ophiura ophiura	Ophiophi
Echiura		Echiuroinea	Echiuridae	*Thalassema thalassemum*	Thalthal

Phylum	Class	Order	Family	Species	Code
Mollusca	Bivalvia	Arcoida	Arcidae	*Arca tetragona*	Arcatetr
		Veneroida	Donacidae	*Donax vittatus*	Donavitt
			Lasaeidae	*Mysella bidentata*	Mysebide
			Mactridae	*Spisula elliptica*	Spiselli
				Spisula subtruncata	Spissubt
			Petricolidae	*Petricola pholadiformis*	Petrphol
			Pharidae	*Phaxas pellucidus*	Phaxpell
			Semelidae	*Abra alba*	Abraalba
			Solenidae	*Ensis arcuatus*	Ensiarcu
				Ensis ensis	Ensiensi
			Tellinidae	*Angulus tenuis*	Angutenu
				Tellina pygmaeus	Tellpygm
				Tellina tenuimana	Telltenu
				Tellina tenuis	Telltenui
	Gastropoda	Heterogastropoda	Epitoniidae	*Epitonium clathrus*	Epitclat
		Mesogastropoda	Naticidae	*Polinices montagui*	Polispec
		Neogastropoda	Nassariidae	*Hinia reticulata*	Hinireti
Nematoda				*Nematode sp.*	Nemaspec
Nemertea				*Nemertea sp.*	Nemespec
		Palaeonemertea	Cephalothricidae	*Cephalothricidae sp.*	Cephspec
Sipuncula				*Sipuncula sp.*	Sipuspec

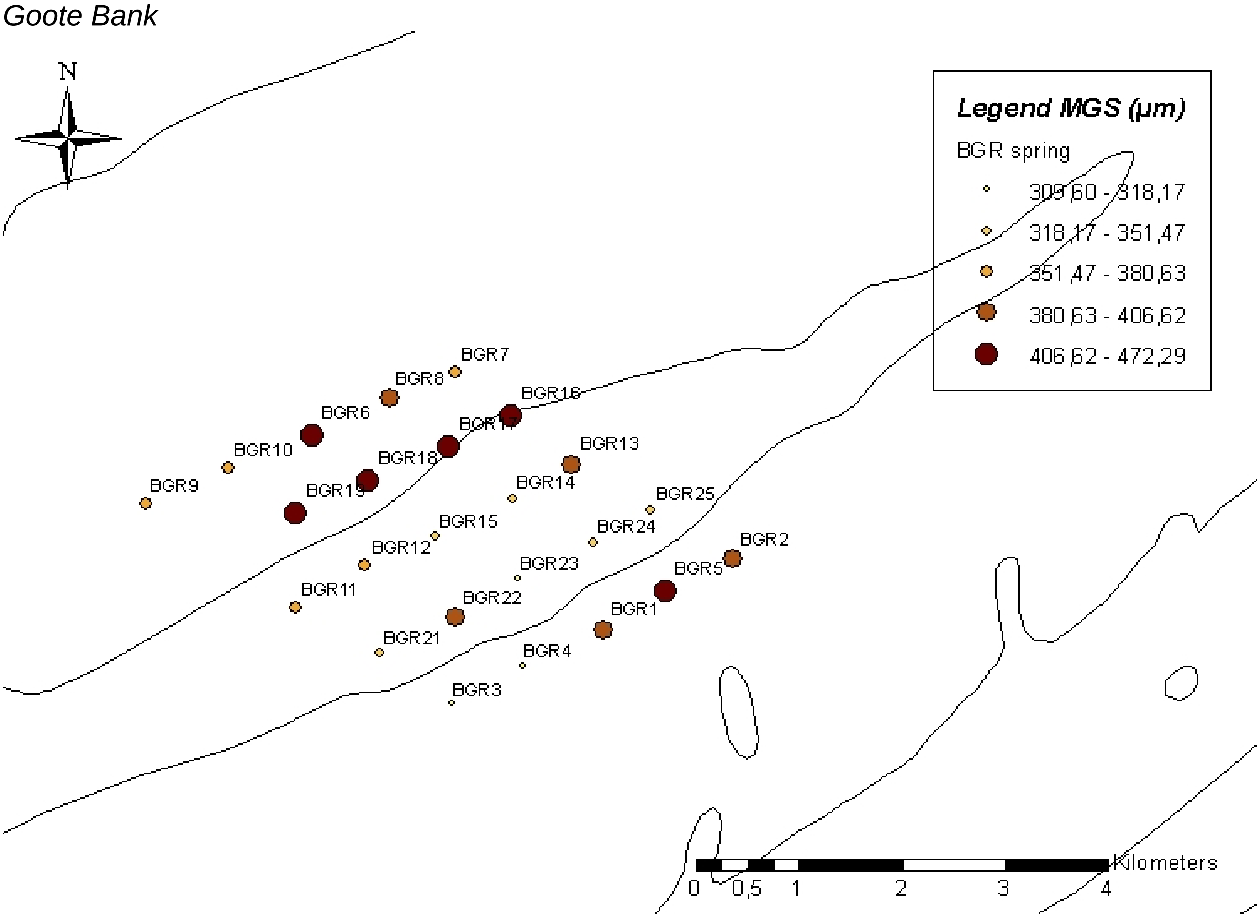
Annex 3: Bubble plots median grain size (µm) 2008

