European flat oysters on offshore wind farms: additional locations

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Opportunities for the development of European flat oyster (*Ostrea edulis*) populations on planned wind farms and additional locations in the Dutch section of the North Sea

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Contents

Summary

To determine the relative suitability for development of self-sustaining European flat oyster (*Ostrea edulis*) beds, potential areas for offshore wind farms in the Dutch Exclusive Economic Zone (EEZ) were analysed following Smaal *et al* (2017). The studied locations are the new wind farm zones "Hollandse Kust ("noordwest", "west" and "zuidwest")", "IJmuiden Ver" and the remaining lot of the North of the Frysian Islands Wind Farm Zone, but also 13 additional potential locations on the EEZ (i.e. CP4-CP6 and CP9-17) and, in addition, the nature area location Borkum Reef Ground (Borkumse Stenen). This research is performed within EZ-program Beleidsondersteunend Onderzoek (BO).

Biotic and abiotic factors of importance for flat oyster survival, growth, reproduction and recruitment, were compared for the 8 wind farm locations of Smaal *et al*. (2017) and the 18 new locations. For the locations on the Dutch EEZ the following habitat factors are important for flat oyster beds: shear stress, suspended sediment, larval retention, temperature, sediment composition and food availability. Presence in historic distribution area was used as a verification. Average shear stress, suspended sediment and temperature are within the range considered suitable for the development of an oyster bed at all locations. Thus, these factors do not discriminate between locations. Maximum shear stress is too high at one location and the sediment is too silty at 7 locations. However, habitat restoration efforts may make the environment more suitable, e.g. by placing shell material or 3D structures which elevate the oysters from the bottom.

Based on the analysis described in this report we recommend to select the following locations that are suitable for flat oyster restoration.

1. Best: Borssele Wind Farm Zone, Buitengaats (part of the Gemini wind park) and CP9 (within historic distribution and high larval retention);
2. Very good: Hollandse Kust (zuidwest) Wind Farm Zone (high larval retention);
3. Good: Offshore Windpark Egmond aan Zee, Prinses Amalia Windpark, Windpark Eneco Luchterduinen, Hollandse Kust (zuid) Wind Farm Zone, Hollandse Kust (noord) Wind Farm Zone (medium larval retention);
4. Suitable: the remaining lot of the North of the Frysian Islands Wind Farm Zone, Zee-energie (part of the Gemini wind park), Borkum Reef Ground (Borkumse Stenen) (within historic distribution, medium or high larval retention, but locally too high maximum shear stress or too silty);
5. Suitable with introduction of substrate: CP5, CP6 (medium or high larval retention, but too silty without introduction of substrate).

Samenvatting

Om de relatieve geschiktheid voor de ontwikkeling van zelfvoorzienende platte oester (*Ostrea edulis*) bedden zijn potentiele gebieden voor offshorewindparken in de Nederlandse exclusieve economische zone (EEZ) geanalyseerd volgens Smaal et al. (2017). De bestudeerde gebieden zijn de nieuwe windenergiegebieden "Hollandse kust ("noordwest", "west" en "zuidwest")", "IJmuiden Ver" en het overblijvende gebied in het windenergiegebied Ten Noorden van de Waddeneilanden, maar ook 13 additionele potentiële locaties in de EEZ (i.e. CP4-CP6 en CP9-17) en het natuurgebied Borkumse Stenen. Dit onderzoek is uitgevoerd in het EZ-programma Beleidsondersteunend Onderzoek (BO).

Biotische en abiotische factoren van belang voor overleving, groei, reproductie en rekrutering van platte oesters zijn vergeleken voor de 8 wind park locaties van Smaal et al. (2017) en de 18 nieuwe locaties. Voor de locaties in de Nederlandse EEZ zijn de volgende habitatfactoren belangrijk voor platteoesterbedden: bodemschuifspanning, zwevendstofgehalte, larvenretentie, temperatuur, sedimentsamenstelling en voedselbeschikbaarheid. Aanwezigheid in het historisch verspreidingsgebied is gebruikt als verificatie. Op alle locaties vallen waarden voor bodemschuifspanning (gemiddeld), zwevendstofgehalte en temperatuur binnen de range die geschikt wordt geacht voor de ontwikkeling van een oesterbank. Deze factoren discrimineren dus niet tussen locaties. De maximale bodemschuifspanning is te hoog op 1 locatie en het sediment te slibbig op 7 locaties. Maar habitatherstelactiviteiten kunnen de omgeving geschikter maken, b.v. door het plaatsen van schelpmateriaal of 3D-structuren die de oesters boven de bodem laten uitstijgen.

Gebaseerd op de analyse beschreven in dit rapport raden we de selectie van de volgende locaties aan die geschikt zijn voor platteoesterherstel.

1. Best: windenergiegebied Borssele, locatie Buitengaats (deel van het Gemini-windpark) en CP9 (binnen de historische verspreiding en hoge larvenretentie);
2. Erg goed: windenergiegebied Hollandse Kust (zuidwest) (hoge larvenretentie);
3. Goed: Offshore Windpark Egmond aan Zee, Prinses Amaliawindpark, Windpark Eneco Luchterduinen, windenergiegebied Hollandse Kust (zuid), windenergiegebied Hollandse Kust (noord) (gemiddelde larvenretentie);
4. Geschikt: het resterende gebied in het windenergiegebied Ten Noorden van de Waddeneilanden, locatie Zee-energie (deel van het Gemini-windpark), natuurgebied Borkumse Stenen (binnen de historische verspreiding, gemiddelde of hoge larven retentie, maar lokaal een te hoge maximum bodemschuifspanning of te slibbig);
5. Geschikt na introductie van substraat: CP5, CP6, (gemiddelde of hoge larvenretentie, maar te slibbig zonder introductie van substraat).

1 Introduction

1.1 Background

The Rutte-III cabinet has the ambition to reduce CO_2-emmisions with an additional 4 million tonnes via Offshore Wind Energy (WoZ) (VVD, CDA, D66 & ChristenUnie 2017), on top of the reduction task of the Energy agreement (SER 2013). For this, a second Offshore Wind Energy Roadmap (2024-2030) has been developed (Min. EZK 2018). Locations that are being considered in the present study are the wind farm zones that were indicated in the most recent National Structural Vision Offshore Wind Energy and include the wind farm zones: "Hollandse Kust (noordwest, west and zuidwest)", "IJmuiden Ver" and remaining lot of North of the Frysian Islands Wind Farm Zone, but also additional locations on the Dutch Exclusive Economic Zone (EEZ) (Figure 1). For the wind farm zones of the first Offshore Wind Energy Roadmap up to 2023 (i.e. the Borssele, Hollandse Kust (zuid) and Hollandse Kust (noord) Wind Farm Zones), the site decisions contain requirements implying that a permit holder must make demonstrable efforts to design and build a wind farm in such a way that it actively helps to foster conservation efforts and goals for species and habitats that occur naturally in the Netherlands ('eco-friendly design' (Lengkeek *et al*., 2017) or 'nature-inclusive building'). This is based on the nature restoration policy task for the Dutch North Sea (Min. IenW & Min. EL&I 2012). It is expected that within the framework of the Offshore Wind Energy Roadmap (2024-2030) and beyond opportunities for nature also need to be considered when selecting designs and locations.

