CHAPTER 4

SEABIRDS AND OFFSHORE WIND FARMS – THE POTENTIAL VALUE OF SENSITIVITY MAPPING IN MARINE SPATIAL PLANNING

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Abstract

In this study we developed species distribution models, intended to feed into a sensitivity map regarding offshore wind farm development. We focused on four species known to be sensitive to wind farm disturbance, i.e., red-throated diver (*Gavia stellata*), northern gannet (*Morus bassanus*), common guillemot (*Uria aalge*) and razorbill (*Alca torda*), and proposed an integrated 'displacement sensitivity index' based on their cumulative distribution. Interestingly, the species distribution models allow to quantify the numbers of seabirds expected to be impacted by wind farm displacement and thus to flag potential conflicts with conservation objectives defined within the European Marine Strategy Framework and/or Birds Directive. Mapping our 'displacement sensitivity index' further highlighted one area as particularly sensitive to wind farm development, situated in front of the western part of the Belgian coast between 5 and 12 nautical miles offshore. While provisional, the results of this study are highly promising, distinguishing one compact area which is historically known as important seabird habitat. Also, it is located well outside all current and planned wind farms, giving the opportunity to avoid future developments there or otherwise to install compensating measures. To ultimately inform the marine spatial planning process, however, we advise finetuning the modelling process and taking in account additional seabird species and anthropogenic pressures.

1. Introduction

Current and planned wind farm developments will soon occupy about 15 % of the Belgian part of the North Sea (BPNS). Knowing that certain seabird species tend to avoid areas occupied by turbines raises concerns regarding the cumulative impact of such extensive developments on seabird population demographics. By informing the marine spatial planning process, well-founded sensitivity maps may serve as a tool to avoid or compensate offshore wind farm (OWF) impacts on seabirds. As such, this study is intended as a first step in outlining a suitable method to map seabird sensitivity related to OWFs across the BPNS.

2. Material and methods

2.1. Seabird monitoring: in the field

In this analysis we used the results of ship-based seabird counts collected across the BPNS in the period 2000-2018. Except for the zone further than 25 nautical miles from the coast there has been good coverage of the BPNS during this timeframe (see Figure 1). The frequency and geographical focus of the monitoring routes, however, strongly varied through time.

Ship-based seabird counts have always been conducted according to a standardised and internationally applied method, combining a 'transect count' for birds on the water and repeated 'snapshot counts' for flying birds (Tasker *et al.* 1984). We focus on a 300 m wide transect along one side of the ship's track, and while steaming at a speed of about 10 knots, all birds in touch with the water (swimming, pecking, diving) observed within this transect are counted ('transect count'). Importantly, the perpendicular distance of each observed bird (group) to the ship is estimated, allowing to correct for decreasing detectability with increasing distance afterwards (distance analysis, see §2.2). The transect is therefore divided in four distance categories (A = 0-50 m, B = 50-100 m, C = 100-200 m and D = 200-300 m). Counting all flying birds inside this transect, however, would cause an overestimation and would be a measure of bird flux rather than bird density. As such, the density of flying birds is assessed through one-minute interval counts of birds flying within a quadrant of 300 by 300 m inside the transect ('snapshot counts'). As the ship covers a distance of approximately 300 m per minute when sailing the prescribed speed of 10 knots, the full transect is covered by means of these subsequent 'snapshots'.

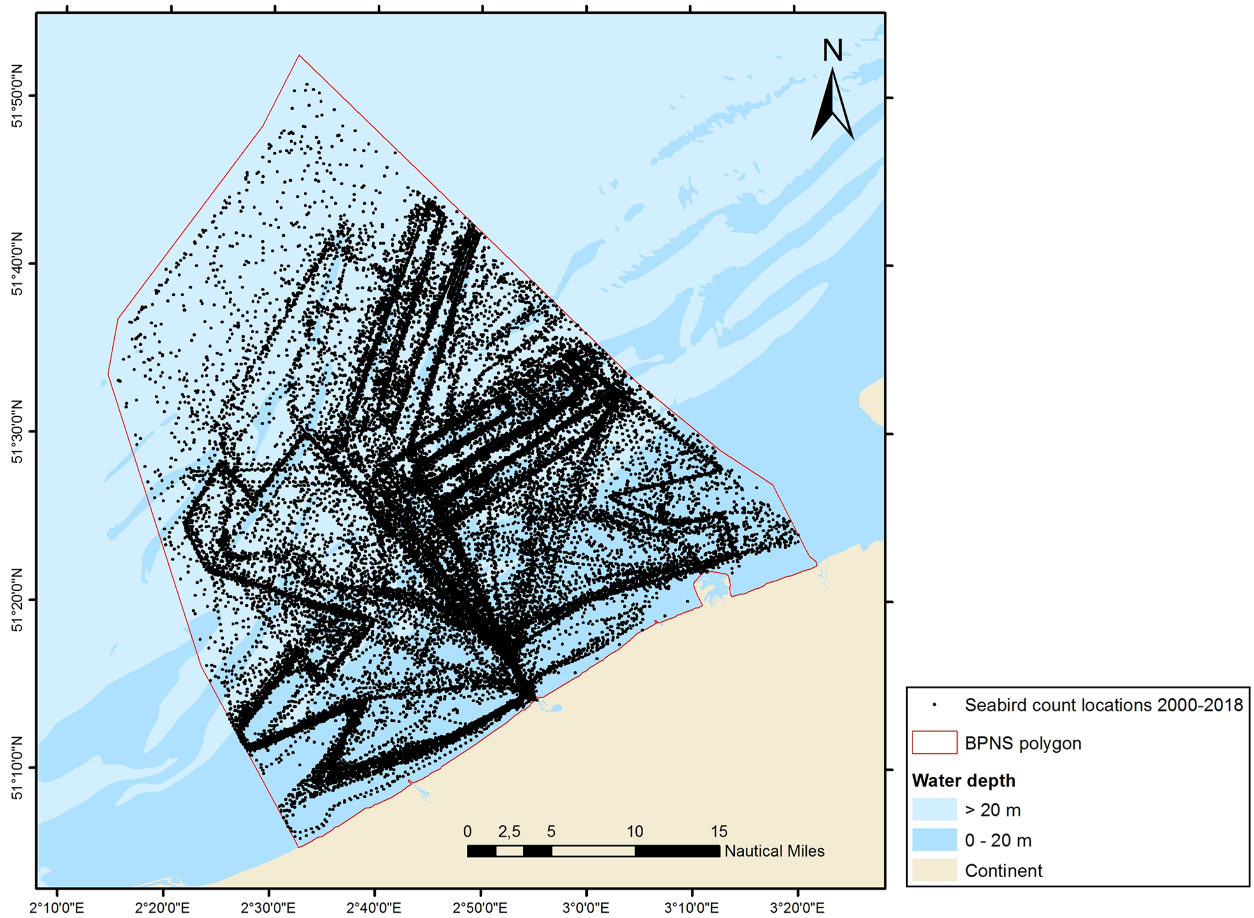

Figure 1. Count locations included in the OWF displacement sensitivity analysis for the period 2000-2018.