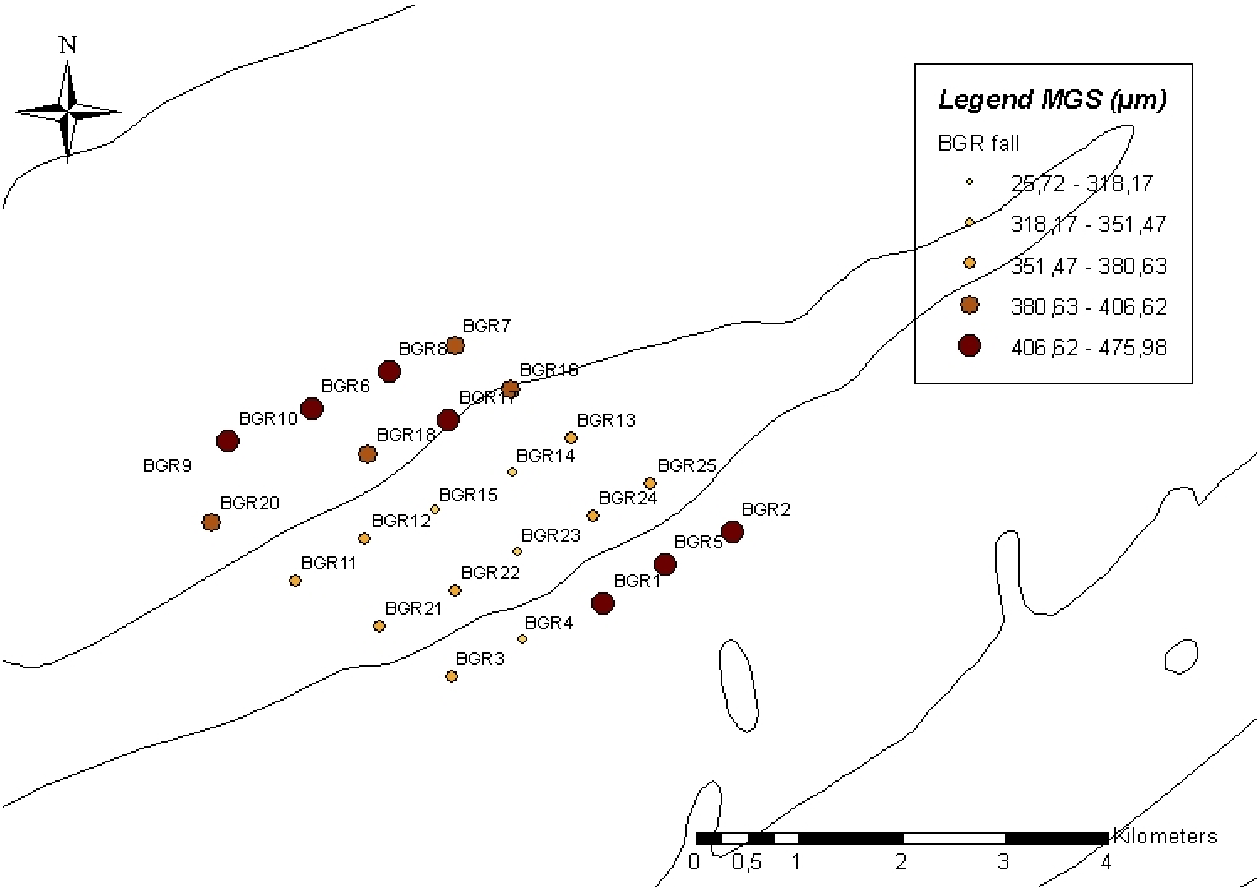
Bligh Bank



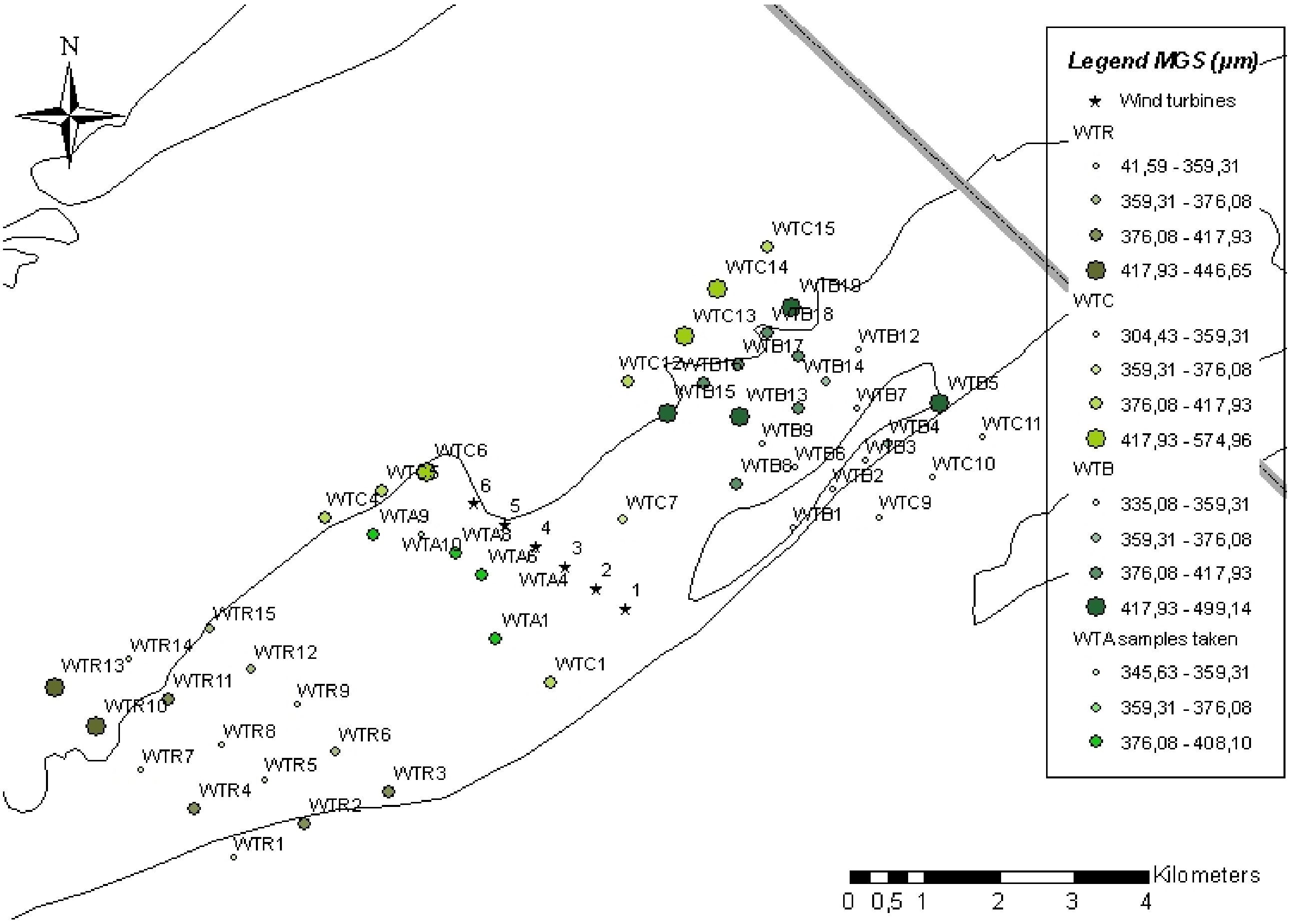


Goote Bank


N
Legend MGS (µm)
BGR spring
309,60 - 318,17
318,17 - 351,47
351,47 - 380,63
380,63 - 406,62
406,62 - 472,29
BGR7
BGR8
BGR6
BGR16
BGR17
BGR10
BGR18
BGR13
BGR9
BGR19
BGR14
BGR25
BGR15
BGR24
BGR2
BGR12
BGR23
BGR5
BGR11
BGR22
BGR1
BGR21
BGR4
BGR3
0 0,5 1 2 3 4 Kilometers


N
Legend MGS (µm)
BGR fall
25,72 - 318,17
318,17 - 351,47
351,47 - 380,63
380,63 - 406,62
406,62 - 475,98
BGR7
BGR8
BGR16
BGR6
BGR17
BGR10
BGR18
BGR13
BGR9
BGR14
BGR25
BGR15
BGR20
BGR24
BGR12
BGR2
BGR23
BGR5
BGR11
BGR22
BGR1
BGR21
BGR4
BGR3
0
0,5
1
2
3
4
Kilometers

Thorntonbank



Annex 4: Simper analyses

SIMPER dissimilarities between clusters at the Bligh Bank and Goote Bank calculated for the grain size partitioning (abiotic) and community analysis based on densities (biotic)

Cluster	Abiotic Dissimilarity %	Biotic Dissimilarity %
BBC spring - BBR spring	2.97	70.26
BBC spring - BGR spring	3.00	73.14
BBR spring - BGR spring	3.88	73.71
BBC autumn - BBR autumn	2.53	70.35
BBC autumn - BGR autumn	2.65	74.43
BBR autumn - BGR autumn	3.39	74.93

SIMPER similarities between clusters at the Bligh Bank and Goote Bank calculated for the grain size partitioning (abiotic) and community analysis based on densities (biotic)

Cluster	**Abiotic Similarity %**	**Biotic Similarity %**
BBC spring	97.35	30.94
BBR spring	96.83	29.23
BGR spring	98.10	25.30
BBC autumn	97.83	32.77
BBR autumn	97.26	25.63
BGR autumn	97.88	34.34