Restoration of European flat oyster beds is part of explicit policy intentions of the ministries of LNV (formerly EZ) and IenW (Min. IenM & Min. EZ 2015a; Min. IenM & Min. EZ 2015b; Min. IenM & Min. EZ 2014; Min. EZ 2014; Min. EZ & Min. IenM 2013). WoZ can, under specific circumstances, contribute to the nature restoration task for the Dutch North Sea (Min. IenM & Min. EL&I, 2012). Development of flat oyster beds is identified as a favourable option for nature-inclusive development of wind farms (Van Duren *et al.,* 2016, Lengkeek *et al*., 2017 and Smaal *et al*., 2017) and is thus desirable for formalising that part of the second Offshore Wind Energy Roadmap (2024-2030). Smaal *et al*. (2017) studied suitability of the following wind farm locations: Borssele Wind Farm Zone, Buitengaats (part of the Gemini wind park), Offshore Windpark Egmond aan Zee (OWEZ), Hollandse Kust (noord) Wind Farm Zone, Hollandse Kust (zuid) Wind Farm Zone, Windpark Eneco Luchterduinen, Prinses Amaliawindpark and Zee-energie (part of the Gemini wind park). The question therefore is: "Which of the WoZ locations are suitable for sustainable development of European flat oyster beds in addition to the locations already identified by Smaal *et al*. (2017)"?

1.2 Knowledge question

What is the potential suitability in relative terms of all wind energy at sea locations (including those analysed in Smaal *et al*, 2017) and other parts of the Dutch EEZ for development of an European flat oyster (*Ostrea edulis*) bed that is capable to sustain itself in terms of recruitment?

2 Materials and Methods

2.1 Locations

The present analysis compares results with the locations of existing and planned wind farms of Smaal *et al* (2017). The studied locations are presented in Figure 1. Eight locations were analysed in Smaal *et al* (2017) (Offshore Windpark Egmond aan Zee (OWEZ) (hereafter: Egmond aan Zee), Prinses Amaliawindpark (hereafter: Prinses Amalia), Windpark Eneco Luchterduinen (hereafter: Luchterduinen), Borssele Wind Farm Zone (hereafter: Borssele), Hollandse Kust (zuid) Wind Farm Zone (hereafter: Hollandse Kust Zuid), Hollandse Kust (noord) Wind Farm Zone (hereafter: Hollandse Kust Noord), Buitengaats and Zee-energie (both are part of the Gemini wind park). The extra analyses concern the planned wind parks in the following five wind farm zones: Hollandse Kust (zuidwest) (hereafter: Hollandse kust West 2), Hollandse Kust (west) (hereafter: Hollandse kust West 3), Hollandse Kust (noordwest) (hereafter: Hollandse kust West 4), IJmuiden Ver and a remaining lot of the North of the Frysian Islands Wind Farm Zone (Ten Noorden van de Waddeneilanden; hereafter: TNvW). In addition, 12 potential locations on the EEZ were added (CP4-CP6 and CP9-CP17) as well as the nature area location Borkum Reef Ground (Borkumse Stenen). The locations CP4-CP6 and CP9-CP17 were selected for this study, with a wide distribution over the Dutch Continental Shelf and over a wide set of physical habitats, including sites on e.g. the Dogger Bank, Cleaver Bank and Frisian front. The Borkum Reef Ground is a location that is considered for oyster restoration by WWF.

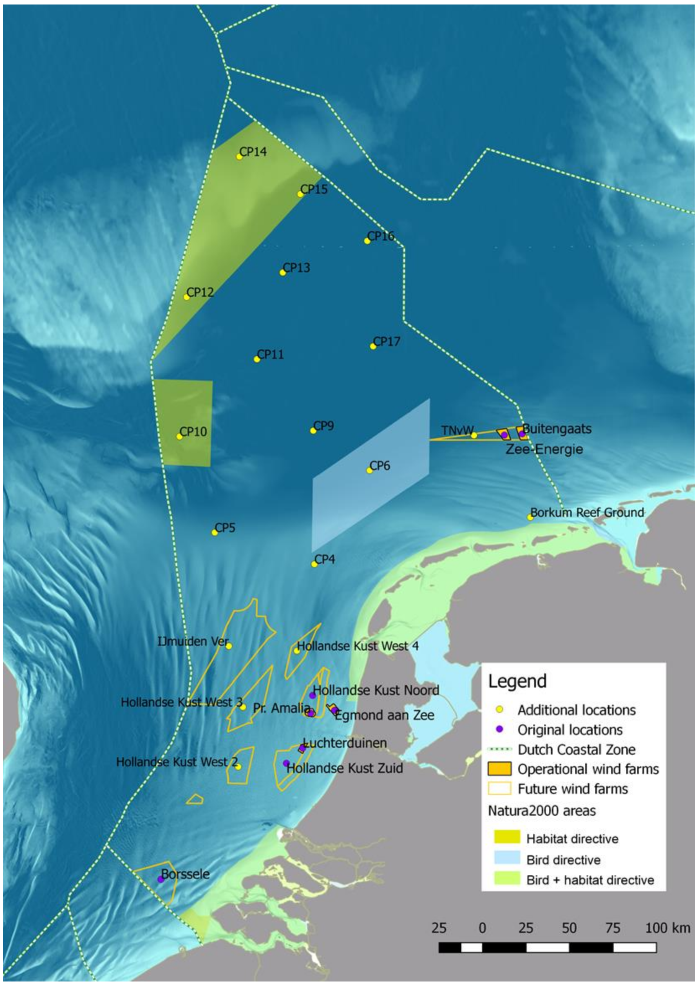

Figure 1. Current locations analysed in this study (orange dots) and the locations assessed in Smaal et al*. (2017) (purple dots). Also indicated in light green Natura 2000 areas protected under the Birds Directive and Habitats Directive, in light blue Natura 2000 areas protected under the Birds Directive and in dark yellow Natura 2000 areas protected under the Habitats Directive.*

2.2 Biotic and abiotic habitat characteristics

Following Smaal *et al*. (2017) biotic and abiotic factors of importance for European flat oyster (*Ostrea edulis*) survival, growth, reproduction and recruitment were analysed for the 18 new locations. Table 1 shows the suitable ranges of factors for flat oysters based on the literature review presented in Smaal *et al*. (2017). Each factor is explained in more detail below.

*Table 1. Habitat suitability characteristics and their ranges for European flat oyster (*Ostrea edulis*). Based on Smaal* et al*. (2017). * Based on new data.*

Characteristic	**Range**
Sediment composition	Fine sand (>63 μm) and firm silty sand or silty gravel with shells and stones
Bed shear stress (tau N/m^2)	Average <1, Max < 10
Bed mobility (cm/day)	< 0.8
Suspended sediment (mg/l)	< 50*
Temperature winter, Tmin (^{0}C)	> 3
Temperature summer, Tmax (^{0}C)	< 30
Oxygen conditions (mg/l)	> 3.5
Salinity	25 – 35
Food concentration (chla in μg/l)	Growth > 0.5, Gonad development > 1.68
Larval retention	Larvae must remain near point of release
Predation	High numbers of predators can decimate a population
Competition	Competition for food can reduce growth and reproduction

2.2.1 Abiotic habitat characteristics

When selecting potential restoration locations it is important that the habitat is suitable for adult populations, but also for settlement of larvae. Flat oysters are ecosystem engineers. This means that they will adapt their physical environment in such a way that conditions improve for the species. Oysters need hard substrate (shells, stones) for their initial settlement, and can in that way develop a bed over soft sediment. A long-term bottom stability is needed to ensure bed survival. Favourable locations are determined by the local sediment composition, but also the bed mobility.

<u>Sediment composition</u>
Sediment composition is important as it determines substrate suitability for recruitment. Shells and existing oyster beds will promote recruitment. In the absence of shells and oyster beds, sediment grain size is the most commonly used parameter. Hydrodynamic conditions have impact on sediment composition. Silt tends to accumulate in sheltered spots, while coarser sediment particles are found in exposed areas. As a rule, average grain size varies according to the average current velocity. Burial under a layer of fine sediment will impede oysters survival.