2.2. Seabird monitoring: aftermath

We corrected our transect count numbers for the decreasing probability of detecting birds with increasing distance to the ship (Buckland *et al.* 2001; Thomas *et al.* 2010). The exact relation between distance and detection probability is expected to be species-specific, and further likely to depend on bird group size and observation conditions (Marques & Buckland 2003). Observation conditions were included in the detection models as 'wind force' (Beaufort scale) or 'wave height' (categorised as 0-0.5 m / 0.5-1.0 m / 1.0-2.0 m / 2.0-3.0 m…), both variables being assessed visually throughout the surveys. To look for suitable species-specific detection models, we fitted each of the following four 'full models' alternatively with a half-normal and a hazard-rate detection function:

- P(detection) ~ group size + wind force
- P(detection) ~ group size + wave height
- P(detection) ~ log(group size) + wind force
- P(detection) ~ log(group size) + wave height

We did not add cosine or polynomial adjustments to the models as doing so sometimes appeared to result in non-monotonic functions. This would imply that the detection probability *increases* with distance, which is assumed to be highly improbable. For each species, the best fitting full model was chosen based on the 'Akaike Information Criterion' (AIC), and a manual backward covariate selection was then performed to obtain a parsimonious detection model. The resulting models were used to estimate detection probabilities, varying with the observed species and selected covariates. Next, the counted numbers were 'distance-

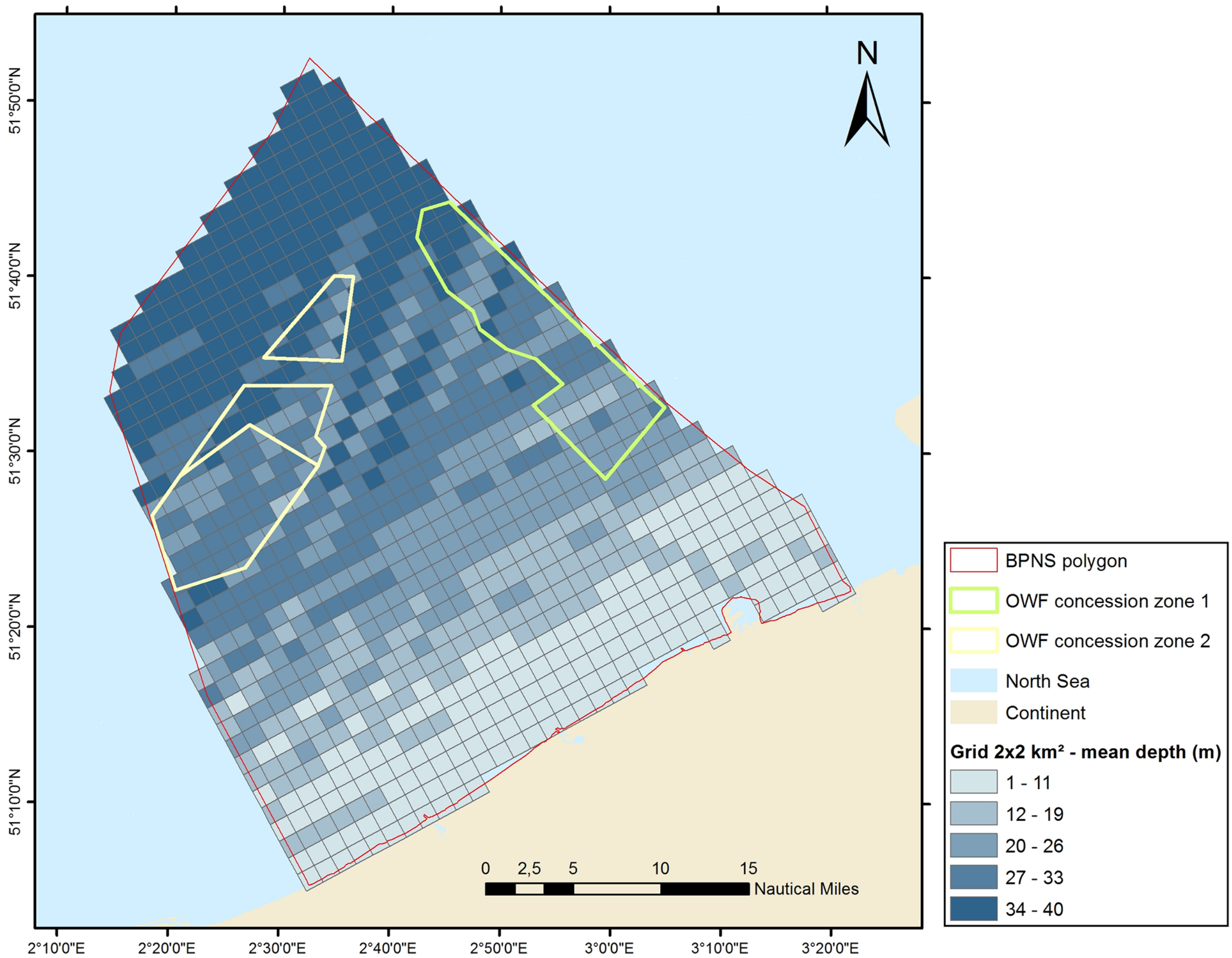

Figure 2. Mean depth parameter values over a 2 × 2 km² grid across the BPNS (geometrical interval scale).

corrected' by dividing them by the predicted detection probabilities.

In this analysis we considered four species, i.e., red-throated diver (*Gavia stellata*), northern gannet (*Morus bassanus*), common guillemot (*Uria aalge*) and razorbill (*Alca torda*), all regarded to be sensitive to OWF displacement (e.g., Vanermen & Stienen 2019). Their 'distance-corrected' numbers were eventually summed per year per month over a 2×2 km² grid across the BPNS, to obtain our response variable. Along with the seabird numbers, the area counted (the transect width of 300 m multiplied by the distance travelled) was summed as well and was used as an offset variable in the models.

2.3. Model parameters

For species distribution modelling (SDM) we considered several abiotic parameters, i.e., water depth, variation in water depth, salinity, distance to the coast and OWF presence.

Water depth data were taken from Van Lancker *et al*. (2007). The mean and standard deviation of water depth were calculated per grid cell of 2×2 km² (see Figures 2-3) to obtain the parameters 'mean depth' and 'SD depth' applied in the SDM.

Salinity data were downloaded from the Copernicus website (Copernicus 2022). There, we obtained hourly sea surface salinity figures for the period 2000-2021 at a 7 km resolution. We transformed this data file to a raster with interpolated values, which in turn were averaged over the forementioned 2×2 km² grid cells (see Figure 4).