SIMPER similarities between clusters at the Thorntonbank and Goote Bank calculated for the grain size partitioning (abiotic) and community analysis based on densities (biotic)

Cluster	**Abiotic Similarity %**	**Biotic Similarity %**
WTA	98.69	27.46
WTB	98.17	39.31
WTC	96.84	29.12
WTR	98.22	33.80
BGR	97.88	31.98

SIMPER dissimilarities between clusters at the Thorntonbank and Goote Bank calculated for the grain size partitioning (abiotic) and community analysis based on densities (biotic)

Cluster	**Abiotic Dissimilarity %**	**Biotic Dissimilarity %**
WTA-WTB	1.53	66.88
WTA-WTC	2.27	74.50
WTA-WTR	1.49	71.75
WTA-BGR	1.78	74.82
WTB-WTC	2.45	68.03
WTB-WTR	1.73	64.20
WTB-BGR	1.99	70.03
WTC-WTR	2.44	69.77
WTC-BGR	2.58	72.17
WTR-BGR	2.00	69.96

SIMPER similarities between clusters at the Thorntonbank and Goote Bank in 2005 and 2008 calculated for the community analysis based on densities (biotic)

Cluster	Biotic Similarity %
WTA	24.14
WTB	44.66
WTC	38.16
WTR	43.04
BGR	34.78
WTA05	46.61
WTB05	38.37
WTC05	28.84
WTR05	43.23
BGR05	34.89

SIMPER dissimilarities between clusters at the Thorntonbank and Goote Bank in 2005 and 2008 calculated for the community analysis based on densities (biotic)

Cluster	Biotic Dissimilarity %
WTA-WTB	63.91
WTA-WTC	67.19
WTA-WTR	66.21
WTA-BGR	70.54
WTB-WTC	57.72
WTB-WTR	56.30
WTB-BGR	64.49
WTC-WTR	58.25
WTC-BGR	64.99
WTR-BGR	64.11
WTA05-WTB05	60.44
WTA05-WTC05	64.01
WTA05-WTR05	54.57
WTA05-BGR05	58.73
WTB05-WTC05	66.24
WTB05-WTR05	63.20
WTB05-BGR05	65.41
WTC05-WTR05	64.45
WTC05-BGR05	68.20
WTR05-BGR05	61.05
WTA-WTA05	69.64
WTB-WTB05	69.80
WTC-WTC05	73.13
WTR-WTR05	64.73
BGR-BGR05	74.98

Annex 5: photographs of beam trawl catches

campaign 08-05 & 08-07 (spring 2008): Thorntonbank and Goote Bank

WT01

WT02

WT03

WT04

WT05

WT06

WT07

WT08

WT09

WG2

campaign 08-05 & 08-07 (spring 2008): Bligh Bank and Oosthinder

WBB01

WBB02

WBB03


WBB05

WBB06

WBB07

WBB04


WBB08

WOH01

WOH02


WOH03

campaign 08-22b & c (autumn 2008): Thorntonbank & Goote Bank


WT1


WT2


WT3


WT4bis


WT5


WT6


WT7


WT8


WT9


WG2

Campaign 08-22 b & c (autumn 2008): Bligh Bank and Oosthinder

WBB01

WBB02

WBB03

WBB05

WBB06

WBB07

WBB04

WBB08

WOH01

WOH02

WOH03

Annex 6: Systematic species list of the demersal fish fauna

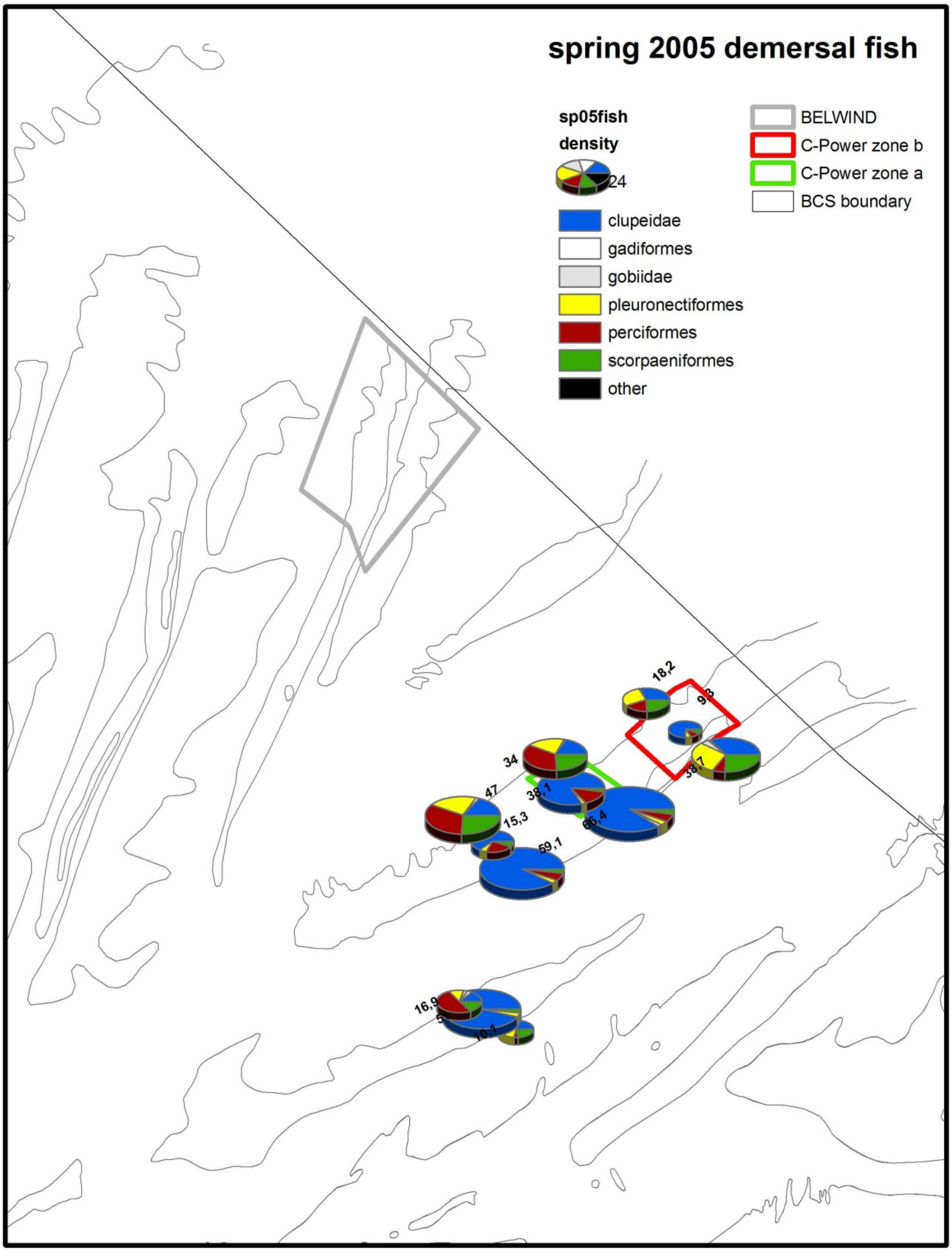
Order	Family	Species	English Name	Dutch Name
Clupeiformes	Clupeidae	*Alosa fallax*	twaite shad	fint
		Clupea harengus	herring	haring
		Sprattus sprattus	sprat	sprot
	Engraulidae	*Engraulis encrasicolus*	anchovy	ansjovis
Gadiformes	Gadidae	*Merlangius merlangus*	whiting	wijting
		Trisopterus luscus	bib / pouting	steenbolk
		Trisopterus minutus	poor cod	dwergbolk
		Gadus morhua	cod	kabeljauw
	Lotidae	*Ciliata mustela*	5 bearded rockling	5-dradige meun
Perciformes	Gobiidae	*Pomatoschistus lozanoi*	Lozano's goby	Lozano's grondel
		Pomatoschistus minutus	sand goby	dikkopje
		Pomatoschistus pictus	painted goby	kleurige grondel
		Gobius niger	black goby	zwarte grondel
	Trachinidae	*Trachinus draco*	greater weever	grote pieterman
		Echiichthys vipera	lesser weever	kleine pieterman
	Ammodytidae	*Hyperoplus lanceolatus*	great sandeel	zandspiering
		Ammodytes tobianus	zandspiering	sandeel
		Gymammodytes semisquamatus	smooth sandeel	/
	Labridae	*Labrus bergylta*	ballan wrasse	gevlekte lipvis
	Carangidae	*Trachurus trachurus*	horse mackerel	horsmakreel
	Callionymidae	*Callionymus lyra*	dragonet	pitvis
		Callionymus reticulatus	reticulated dragonet	rasterpitvis
	Mulidae	*Mullus surmuletus*	mullet	mul
	Scombridae	*Scomber scombrus*	mackerel	makreel
	Moronidae	*Dicentrarchus labrax*	sea bass	zeebaars
	Mugilidae	*Chelon labrosus*	mullet	diklipharder
Pleuronectiformes	Pleuronectidae	*Limanda limanda*	dab	schar
		Platichthys flesus	flounder	bot
		Pleuronectes platessa	plaice	pladijs
		Microstomus kitt	lemon sole	tongschar
	Soleidae	*Buglossidium luteum*	solenette	dwergtong
		Pegusa lascaris	Dover sole	Franse tong
		Solea solea	sole	tong
	Bothidae	*Arnoglossus laterna*	scaldfish	schurftvis
	Scopthalmidae	*Psetta maxima*	turbot	tarbot
		Scophthalmus rhombus	brill	griet
Scorpaeniformes	Cyclopteridae	*Liparis liparis*	striped sea-snail	slakdolf
		Cyclopterus lumpus	lumpfish	snotolf
	Triglidae	*Trigla lucerna*	tub gurnard	rode poon
		Eutrigla gurnardus	grey gurnard	grauwe poon
		Aspitrigla cuculus	red gurnard	Engelse poon
	Cottidae	*Myoxocephalus scorpius*	scorthorn sculpin	zeedonderpad
	Agonidae	*Agonus cataphractus*	hooknose	harnasmannetje
Syngnathiformes	Syngnathidae	*Syngnathus rostellatus*	Nilsson's pipefish	kleine zeenaald
		Hippocampus hippocampus	short-snouted seahorse	kortsnuitzeepaardje
		Entelurus aequoreus	snake pipefish	adderzeenaald
		Syngnathus acus	greater pipefish	grote zeenaald
Carcharhiniformes	Scyliorhinidae	*Scyliorhinus canicula*	dogfish	hondshaai