<u>Bed shear stress</u>
This parameter is indicative of the force that currents and waves exert on the bed. If these forces regularly exceed the limit required to induce bed-load transport of oysters, this is deemed unsuitable. The critical shear stress to induce bed-load transport is at present not yet known for living oysters. It is certain that this will strongly depend on the bed composition and on the presence of other oysters. Average and maximum bed shear stresses are calculated over the period of 2003-2011, using the hydrodynamic model ZUNO-DD developed for the Environmental Assessment study for sand mining on the Dutch continental shelf (Van der Kaaij *et al*., 2017). In the model bed shear stress is calculated for both currents and waves. The data presented here are the cumulated shear stresses.

Bed mobility

Although oysters can take a certain amount of erosion or deposition, there are certain areas in the North Sea where the sea bed is too changeable. The seafloor of the Dutch Continental Shelf is covered with bed forms that are often categorized into sand banks, sand waves and mega ripples (Table 2). The sand banks can be traced individually over large areas and are relatively stable bed forms with low migration rates. In many cases the sand banks are covered with sand waves, dynamic bed forms that move with 0-20 m/yr. High-resolution multi-beam data and video images show that the sand waves in their turn are covered with mega ripples that move with speeds of 30-40 m/yr.

Table 2. Characteristics of different types of bed forms (after Van Dijk et al.*, 2011).*

Bed form	Height (m)	Length (m)	H:L	Morphodynamic time scale
mega ripple	0.06-1.5	0.6-30	1:10-15	hours / days
sand wave	1.5-15	100-1000	1:33-50	months/years
sand bank	>10	5000-150000	1:500-1000	decades / centuries

Sand banks are generally not relevant for the determination of habitat suitability of European flat oysters, as these structures are stable over decades to centuries. Sand waves and mega ripples can be an issue. Areas with very dynamic bed motion are likely to be unsuitable. For several prospective windfarms there are analyses available regarding the presence and mobility of sand waves. These have been interpreted in this study. There is much less spatial information available on mega ripples. In most areas they will not be an issue as they are generally not high enough, however in certain dynamic areas with high mega ripples these bed forms may also be limiting to the stability of oyster beds. However, sufficient spatially explicit information on mega ripples is lacking. The development and mobility of mega ripples will also be affected by the presence of ecosystem engineering biota such as flat oysters, but we currently lack the fundamental knowledge about the interaction between these biogenic structures and morphology to interpret this in terms of habitat suitability. The current analysis therefore considers sand waves, but not mega ripples.

Suspended sediment

Suspended sediment (SPM) can interfere with the feeding efficiency of European flat oysters. Literature indicates that concentrations above 50 mg/l are unsuitable for oyster growth (Duchêne *et al*., 2015). It is not entirely clear if short periods of high concentrations are also detrimental. High concentrations, exceeding this value are found regularly in the entire coastal zone, the Wadden Sea and large areas of the former Oyster Grounds. These are areas that are either very shallow (hence very exposed to wave forces) or areas that are usually relatively calm, with a lot of fine sediment deposits, that can get stirred up during heavy storms when waves are large enough to reach the bed. Very likely, oysters will be able to withstand short periods (order of magnitude a few days) with unfavourable conditions.

Temperature

Survival, growth and reproduction each have their own optimal temperature range. The extremes are survival that needs a temperature higher than 3 °C and lower than 30 °C. Note however that populations are able to adapt to local water temperature ranges.

Oxygen conditions

Oxygen content is another important factor in survival rates. European flat oysters can survive without oxygen for a time, because they are adapted to temporary exposure to the air at low tide when they close their shells and switch to anaerobic metabolism. At low temperatures they can survive like that for several days. The water at the wind farm sites considered by Smaal *et al*. (2017) is generally mixed, which prevents stratification and eliminates the risk of low oxygen levels. However, at the central part of the North Sea, stratification can occur and occasionally leads to oxygen depletion (Greenwood *et al*., 2010; Queste *et al*., 2016). Areas with regular stratification are also likely to have problems with low food supply to the bed. The stratified areas where low oxygen conditions may possibly influence habitat suitability, are also areas with potential food limitation. In the present study, oxygen is therefore also not considered an independent limiting factor for habitat suitability for oysters.

Salinity

In the North Sea, lower salinity is only occurring close to the coast. The present study did not include coastal locations. Therefore, as in Smaal *et al*. (2017) salinity was also not included as a discriminating factor between potential oyster restoration sites of the present study.

2.2.2 Biotic habitat characteristics

Food concentration

The availability of food is important to sustain growth and gonad development. Microalgae are the main food source for European flat oysters. In this study we use the amount of chlorophyll per litre as a proxy for food availability. In Smaal *et al*. (2017) food availability was not considered to be a factor limiting the suitability for European flat oysters. For locations further off shore, with lower nutrient concentrations, food concentration may be less. In addition, in some areas stratification may reduce food availability near the bottom.

Larval retention and dispersal

Sites should be self-sufficient with respect to larval supply. This means that larvae produced should settle close to the adult population (larval retention). Also, the probability of colonising other suitable habitat is taken into account (larval dispersal). The larval dispersal model assumes that larvae remain in the water column for 10 days. This is based on literature data (Smaal *et al*., 2017). In reality this may vary by a couple of days because the larval phase is temperature dependent, i.e. early in the season and in cold years this may be slightly longer, at the end of summer and in hot years, this may be slightly shorter. The model assumes larvae to behave like passive, neutrally buoyant particles. In reality larvae exhibit some behaviour that can influence their vertical distribution (Knights *et al*., 2006). This is not included in the model. Larval dispersal is expressed in relative terms, as a fraction of the larvae released at a site. The shape of the spatial distribution provides information on dispersal and retention. The closer the larvae remain near the source, the better the retention. It is a qualitative measure, the actual retention needed for a self-sustaining beds is unknown.

Predation

Most generalist predators, including starfish and crab species, can be found at all studied locations in the North Sea. Therefore, predation was not included as discriminating factor between potential sites.

Competition

A number of invertebrates compete with European flat oysters for food (throughout their life cycle) and space. However, the distribution of the species and the extent to which competition will occur is not known in sufficient detail to be used as discriminating factor. Therefore, competition was not included as discriminating factor between potential sites.

2.3 Historical occurrence

Information on the historical range of European flat oysters in the North Sea is available (Olsen, 1883). Following Smaal *et al*. (2017), this information is used as a verification in evaluating the suitability of areas in the North Sea for European flat oysters. It is however very likely that circumstances have changed since the distribution map was made. These changes may have reduced the suitability of the habitat. E.g., the silt concentration in the sediment at the Oyster Grounds is relatively high, which can easily resuspend under high wind conditions. In former times, when most of the sediment was covered by oyster beds, waves would have had far less effect on resuspension of sediment. It is not certain if the high sediment concentrations under windy conditions are limiting for oysters. Also, it is possible that the reduced resuspension and the increased nutrient recycling over the large oyster beds would have increased primary production and therefore the carrying capacity in the situation of 150 years ago. However, historical occurrence can give an indication that the area could be suitable.

3 Results and discussion

3.1 Abiotic habitat characteristics

3.1.1 Sediment composition

Most of the selected locations have a suitable bottom composition for European flat oyster habitat (Fig. 2). Only is silty sediment not considered suitable. Some of the locations further away in the EEZ may be too silty (CP5, CP6, Zee-Energie, TNvW ,CP11, CP13, CP17).