Lastly, grid cells including at least one of the offshore wind turbines of the Belwind (2011-2018), C-Power (2013-2018), or

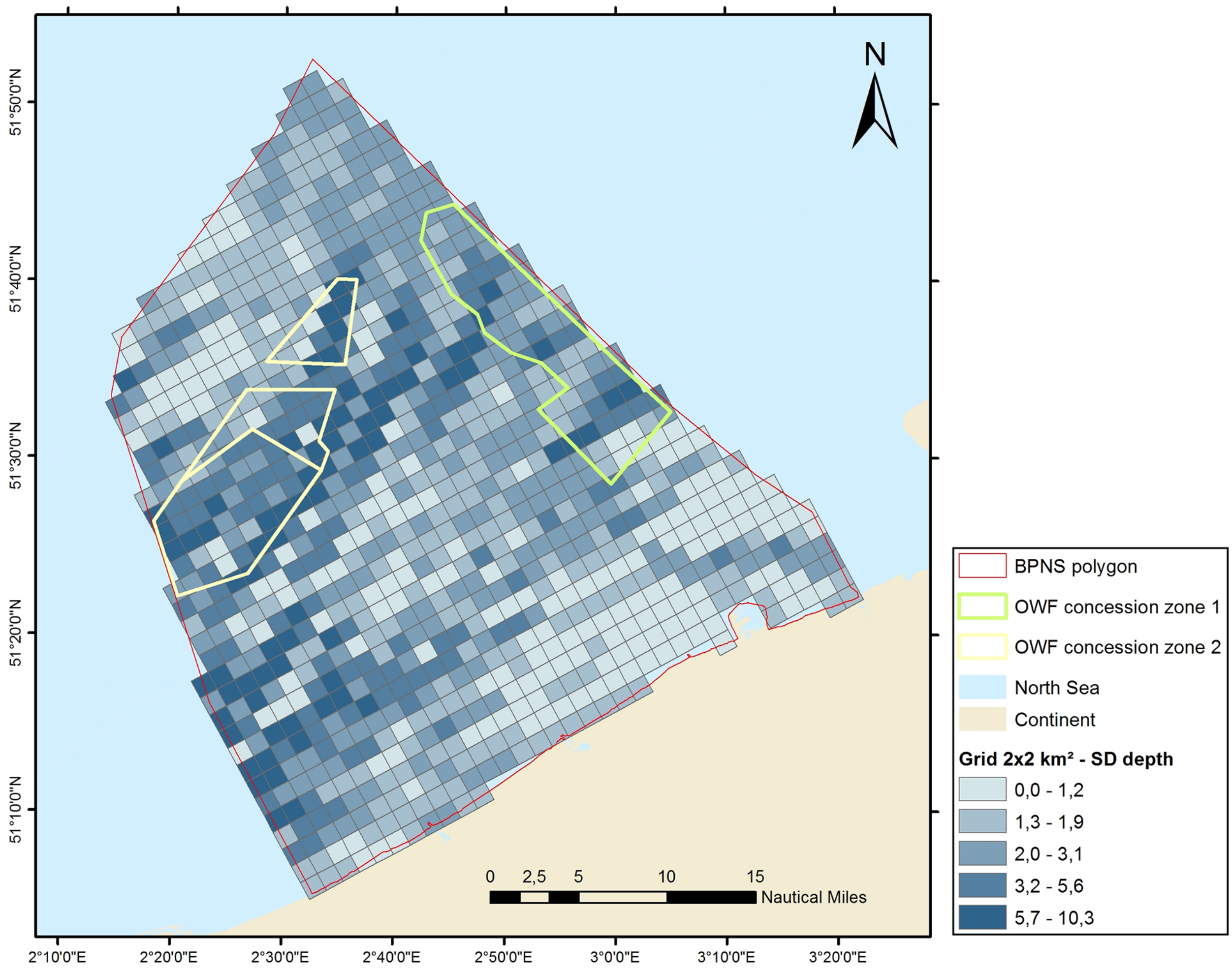

Figure 3. SD depth parameter values over a 2×2 km² grid across the BPNS (geometrical interval scale).

Norther (2015-2018) wind farms were set at TRUE for the Boolean OWF parameter, for the indicated periods in which these wind farms were operational.

2.4. Species distribution models

We modelled our response variable (number counted per year per month per grid cell) using area (i.e., the area counted) as an offset, mean depth, SD depth, salinity and month as thin-plate smoothers, OWF as a factor variable and year as a random intercept, the full (fixed) part of the model thus according to:

N ~ offset(area) + s(mean depth) + s(SD depth) + s(salinity) + s(month) + OWF

All smoothers were limited to 6 knots to avoid overfitting, while the smoother of month was further defined as a cyclic smoother.

We chose between a Poisson and negative binomial distribution based on the AIC, after which we performed backward model selection until the AIC reached its minimum or alternatively, until all parameters were significant ($P < 0.05$).

2.5. Displacement sensitivity

To come to a measure of displacement sensitivity, the predicted densities (assuming a scenario without OWFs) of the four species considered in this analysis were standardised to a value between 0 and 1 by dividing the prediction per grid cell by the maximum predicted value for a specific month (the one with highest overall occurrence). This way we ensure that all species contribute equally, independent of the variation in densities between species. Next, the standardised values for all four species were summed per