Annex 7: Systematic species list soft substrate epibenthos

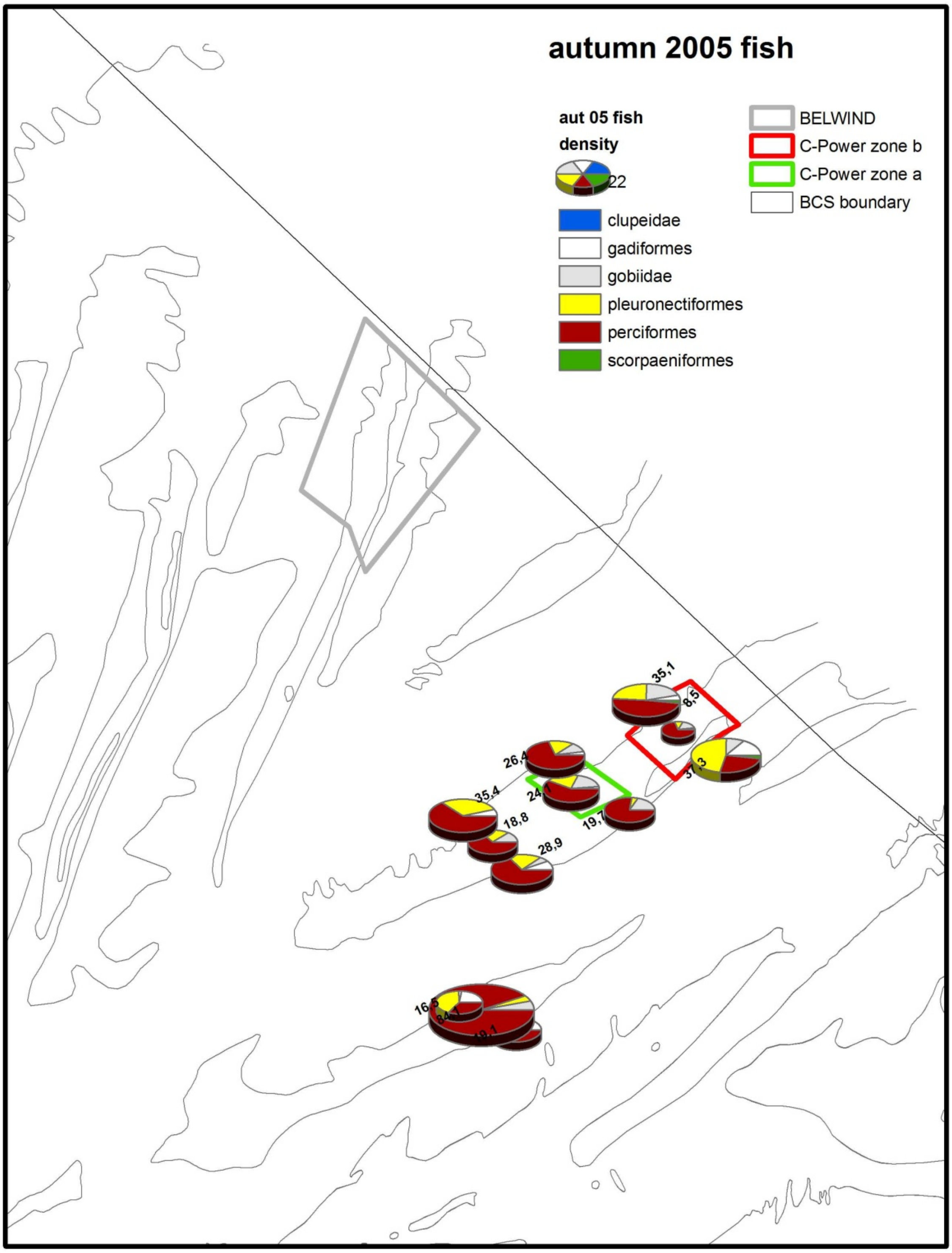
(Sub)phylum	Class/Order/ Infra order	Species	English Name	Dutch Name
Crustacea	Anomura	*Callianassa tyrrhena*	mud shrimp	graafgarnaal
		Diogenes pugilator	south claw hermit crab	kleine heremietkreeft
		Pagurus bernhardus	hermit crab	heremietkreeft
	Bivalvia	*Aequipecten opercularis*	queen scallop	wijde mantel
		Diplodonta rotundata	round double-tooth	ronde komschelp
		Donax vittatus	banded wedge-shell	zaagje
		Dosinia exoleta	rayed Artemis shell	Artemisschelp
		Ensis arcuatus	sword rasor	grote zwaardschede
		Ensis directus	Atlantic jacknife clam	Amerikaanse zwaardschede
		Glycymeris glycymeris	dog cockle	marmerschelp
		Lutraria lutraria	common otter shell	otterschelp
		Mytilus edulis	mussel	mossel
		Spisula elliptica	elliptic trough shell	elliptische strandschelp
		Spisula solida	thick trough shell	stevige strandschelp
		Spisula subtruncata	cut trough shell	halfgeknotte strandschelp
	Brachyura	*Cancer pagurus*	North sea crab	Noordzeekrab
		Corystes cassivelaunus	masked crab	helmkrab
		Liocarcinus depurator	harbour crab	blauwpootzwemkrab
		Liocarcinus holsatus	flying crab	gewone zwemkrab
		Liocarcinus marmoreus	marbled swimming crab	gemarmerde zwemkrab
		Liocarcinus navigator	arch-fronted swimming crab	gewimperde zwemkrab
		Liocarcinus vernalis	vernal crab	grijze zwemkrab
		Macropodia rostrata	long legged spider crab	gewone hooiwagenkrab
		Necora puber	velvet swimming crab	fluwelen zwemkrab
		Pinnotheres pisum	pea crab	erwtenkrabbetje
		Thia scutellata	thumbnail crab	nagelkrab
	Caridea	*Crangon allmanni*	Almann shrimp	groefstaartgarnaal
		Crangon crangon	brown shrimp	grijze garnaal
		Palaemon serratus	common prawn	steurgarnaal
		Pandalus montagui	Aesop shrimp	ringsprietgarnaal
		Philocheras trispinosus	/	driepuntsgarnaaltje
Mollusca	Cephalopoda	*Alloteuthis subulata*	/	dwergpijlinktvis
		Loligo vulgaris	common squid	gewone pijlinktvis
		Sepia officinalis	common cuttlefish	zeekat
		Sepiola atlantica	atlantic bobtail	dwerginktvis
	Gastropoda	*Buccinum undatum*	common whelk	wulk
		Crepidula fornicata	common slipper limpet	muiltje
		Nassarius reticulatus	netted dogwhelk	fuikhoorn
Echinodermata	Asteroidea	*Asterias rubens*	common sea star	gewone zeester
	Echinoidea	*Echinocardium cordatum*	common heart urchin	zeeklit
		Psammechinus miliaris	green sea urchin	gewone zeeëgel
	Ophiuroidea	*Ophiothrix fragilis*	brittle star	brokkelster
		Ophiura albida	lesser brittle star	kleine slangster
		Ophiura ophiura	common brittle star	gewone slangster
Cnidaria	Anthozoa	*Anthozoa* sp.	anemone	anemoon
Chordata	Ascidiacea	*Ascidiacea* sp.	sea squirt	zakpijp
Annelida	Polychaeta	*Lanice conchilega*	sand mason	schelpkokerworm
		Nephtys sp.	catworm	zandzager
		Nereis sp.	sand worm	zeeduizendpoot
		Ophelia limacina	/	/
		Pectinaria koreni	trumpet worm	goudkammetje
Porifera		*Porifera* sp.	sponge	spons