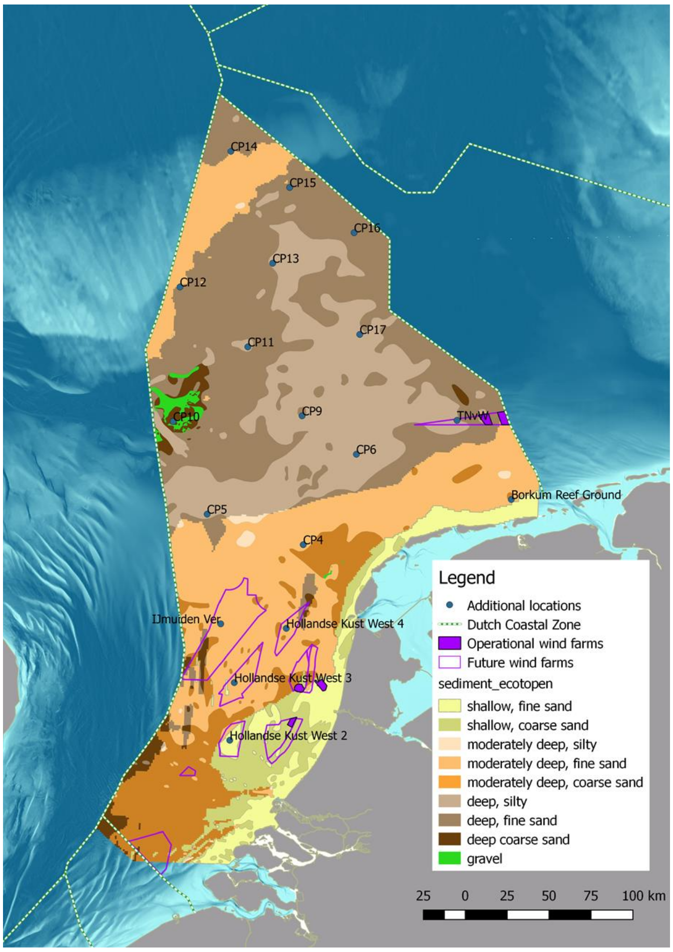

Figure 2. Ecotopes, based on grain size and depth in the North Sea Source of data .Noordzeeatlas: https://www.noordzeeloket.nl/beheer/noordzeeatlas/deel-watersysteem-0/ecotopen/

3.1.2 Bed shear stress

The hydrodynamic model predicts that average bed shear stresses are not exceeding critical values in any of the studied locations (Fig. 3A). Maximum values are too high only at the location Borkum Reef Ground (Fig. 3B). Due to the shallowness of the area the bed is prone to wave attack. However, it is important to realise that this is a highly heterogeneous area with large stones present that may create local shelter from hydrodynamic forces. The model resolution is not sufficient to resolve such local features.

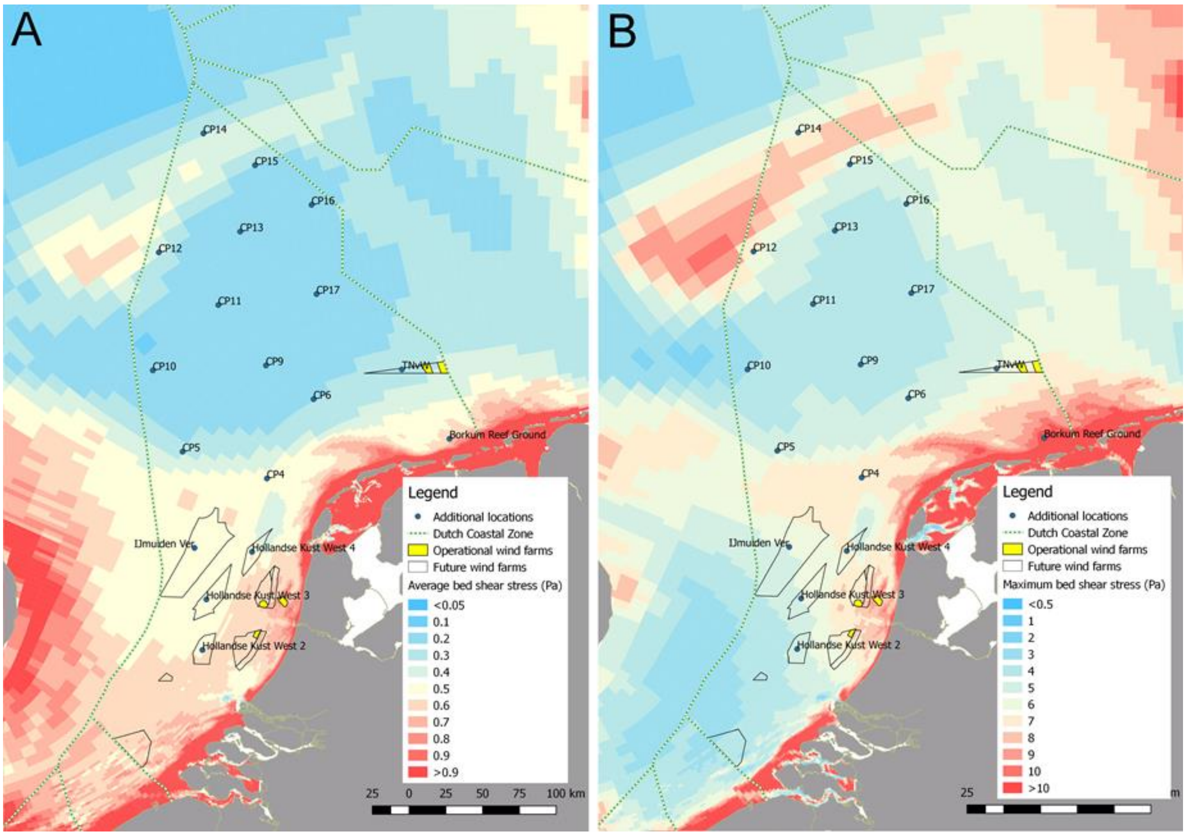

Figure 3. Average (A) and maximum (B) bed shear stress on the Dutch continental shelf. Source of data: Deltares ZUNO-DD model.

3.1.3 Bed mobility

In the southern part of the Dutch continental shelf mobile sand waves occur (Damen *et al*., 2018). These sand waves develop under the influence of tidal currents. These features can range in height from less than 1.5 m up to 10 metres and a wave length of 100 – 1000 m. Under the influence of residual currents and waves these waves can move over the bed surface of the North Sea, with speeds up to several metres per year. In areas where significant erosion or deposition occurs under influence of the movement of these sand waves, habitat may be less suitable for oysters as they may get eroded or buried with the moving sediment. In Smaal *et al*. (2017) tolerance limits for change in bed height of 0.8 cm/day were identified. In Borssele, a location with very high sand waves, but very little tidal asymmetry resulting in low speeds, we estimated in Smaal *et al*. (2017) that *annual average* changes in bed height were generally below this threshold. However, as most movement occurs during storms, when sediment is suspended into the water column by waves and subsequently transported by tidal currents, there are probably areas in this park where conditions are not suitable, while the more stable areas in this park are suitable. For the other locations examined during the previous study, sand waves were not deemed problematic. Wind farm “Luchterduinen” (investigated in Smaal *et al*. (2017)) is also in a sand wave area, but these are relatively low and very long sand waves, 900-1000 m in length (Damen *et al*., 2018). This means when these move a few metres the actual change in bed height is very low.