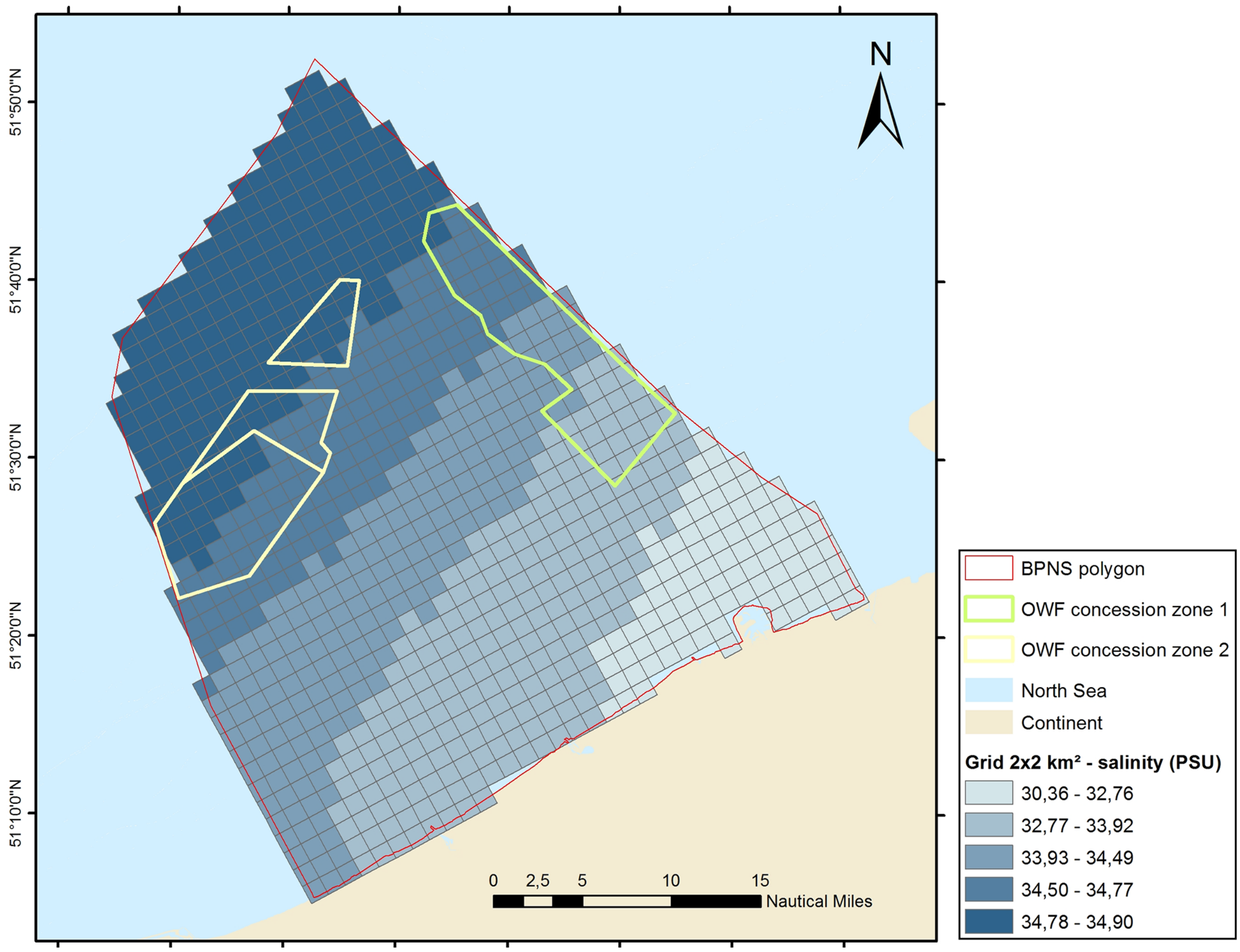

Figure 4. Salinity parameter values over a 2×2 km² grid across the BPNS (geometrical interval scale).

grid cell, thus obtaining a value which in theory could vary between 0 and 4, hereby called the displacement sensitivity index (DSI). Grid cells with a high DSI thus imply high numbers (relative to their maximum predicted densities) of at least some of the four displacement-sensitive species.

3. Results

3.1. Red-throated diver

All variables were retained in the model except for salinity. Looking at the predicted distribution we see that red-throated divers are expected to occur in highest numbers in an area 2 to 8 nautical miles offshore, where densities of 0.2 to 0.5 birds/km² are reached during midwinter (Figure 5). The current OWF concession zones do not overlap with this area of highest occurrence.

3.2. Northern gannet

For northern gannet, only SD depth was discarded from the model. Highest densities are reached in October, with predicted densities up to 5 birds/km² during autumn migration. The species' distribution is oriented offshore, with a clear influence of the saline gradient on top. Highest predicted densities are reached between the ridges of the 'Hinderbanken', and also in the far north-western corner of the BPNS (Figure 6). Yet, considering the limited number of observations in the latter area (Figure 1) we should be careful in emphasizing the high predictions there. For northern gannet, the OWF concession

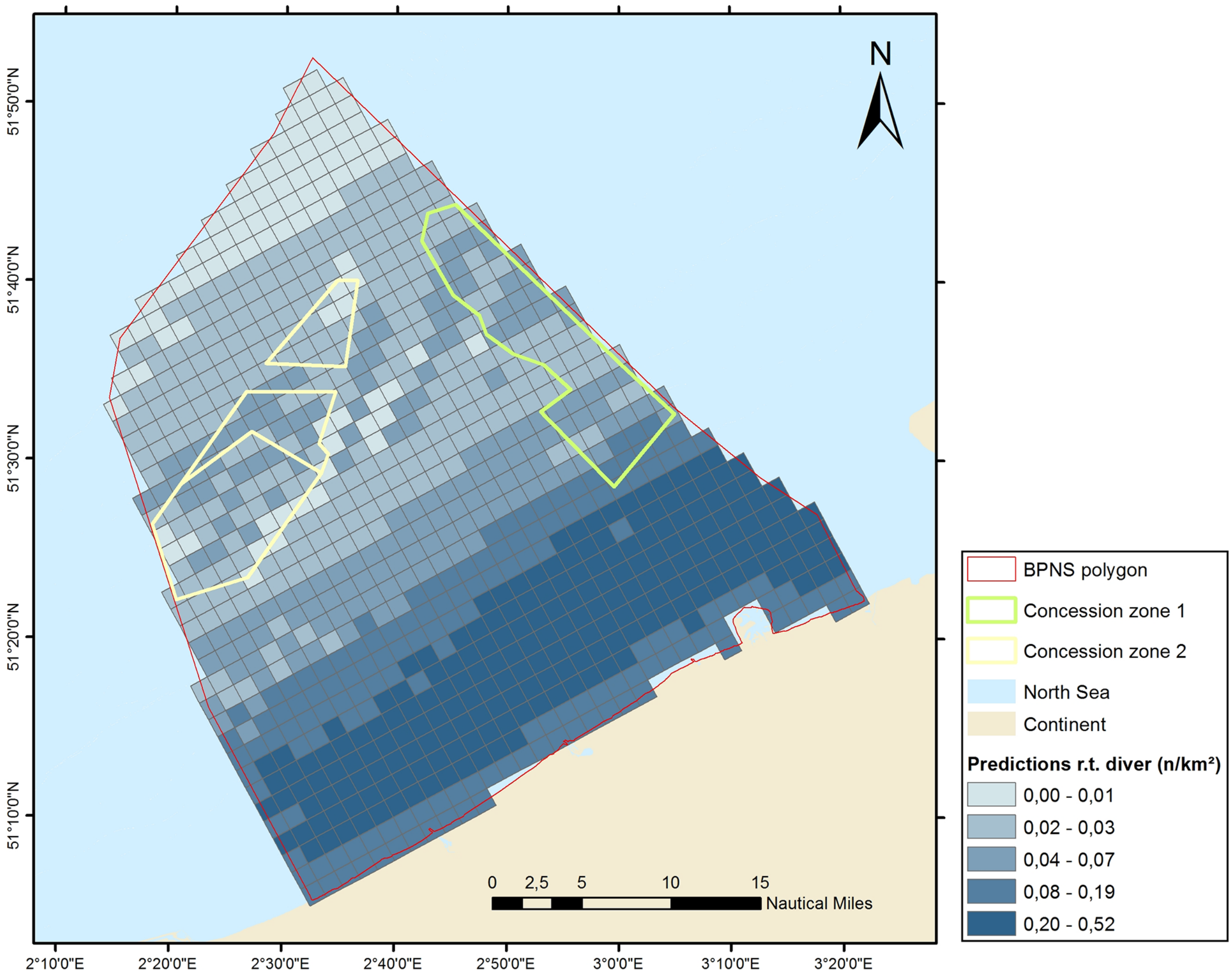

Figure 5. Predicted distribution of red-throated diver for the month December with the OWF factor set at FALSE (geometrical interval scale).