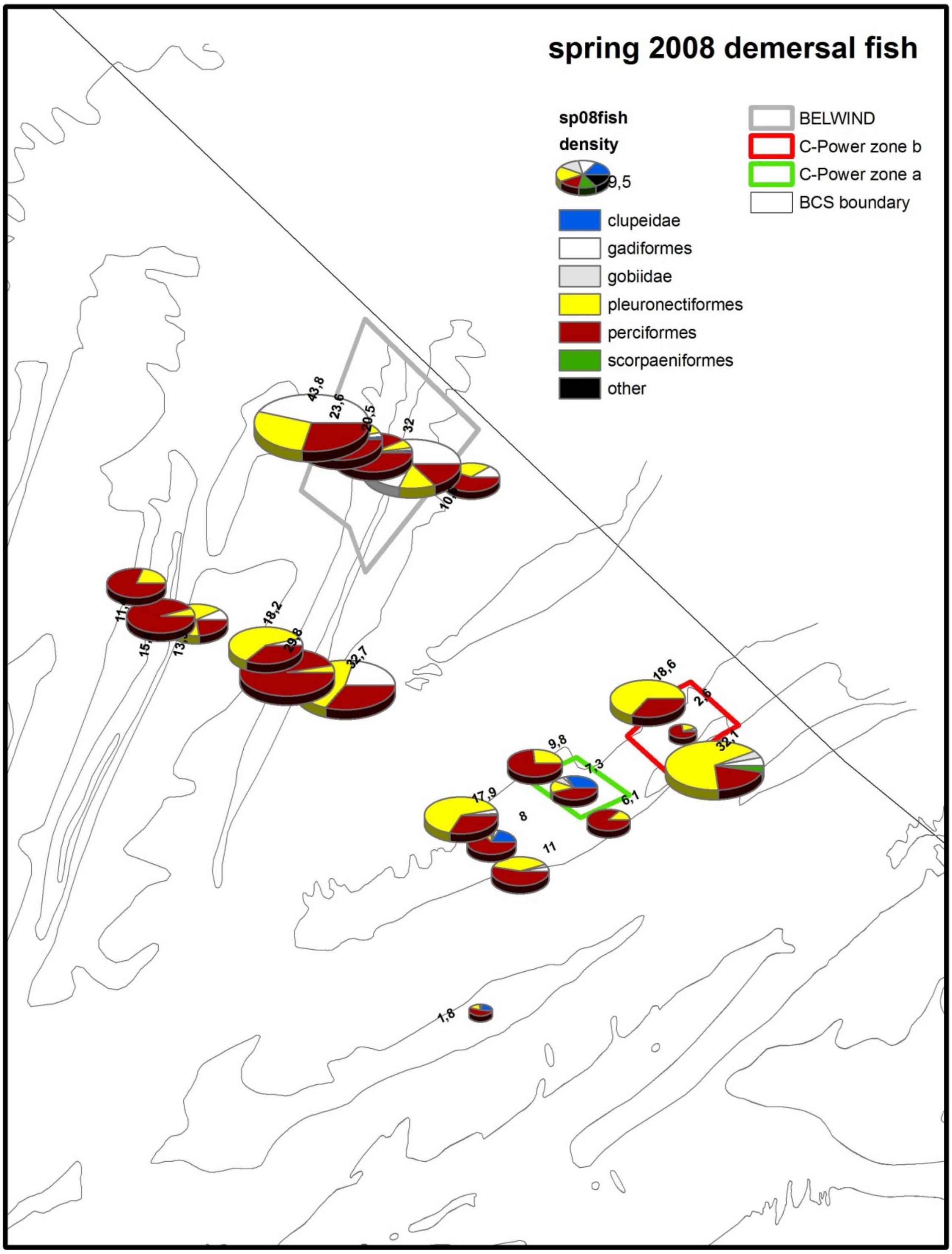
Annex 8: summarizing maps – densities of demersal fish and epibenthos per fish track

The GIS maps present pie charts of taxonomic composition that vary in size with total density. The sizes of the pie charts are relative per map and are not intercomparable between maps. The labels accompanying the pie charts represent the absolute values of total density, expressed as number of individuals per $1000m^2$.