Of the planned additional locations there are 3 locations that are also in sand-wave areas (Figure 4)

- Hollandse Kust West-2
- Hollandse Kust West-3
- IJmuiden Ver

The sand waves in IJmuiden Ver and Hollandse Kust West-3 are relatively low in comparison to Borssele, Hollandse Kust-2 has sand waves of similar heights (up to 8 metres). However, one important difference in these three wind farms is that in Borssele tidal asymmetry is close to 0. Tidal velocities are relatively high, but there is no residual current, which means that the speed at which sand waves move is very low. This also results in a relatively high larval retention in Borssele (Smaal *et al*., 2017). Another indication that sand waves are relatively stable at the Borssele location is the fact that the sand waves in this area are very symmetrical (dark colours in figure 5)

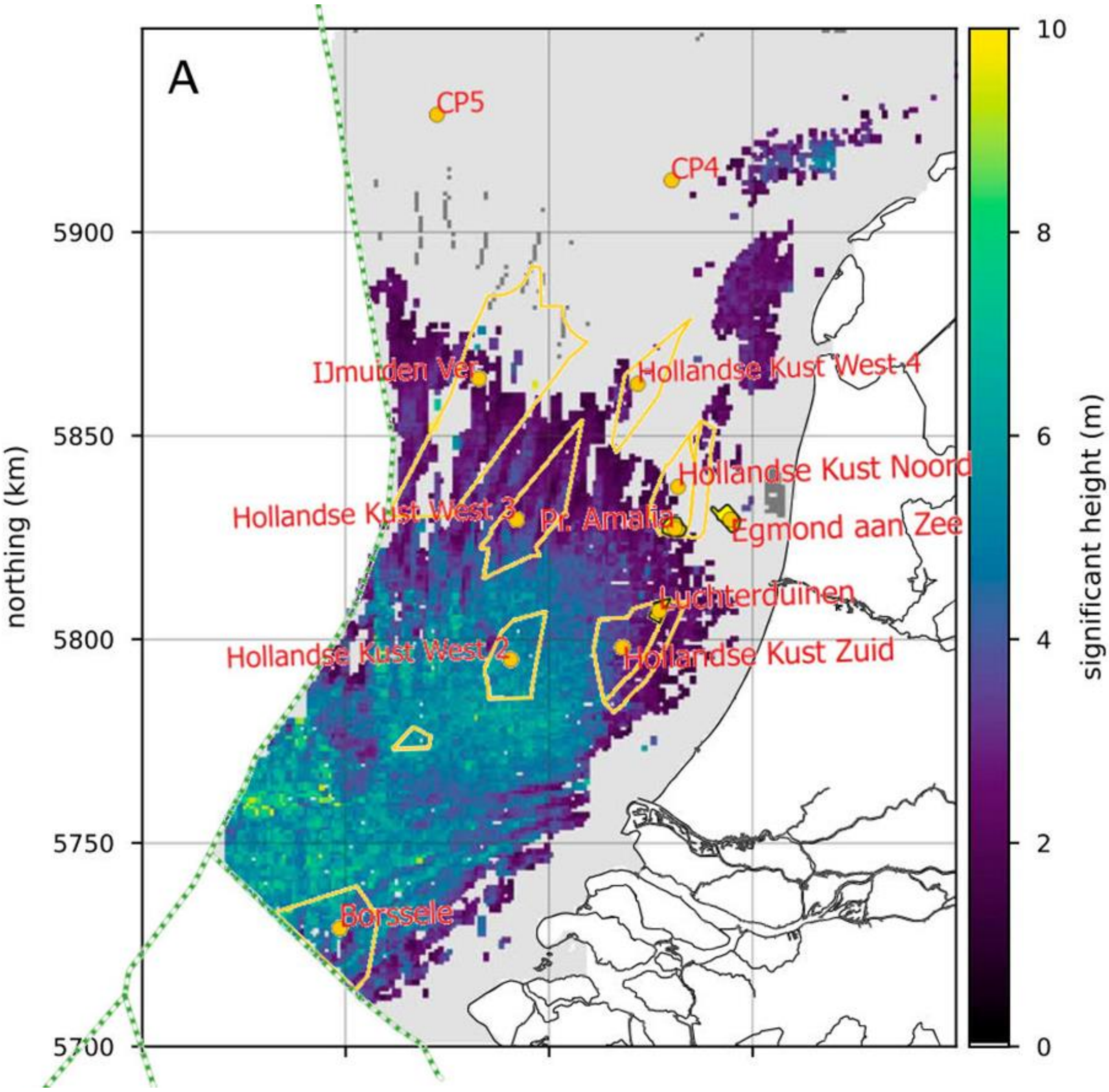

Figure 4. Significant height of sand waves in the Dutch coastal zone (taken from Damen et al.*, 2018) with the current wind farms superimposed.*

For the three additional locations this is rather different. Particularly in Hollandse Kust 2 there is a clear asymmetry, indicating that there is a clear direction in which the sand waves move. Hollandse Kust-3 appears to be very patchy, with areas that are more symmetrical and areas that appear to be more dynamic. IJmuiden Ver has sand waves in the southern half of the wind farm. These all are to a certain degree asymmetrical. The three relevant wind farms are discussed slightly more in depth below. Sand waves in these areas are lower than in Borssele, but they appear to be more mobile. Based on a quick scan of all three additional "Hollandse Kust" wind farm zones (Vermaas *et al*., 2017) sand waves in this park typically range between 2 and 5 metres in height, with an occasional extreme of about 7 m. and migrate 2-4 m. per year. The quick scan is not a comprehensive analysis over the whole surface area, but an analysis along a transect, indicated with the pink line in Figure 6.

Hollandse Kust West-2

Sand wave patterns indicate a clear north-easterly direction of movement. Most vertical dynamics fall in the range of -0.05 and 0.05 m/yr, with peaks around -0.15 and 0.15 m/yr. The average is therefore similar to the average vertical dynamics in Borssele, but the maximum is lower. However, there appear to be fewer places within this wind farm zone with very low dynamics, as is the case in Borssele. It is likely that a large part of this wind farm zone will see exceedance of the tolerance limit (0.8 cm / day) several times per year.

Hollandse Kust West-3

In this wind farm zone and waves have been investigated along 2 transects. The bed morphology in this wind farm zone is characterised by sand waves superimposed on sand banks. The sand banks are relatively stable; the sand waves can be mobile. Sand waves migrate in north-easterly direction. The level of mobility of sand waves is influenced by the relative position on the underlying sand banks. The sand banks are relatively low with heights of 5-10 m. Also the sand waves are relatively low (1-3 m high) in comparison with the heights of the sand waves in Hollandse Kust West 2. The sand waves on the sand banks are smaller than the sand waves in the troughs. Most vertical trends fall between -0.05 and 0.05 m/yr, with peaks around -0.1 and 0.1 m/yr. Sand waves in the troughs migrated approximately 3 m per year, while the sand waves on the peaks of the sand banks migrated approximately 6 m / year in transect 1. In transect 2 the average migration was 1.5 m/yr. Due to the presence of the sand banks this wind farm zone is more heterogeneous than Hollandse Kust West-2. Large parts are likely to be too dynamic, however, further analysis may indicate that there may be areas in this wind farm (particularly in the sand bank troughs) that are relatively stable.