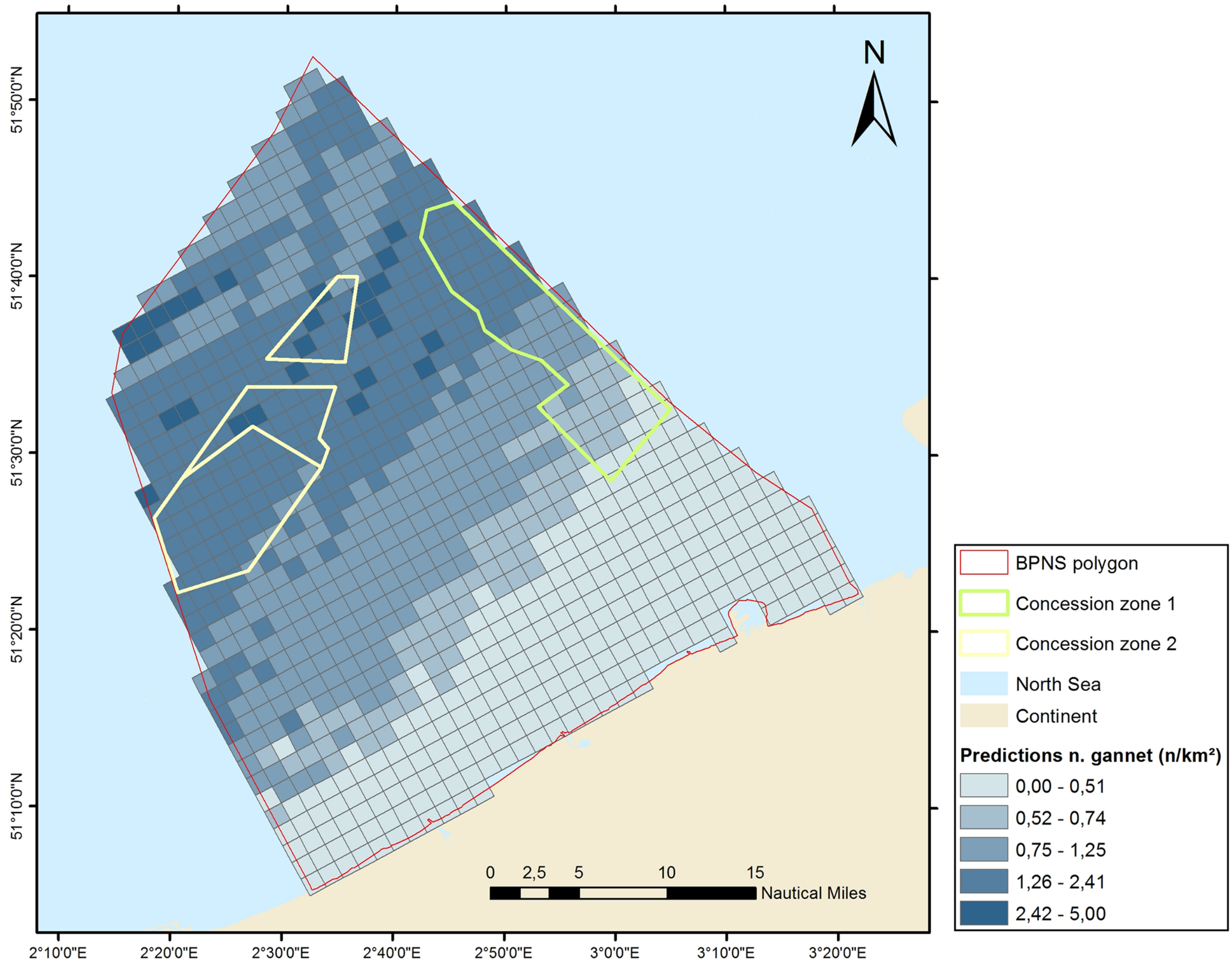

Figure 6. Predicted distribution of northern gannet for the month October with the OWF factor set at FALSE (geometrical interval scale).

zones clearly overlap with areas of abundant occurrence, which is especially the case for concession zone 2.

3.3. Common guillemot

All parameters were retained in the model for common guillemot, which explained 58 % of the deviance of the data. During midwinter, predicted densities go up to 10.5 birds/km². The birds clearly avoid the low-saline waters in front of the eastern coast and reach highest densities on top of the ridges of the 'Vlaamse Banken' (Figure 7). There is large overlap between high-density areas and the OWF concession zones, especially in case of concession zone 2.

3.4. Razorbill

As for common guillemot, we retained all parameters in the model, which achieved to explain 52 % of the deviance in the data. The species reaches its highest densities on the 'Vlaamse Banken', with locally 1.9-2.6 birds/km² in the month November, and lowest densities in the low-saline waters near the Westerschelde estuary (Figure 8). Razorbill has a distinct seasonal pattern, with generally increased numbers in the winter half year, yet with secondary peaks in numbers in February and November, illustrating that a certain part of the birds only migrates through. There appears to be limited overlap between areas with high abundance of razorbill on the one hand and the OWF concession zones on the other hand.

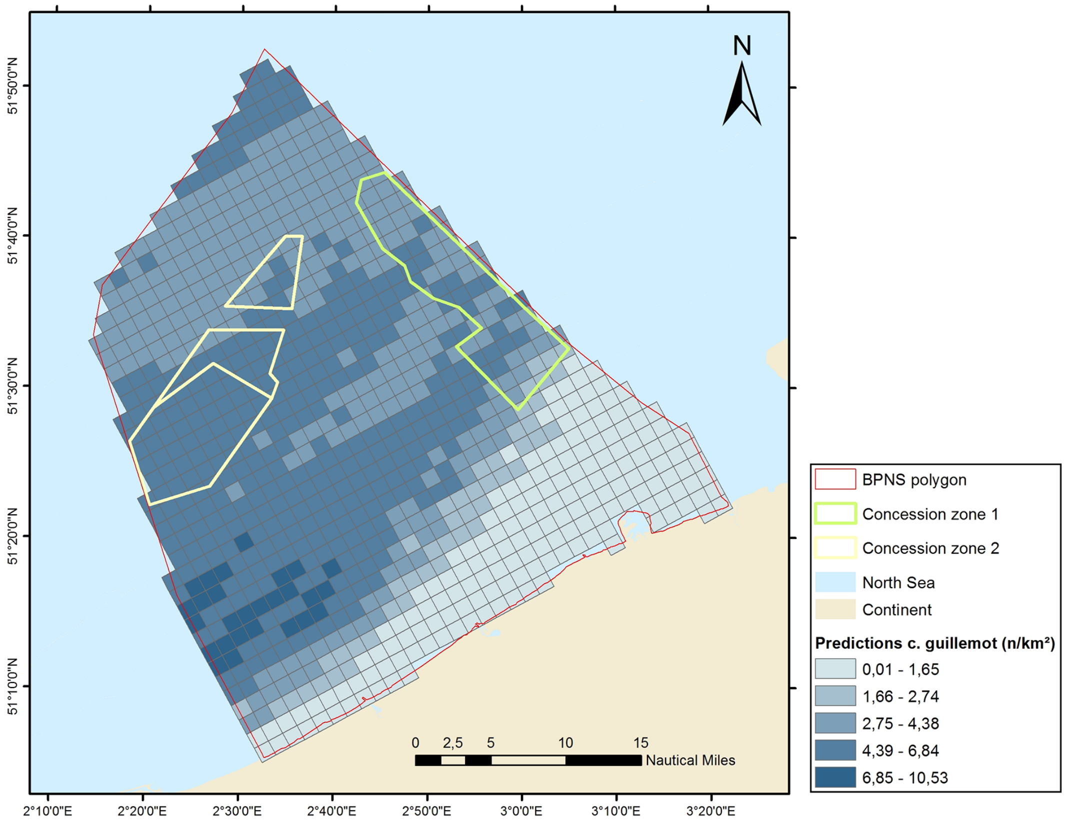

Figure 7. Predicted distribution of common guillemot for the month January with the OWF factor set at FALSE (geometrical interval scale).