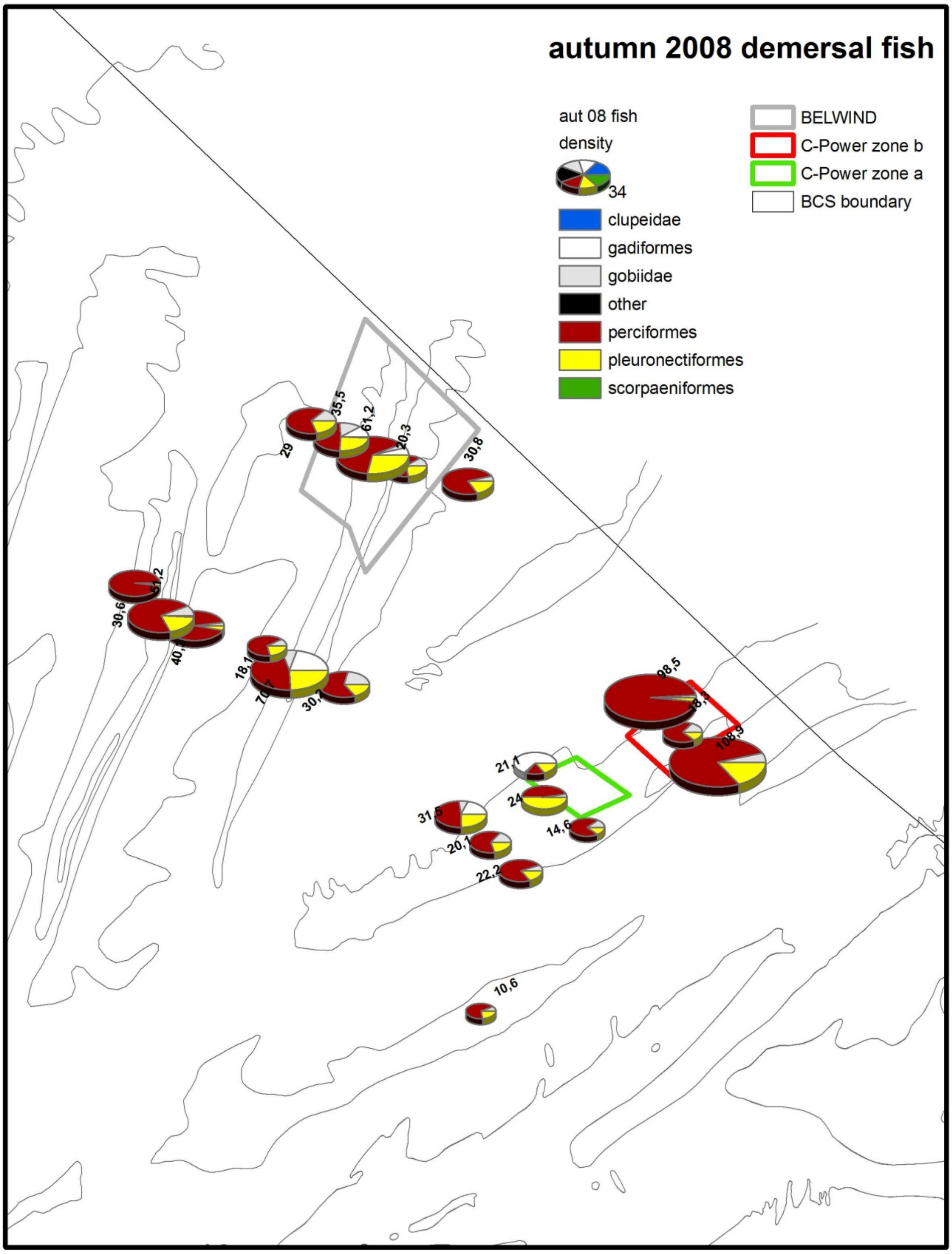


spring 2005 demersal fish
sp05fish
density
24
clupeidae
gadiformes
gobiidae
pleuronectiformes
perciformes
scorpaeniformes
other
BELWIND
C-Power zone b
C-Power zone a
BCS boundary
18,2
34
47
38,1
15,3
59,1
38,7
16,9
10,1