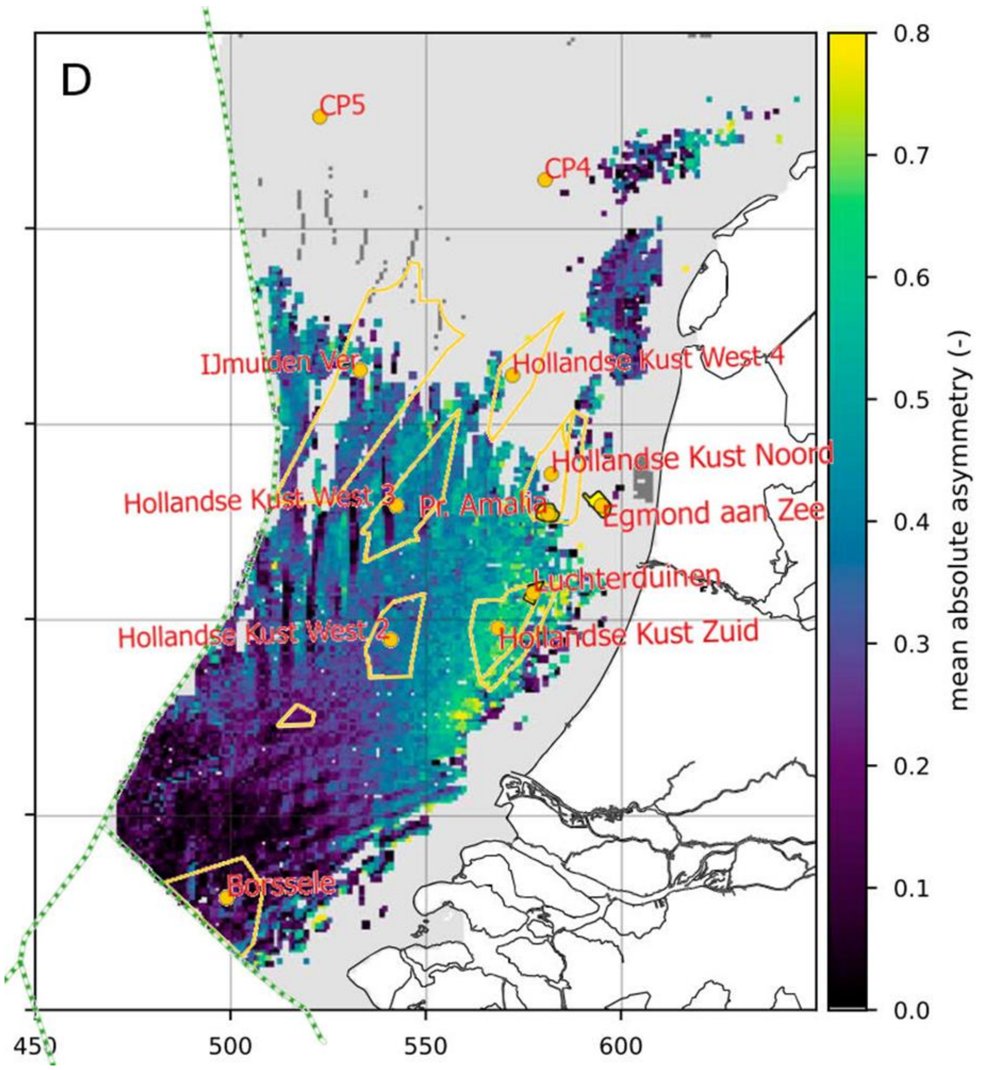

Figure 5. Mean absolute asymmetry of sand waves in the Dutch coast (based on the calculations of Damen et al *(2018).*

IJmuiden Ver

This wind farm zone is also characterised by sand banks, including part of the Brown Bank. In the southern part of this wind farm area sand waves are superimposed on the sand banks. The northern part (above the purple line in figure 6) is devoid of sand waves. South of this line sand waves vary in height between 1 and 3.5 meters, with lengths of a few hundreds of metres to over 1km. Sand waves travel in north-north-easterly direction. Net migration speed varies between 2-4 m/y. Analysis has been performed on 2 transects within the blue box in figure 6. Most vertical trends fall between -0.1 and 0.1 m/yr, with peaks around -0.15 and 0.15 m/yr. If suitable areas are sought within this wind farm it makes sense to do this in the northern part where sand waves are absent.

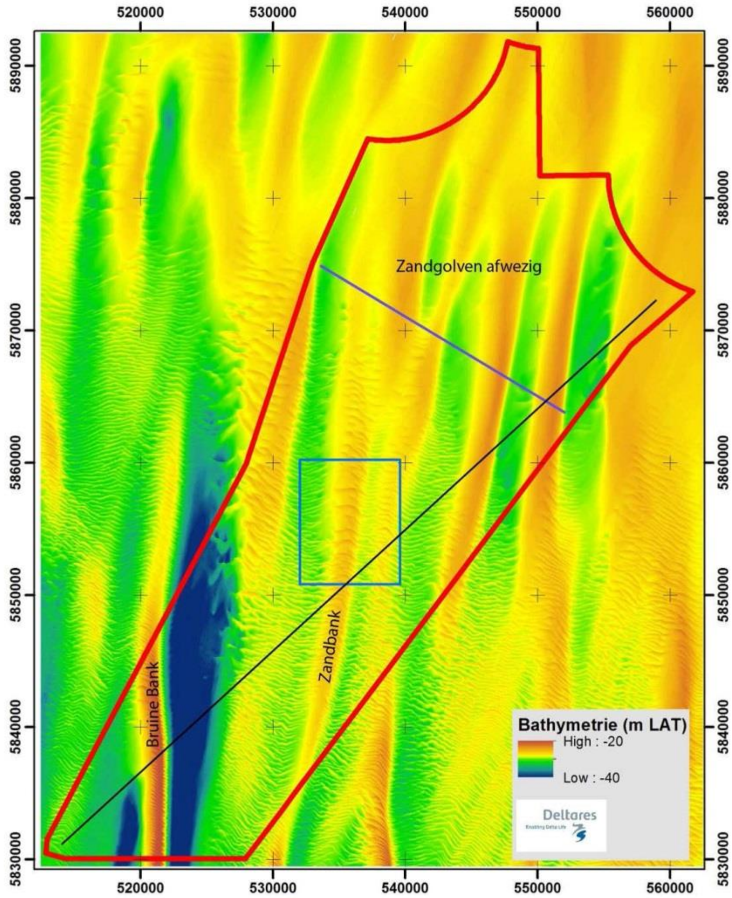

Figure 6. Bathymetry of the designated IJmuiden Ver Wind Farm Zone (Hijma and Hoekstra, 2016).

3.1.4 Suspended sediment

Average SPM concentrations only exceed 50 mg/l very near the coast, particularly in the Voordelta and in parts of the Wadden Sea (Fig. 7). Bivalves can withstand short periods of maximum SPM concentrations. Therefore, it was assumed that "average conditions" were most relevant. None of the investigated areas are thus unsuitable in terms of suspended matter.