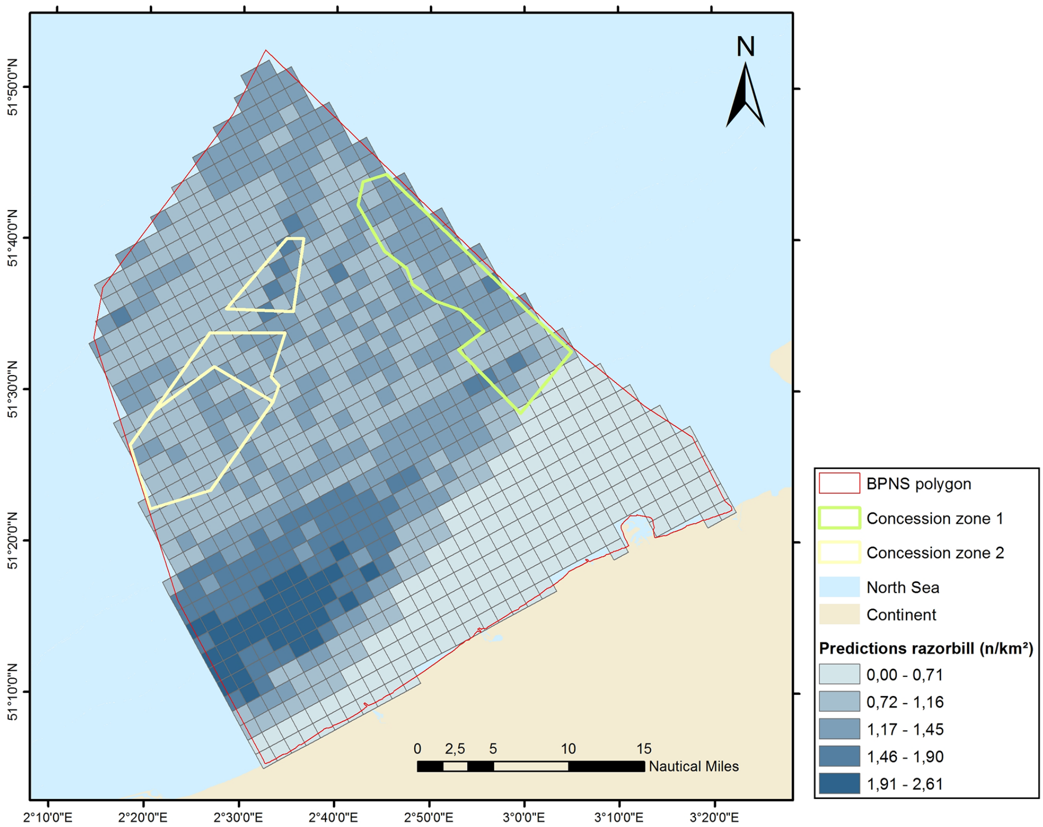

Figure 8. Predicted distribution of razorbill for the month November with the OWF factor set at FALSE (geometrical interval scale).

Table 1. Estimated OWF coefficients and accompanying expected decreases in numbers.

	OWF coefficient	P-value	Expected decrease inside OWFs
Red-throated diver	-1.66	0.105	81 %
Northern gannet	-1.85	< 0.001	84 %
Common guillemot	-1.13	< 0.001	68 %
Razorbill	-0.53	0.007	41 %

3.5. OWF effect

Interestingly, in all models the OWF factor was retained. Though not statistically significant in case of red-throated diver, the OWF factor did contribute positively to this model as well based on the AIC. The fact that the main distribution of divers does not overlap with the current wind farm developments clearly makes it hard for statistical evidence to occur. For the three other species, the coefficient was both negative and significant, underpinning the negative effect of OWFs on their presence. The estimated coefficients and associated P values for the OWF factor are summarised in Table 1. The third column shows the expected decrease in numbers in the wind farm concession zones (calculated as 1 minus the exponentiation of the OWF coefficient).

The SDM results further allow to estimate the species' total numbers residing at the BPNS, as well as the number of birds that are expected to be impacted by current and planned OWFs (Table 2). In absolute numbers, common guillemot is the most impacted species, with about 1600 individuals being displaced by the (future) OWFs in concession zones 1 and 2. The strongest relative impact, however, was found for northern gannet with 17.4 % of 3340 individuals expected to be displaced.

3.6. Displacement sensitivity

By summing the standardised density predictions of four displacement-sensitive species per grid cell and mapping the resulting DSI values (see §2.5), we obtained the displacement sensitivity map as shown in Figure 9. One zone with DSI values higher than 1.8 jumps out clearly, and is situated in front of the western part of the Belgian coast between 5 and 12 nautical miles offshore. This area is often referred to as 'Vlaamse Banken', and more precisely, it includes part of the 'Oostdyck' and most of the sandbanks 'Buitenratel', 'Kwintebank' and 'Middelkerkebank'.

Assessing the contribution of the different species to the DSI values across three areas of interest (OWF concession zone 1, OWF concession zone 2 and the aforementioned area with high displacement sensitivity) resulted in the bar plot below (Figure 10). This plot illustrates how the species contribution at 'Vlaamse Banken' is quite different from those in the wind farm concession zones,

Table 2. Predicted numbers at the BPNS for scenarios with and without OWFs, in the month with maximum densities.