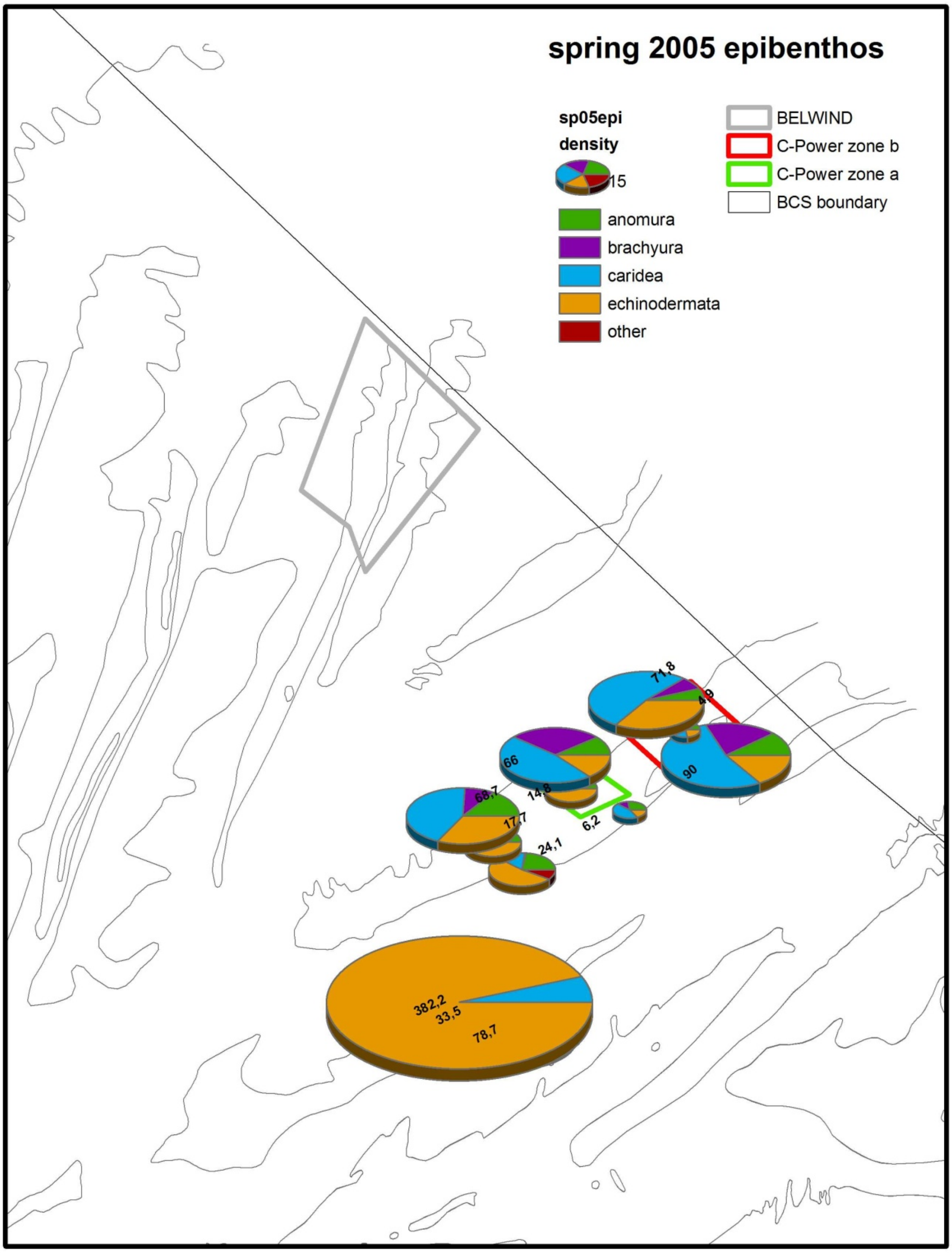

autumn 2005 fish
aut 05 fish
density
22
clupeidae
gadiformes
gobiidae
pleuronectiformes
perciformes
scorpaeniformes
BELWIND
C-Power zone b
C-Power zone a
BCS boundary
35,1
8,5
26,4
24,1
35,4
18,8
19,7
28,9

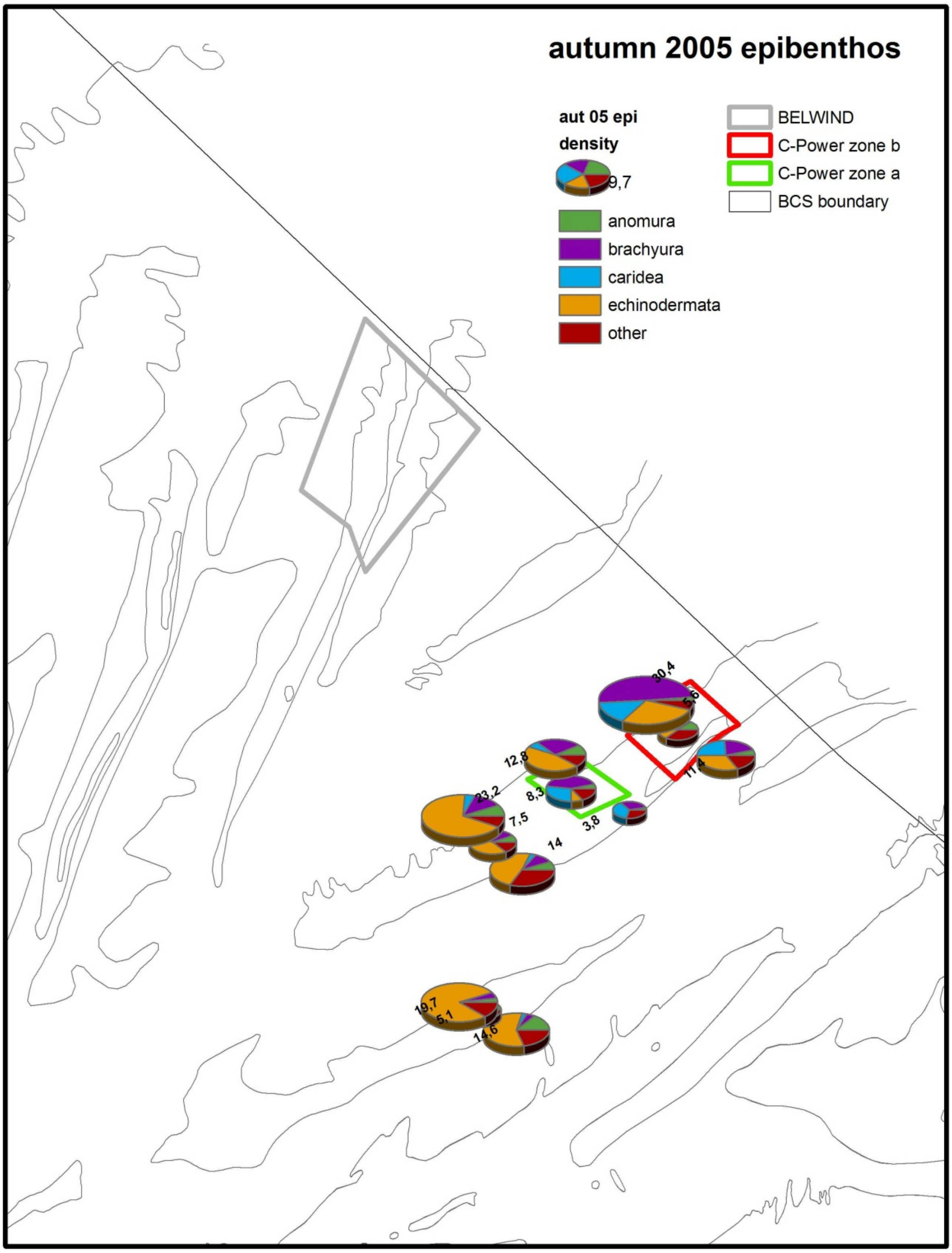


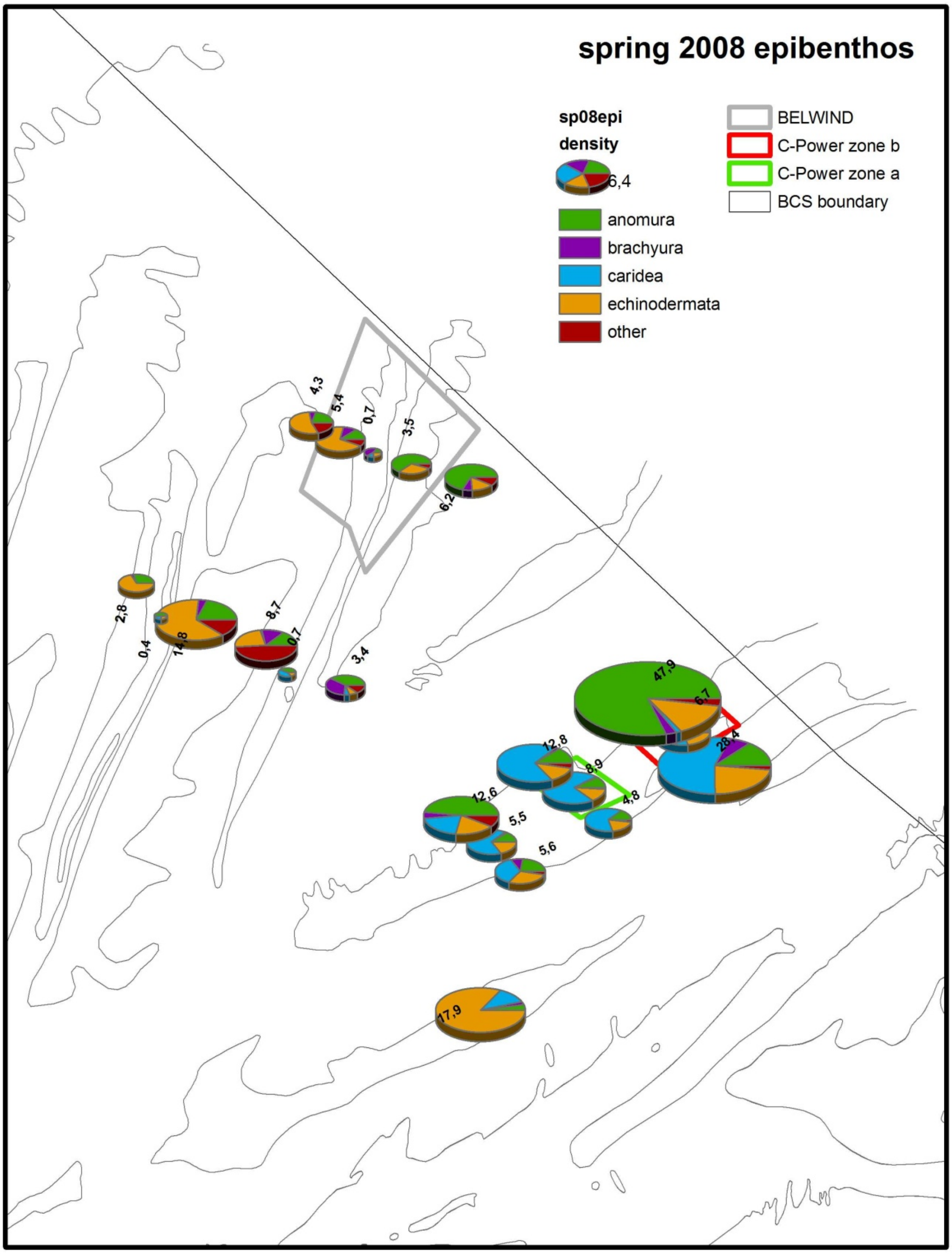
spring 2008 demersal fish
sp08fish
density
9,5
clupeidae
gadiformes
gobiidae
pleuronectiformes
perciformes
scorpaeniformes
other
BELWIND
C-Power zone b
C-Power zone a
BCS boundary
43,8
23,6
20,5
32
18,2
29,8
32,7
18,6
2,6
32,1
9,8
7,3
6,1
17,9
8
11
1,8