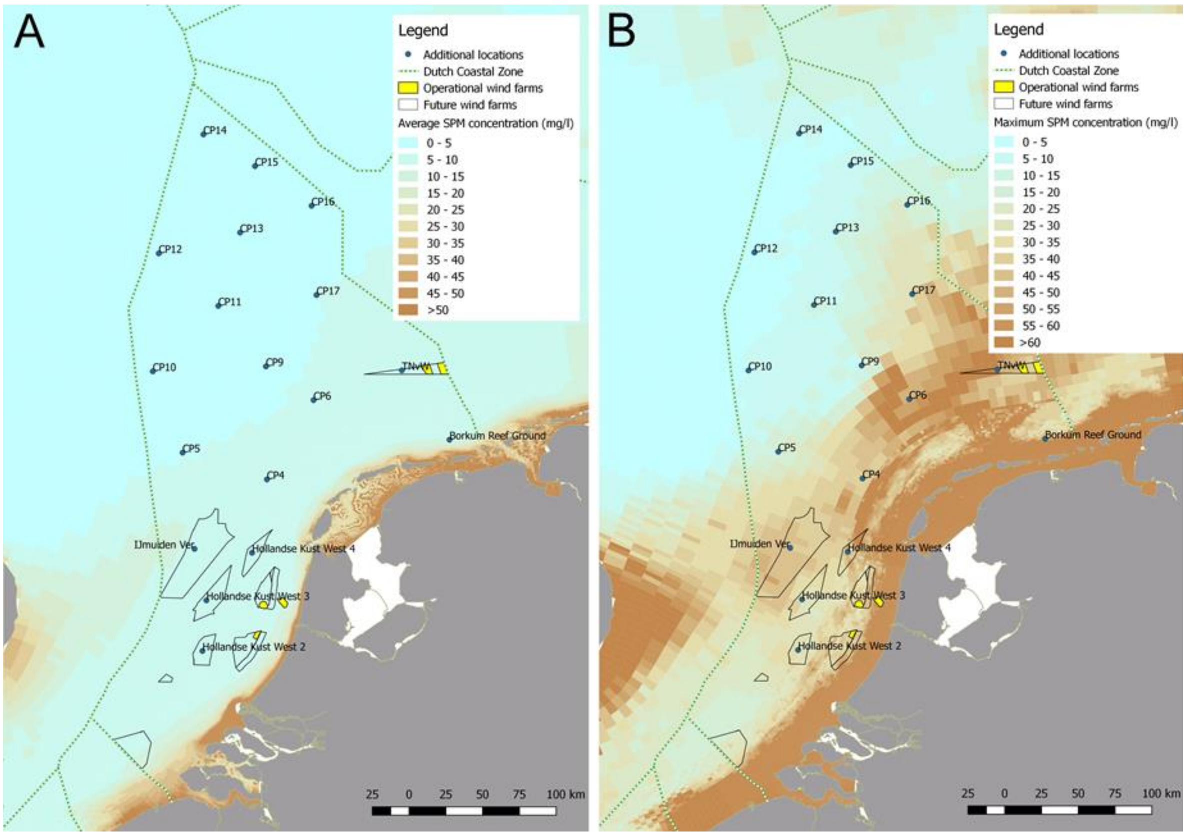

Figure 7. Average (A) and maximum (B) concentrations of SPM in the Dutch coastal zone over the period 2003-2011. Source of data Deltares ZUNO-DD model.

3.1.5 Temperature

Winter temperatures are higher than the required 3 ^{0}C at all locations. Summer temperatures are lower at the locations that are situated more off shore (CP10-CP17) (Fig 8). However, these are still above 14 ^{0}C, which is the minimum temperature for gonad development and spawning (Smaal *et al*., 2017).

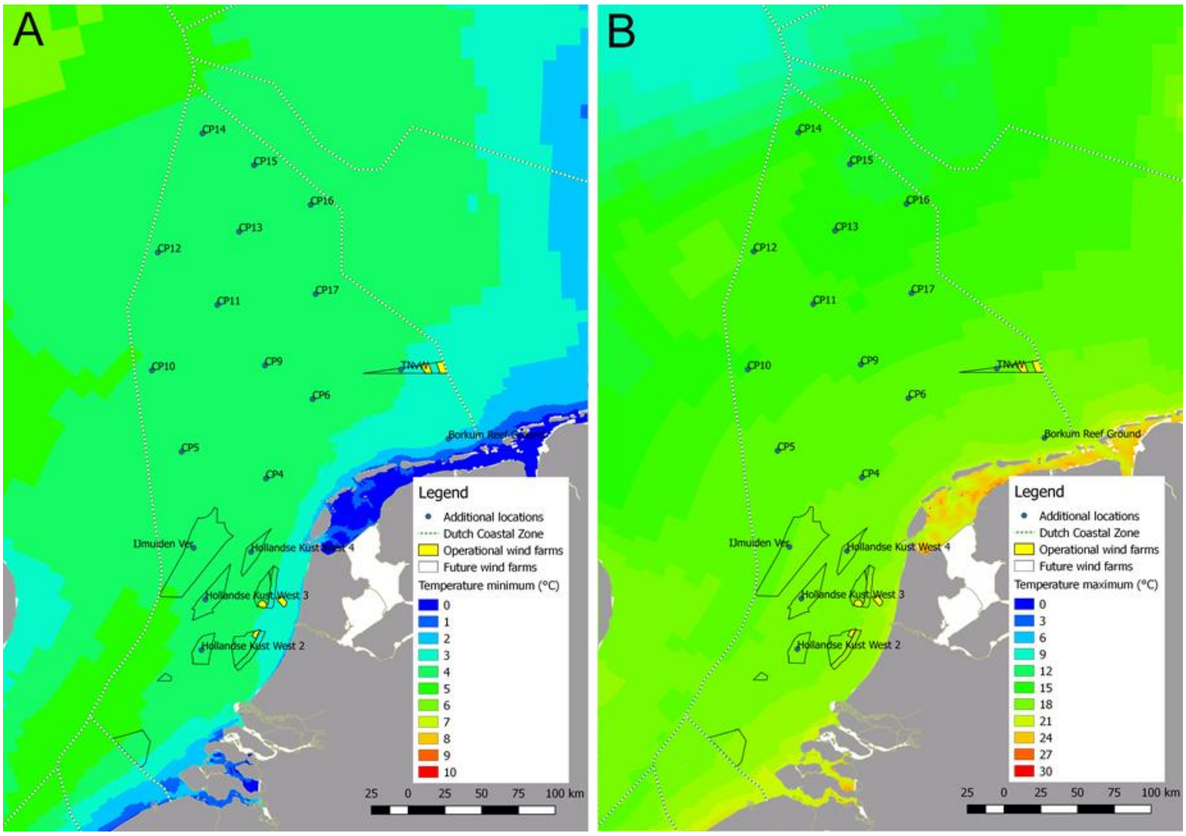

Figure 8. Minimum (A) and maximum (B) surface water temperature (period 2003-2011). Source: Deltares hydrodynamic model.

3.2 Biotic habitat characteristics

3.2.1 Food concentration

For the locations currently under investigation food may be limiting in some cases (Figure 9). Although there are no locations where the concentrations drop below 0.5 µg/l, some locations come very close, especially in winter. For gonad development the spring concentrations are relevant. There are 8 locations (indicated in red in Table 3) that do not meet the criterion of 1.7 µg/l. It is important to realise that these are surface data – we have no near-bottom data available that cover the whole North Sea. A large part of the Dutch continental shelf is seasonally stratified and concentrations near the bed will be lower. Stratification (when the water column has distinct layers of water that do not mix) can occur due to the influence of salinity and temperature. Freshwater is less dense than saltwater and warm water is less dense than cold water. Particularly in summer, when temperature stratification is more prevalent, there may be areas where the ambient concentrations will drop below this level near the bed. This is the most crucial period for the larval development. Table 3 lists the concentrations at the different stations, with the winter concentrations below 0.7 µg/l highlighted in yellow and the summer locations with concentrations lower than 1 also highlighted in yellow. Although the concentrations high in the water column are not limiting, particularly in summer the concentrations near the bed at these locations are likely to be significantly lower and possibly limiting. The North Sea can be divided into regions with specific stratification regimes (Figure 10). The southern part of the North Sea is shallow and some areas on the Dutch continental shelf are permanently mixed. However due to the influence of the Rhine, there is a 'region of freshwater influence' (ROFI) near the coast where water is always somewhat stratified due to salinity differences (indicated in orange in table 3 as semi-permanently stratified). Other areas are seasonally stratified (generally the whole of the summer period – indicated green in table 3), and some areas intermittently, depending on wind and weather conditions (indicated purple in table 3) and there are areas with no clear dominant regime. Here, stratification may occur occasionally, but a large part of the time it will be fully mixed (Van Leeuwen *et al*., 2015). We fitted the research locations on this map and indicated in table 3 which regime applied to the locations. Particularly the seasonal stratification in summer (green areas in Figure 10) will have a major impact on food supply for oysters, as well as on oxygen conditions. Occasional short periods of stratification are unlikely to reduce food supply by much. This means that locations such as "Buitengaats" and "Zee-energie", CP6, TNvW and CP9, which have relatively low chlorophyll concentrations, but no prolonged periods of stratification should still be suitable. Locations CP10 and CP16 are not only unsuitable because of low concentrations in spring, but also seasonally stratified conditions with low chlorophyll levels in summer.