	Total predicted numbers at BPNS *without* OWFs	Total predicted numbers at BPNS *with* OWFs	Predicted % of numbers impacted by OWFs
Red-throated diver (December)	414	403	2.8 %
Northern gannet (October)	3340	2760	17.4 %
Common guillemot (January)	13233	11629	12.1 %
Razorbill (November)	3535	3298	6.7 %

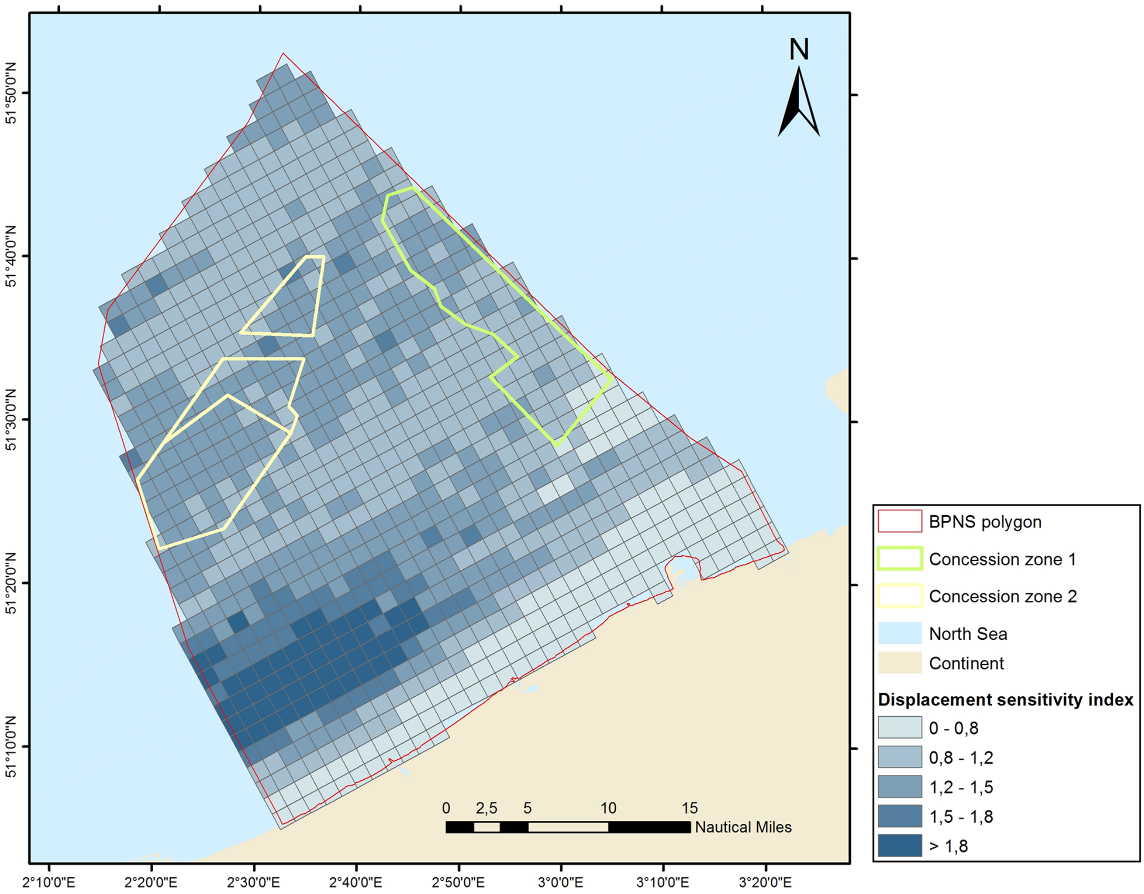

Figure 9. OWF displacement sensitivity map.

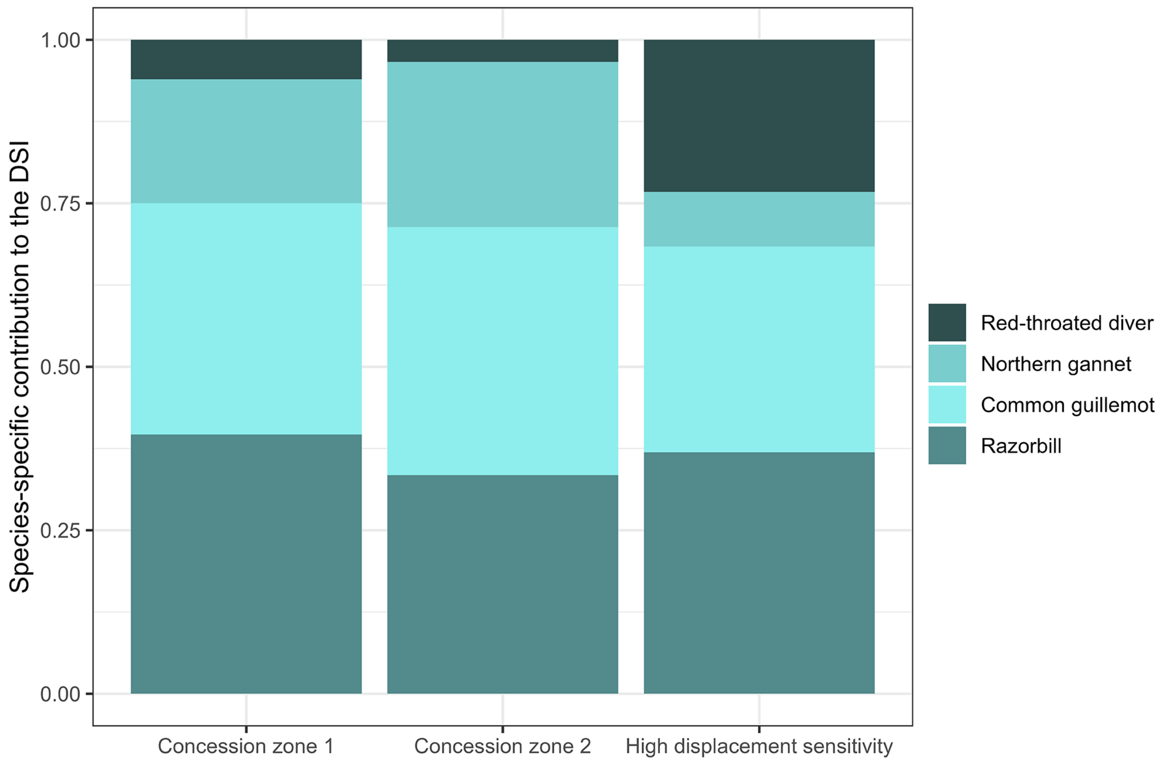

Figure 10. Contribution of the four selected species to the DSI values in the OWF concession zones 1 and 2 on the one hand and the 'high displacement sensitivity' area on the other hand.

mainly because of high predicted densities of red-throated diver, compared to relatively low densities of northern gannet. The wind farm concession zones on the other hand show a quite comparable species contribution.

4. Discussion

This study intended to look for a suitable method to produce an integrated sensitivity map regarding OWF-induced seabird displacement. For this purpose, we first corrected observational data for distance-related bias and then linked the corrected seabird numbers with a range of explanatory environmental variables to produce species distribution models (Waggit *et al*. 2020; Mercker *et al*. 2021) of four species known to be sensitive to OWF disturbance (red-throated diver, northern gannet, common guillemot and razorbill).