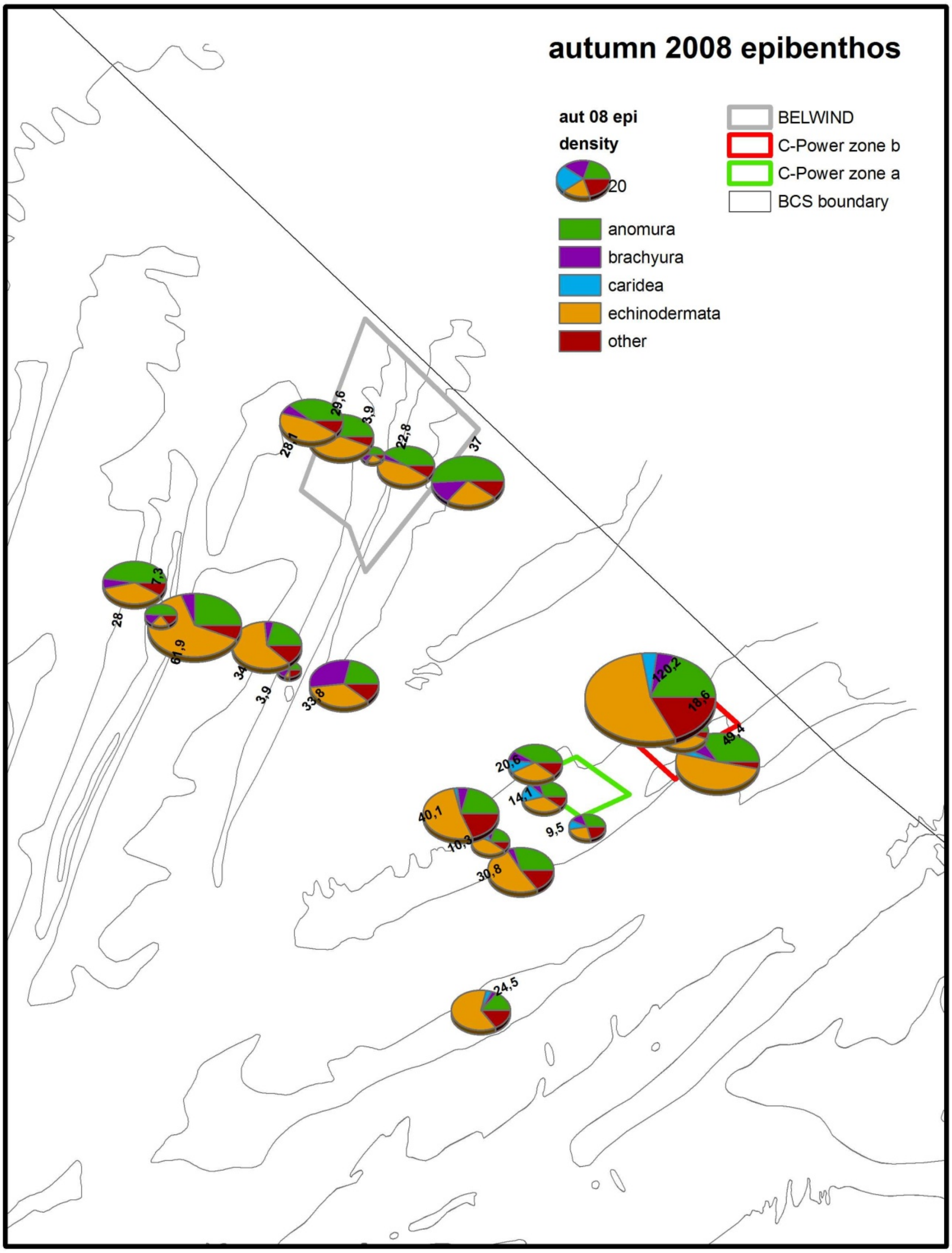


autumn 2008 demersal fish
aut 08 fish
density
34
clupeidae
gadiformes
gobiidae
other
perciformes
pleuronectiformes
scorpaeniformes
BELWIND
C-Power zone b
C-Power zone a
BCS boundary
29
35,5
61,2
20,3
30,8
30,6
40,1
18,1
70,7
98,5
108,9
21,1
24
31,5
14,6
20,1
22,2
10,6


spring 2005 epibenthos
sp05epi
density
15
anomura
brachyura
caridea
echinodermata
other
BELWIND
C-Power zone b
C-Power zone a
BCS boundary
71,8
4,9
66
90
68,7
14,8
6,2
17,7
24,1
382,2
33,5
78,7


autumn 2005 epibenthos
aut 05 epi
density
9,7
anomura
brachyura
caridea
echinodermata
other
BELWIND
C-Power zone b
C-Power zone a
BCS boundary
30,4
5,6
12,8
11,4
8,3
23,2
7,5
3,8
14
19,7
5,1
14,6


spring 2008 epibenthos
sp08epi
density
6,4
anomura
brachyura
caridea
echinodermata
other
BELWIND
C-Power zone b
C-Power zone a
BCS boundary
4,3
5,4
0,7
3,5
6,2
2,8
0,4
14,8
8,7
0,7
3,4
47,9
6,7
28,4
12,8
8,9
4,8
12,6
5,5
5,6
17,9



autumn 2008 epibenthos
aut 08 epi
density
20
anomura
brachyura
caridea
echinodermata
other
BELWIND
C-Power zone b
C-Power zone a
BCS boundary
29,6
3,9
28,1
22,8
37
7,3
28
61,9
34
3,9
33,8
120,2
18,6
49,4
20,6
14,1
9,5
40,1
10,3
30,8
24,5