Compared to the targeted BACI analyses reported throughout the WinMon.BE research program, this analysis was less focussing on wind farms alone, including the whole BPNS. Nevertheless, our SDM revealed strong effects of the presence of OWFs in all 4 species. With predicted decreases of 84 % for northern gannet and 68 % for common guillemot, the results are highly comparable to the decreases reported in Vanermen *et al*. (2019), i.e., 82-98 % for northern gannet and 63-75 % for common guillemot. For razorbill the predicted decrease found here (41 %) is lower compared to the one reported earlier (67-75 %), while for red-throated diver we never reported any estimates due to very little overlap between this species' distribution at the BPNS and OWFs. Interestingly, the SDMs provide quantitative insight in the numbers of seabirds expected to be impacted by OWF developments in the BPNS and thus allow to flag potential conflicts with conservation objectives defined within the Marine Strategy Framework and/or Birds Directive.

It is important to note that this is a first explorative analysis, and the SDMs can be finetuned in various ways. One way would be incorporating distance to the nearest OWF instead of including the OWF effect as a Boolean factor. The wind farm effect could in theory also interact with the other parameters, which was not investigated here. Clearly, other human pressures too may influence seabird distribution, such as fishing activities and ship traffic (Mercker *et al*. 2021), parameters that were not included in the SDM here.

In a next step, we cumulated the standardised model predictions to obtain our intended sensitivity map. In this map one compact area in front of the western part of the Belgian coast clearly stands out due to particularly high DSI values. Interestingly, roughly the same area has always been conceived as good seabird habitat during ship-based surveying and was already highlighted as being sensitive to seabird disturbance and oil pollution by Seys (2001). The area is further enclosed entirely by the special area for conservation 'The Flemish Banks' (Habitats Directive), yet shows very little overlap with the special areas for the protection of birds 'SPA 1', 'SPA 2' and 'SPA 3' (Birds Directive) (Figure 11). This can easily be explained by the fact that the latter were delineated based on an entirely different set of species, namely great crested grebe (*Podiceps cristatus*), common scoter (*Melanitta nigra*), little gull (*Hydrocoloeus minutus*) and two tern species (*Sterna hirundo* and *Thalasseus sanvicensis*) (Haelters *et al*. 2004), none of which were included in this analysis.

For a more thorough displacement sensitivity mapping, ideally, we should also include common scoter, as this species is also known to be sensitive to displacement by wind farms. At the BPNS, the numbers of common scoters are monitored yearly through aerial instead ship-based surveys, yet these surveys only cover a rather narrow strip along the Belgian coast, thus hampering reliable SDM across the full extent of the BPNS.

To conclude, well-founded sensitivity maps can be an important tool in informing marine spatial planning. It allows to avoid developments in areas with large numbers

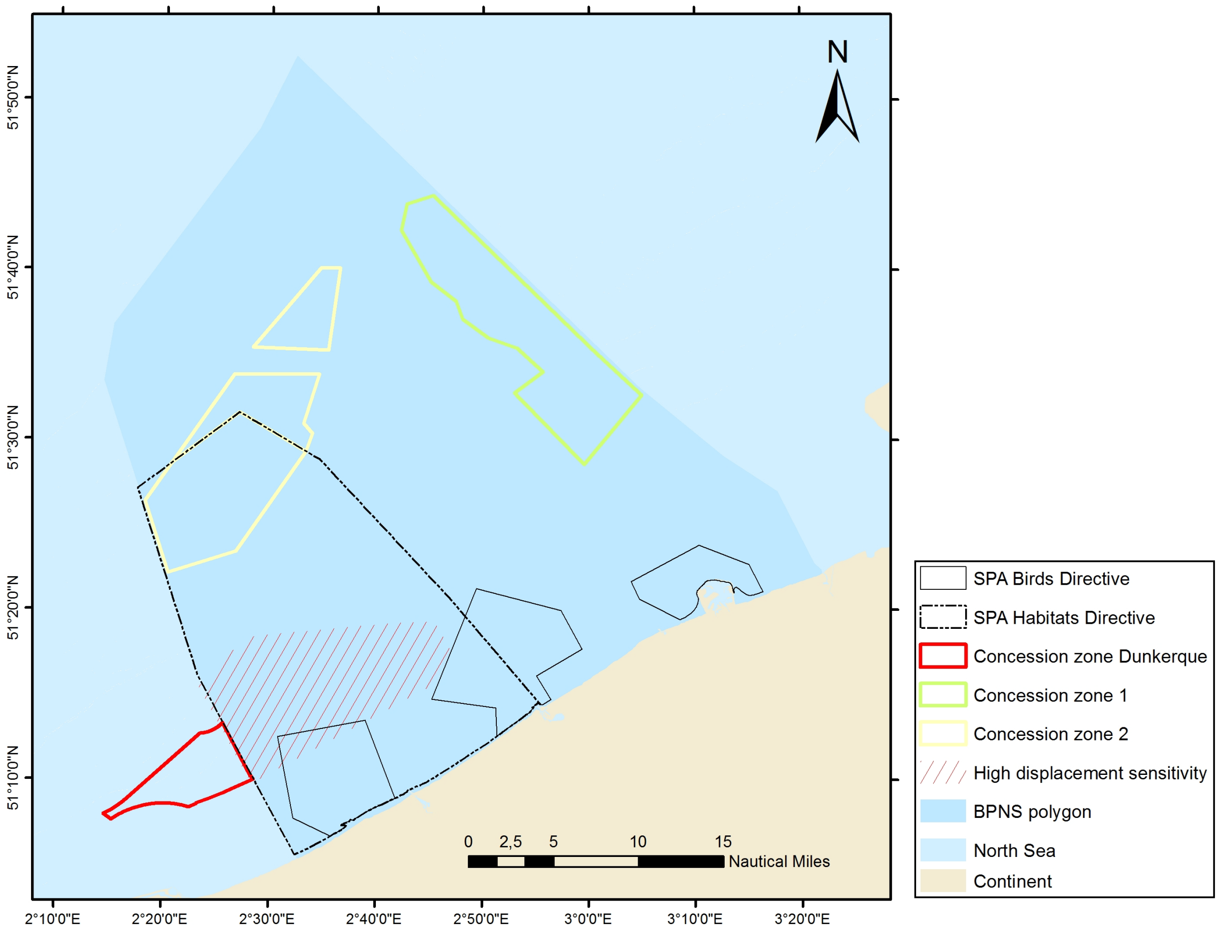

Figure 11. Location of the area with high DSI values relative to the Habitats and Birds Directive areas and planned and operational OWF concession zones.

of birds that are sensitive to wind farm disturbance, or alternatively, to install protective measures in sensitive areas in order to compensate for wind farm impacts elsewhere. In the highly dynamic marine environment, it may prove hard to find areas that compensate the same species and numbers that are impacted, as for example illustrated by the limited contribution of northern gannet in the area with high DSI values (Figure 10) compared to the concession zones. Likewise, it can be difficult to quantify the benefits of protective measure to any given species. All this, however, should not impede the implementation of compensating measures since species protection laws are not only intended to protect single species, but also to conserve their habitat and all other species associated with that habitat. In accordance to this 'umbrella' concept of nature conservation, installing a marine protected area aimed at compensating the loss of suitable seabird habitat caused by offshore wind farming at the BPNS should be given consideration.

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