It is also important to realise that chlorophyll is not the best indicator for carrying capacity for shellfish. Chlorophyll concentration (or biomass) is the resultant of primary production and algal mortality (quite often grazing). The current chlorophyll distribution is a reasonable first indicator for small scale oyster introductions. However, for significant populations (certainly the size of the historic one) the grazing of the oysters will have an impact on the chlorophyll concentration and possibly even on primary production itself. The large areas covered by oysters are less susceptible to resuspension of sediment (as the sediment is covered by the oyster beds). The light climate is likely to be better. Also, the grazing pressure of the oysters will have stimulated remineralisation of nutrients, making nutrients that were stored in algal biomass faster available for new primary production.

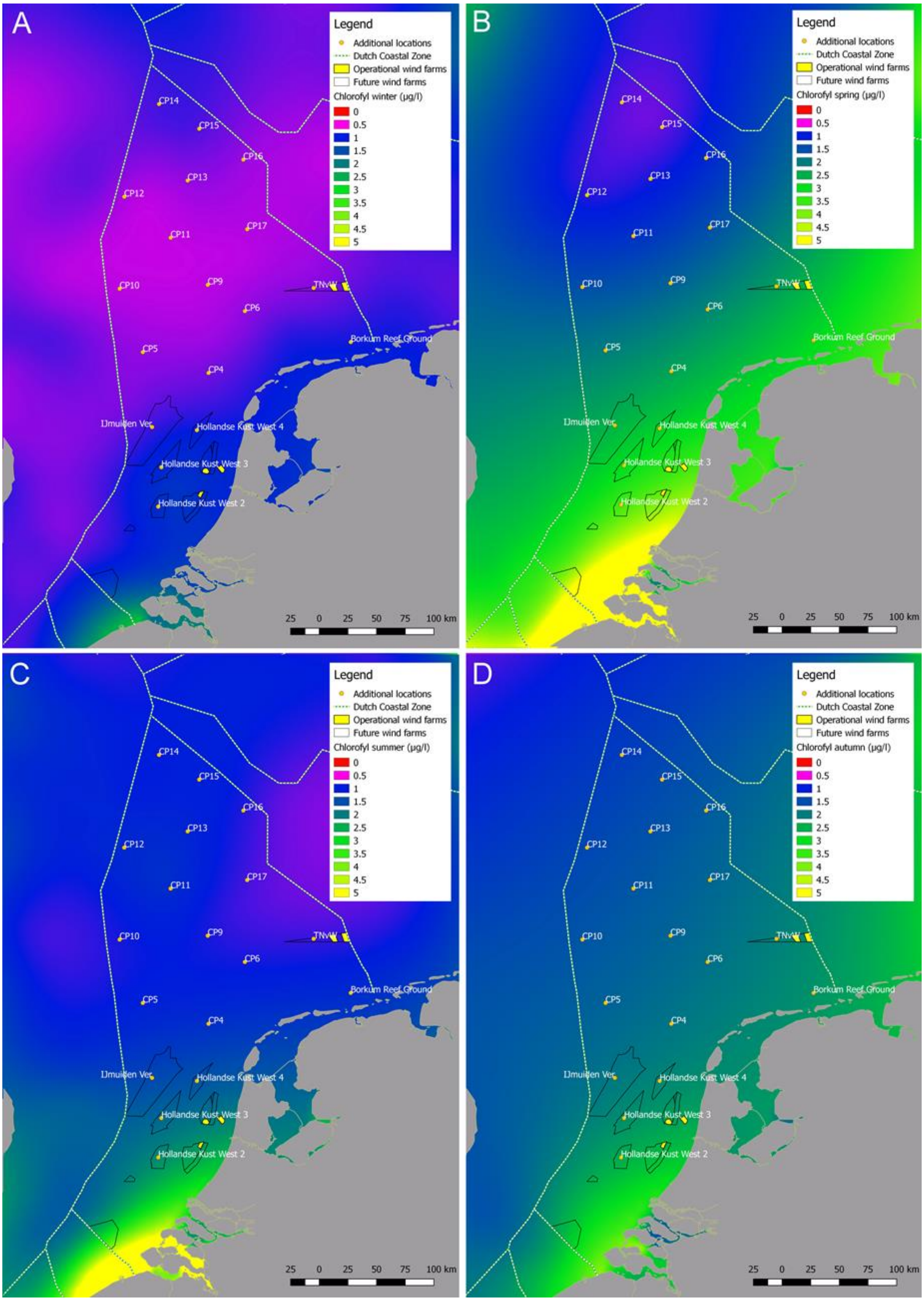

Figure 9. 10-year average chlorophyll a concentrations in the North Sea in winter (A), spring (B), summer (C) and autumn (D). Data downloaded from EMODNET (http://www.emodnet-chemistry.eu/products/catalogue#/), data from 2005-2015.

Table 3. Chlorophyll a concentrations in the upper water layer in winter, spring, summer and autumn and the annual average as well as the expected stratification regime at the locations of Smaal et al. *(2017) and the 18 additional locations. Spring concentration below 1.7 µg/l highlighted in pink, winter concentrations below 0.7 µg/l and summer concentrations below 1 µg/l highlighted in orange. Stratification is not limiting (seasonal, green) or of concern (intermittent, purple or semi-permanent, pink).*

Name	Chl*a* winter	Chl*a* spring	Chl*a* summer	Chl*a* autumn	Chl*a* annual average	Stratification
Egmond aan Zee	1.11	3.53	2.02	2.41	2.27	Semi-permanent
Pr. Amalia	1.14	3.43	1.98	2.37	2.23	Semi-permanent
Luchterduinen	1.17	3.81	2.26	2.56	2.45	Semi-permanent
Borssele	1.22	4.43	2.89	2.70	2.81	Intermittent
Holl. Kust Z	1.21	3.91	2.34	2.62	2.52	Semi-permanent
Holl. Kust N	1.12	3.26	1.86	2.29	2.13	Semi-permanent
Buitengaats	0.78	2.57	0.90	2.14	1.60	No clear regime
Zee-energie	0.76	2.49	0.89	2.10	1.56	No clear regime
Hollandse Kust West 2	1.17	3.56	2.13	2.48	2.33	Semi-permanent
Hollandse Kust West 3	1.11	3.01	1.78	2.18	2.02	Semi-permanent
Holalndse Kust West 4	0.99	2.84	1.56	2.09	1.87	Semi-permanent
IJmuiden Ver	0.88	2.57	1.45	1.95	1.71	Intermittent
CP4	0.77	2.40	1.20	1.91	1.57	Semi-permanent
CP5	0.70	2.01	1.05	1.73	1.37	Intermittent
CP6	0.70	2.09	0.96	1.87	1.41	No clear regime
TNvW	0.73	2.35	0.89	2.03	1.50	No clear regime
Borkum Reef Ground	0.97	2.95	1.15	2.22	1.82	Intermittent
CP9	0.63	1.71	0.95	1.74	1.26	No clear regime
CP10	0.63	1.52	0.96	1.58	1.17	Intermittent
CP11	0.61	1.22	1.16	1.59	1.14	No clear regime
CP12	0.66	0.93	1.12	1.43	1.04	Intermittent
CP13	0.70	0.95	1.09	1.53	1.07	Seasonal
CP14	0.86	0.82	1.01	1.33	1.00	No clear regime
CP15	0.83	0.81	1.04	1.47	1.04	Seasonal
CP16	0.69	1.11	0.93	1.63	1.09	Seasonal
CP17	0.64	1.52	0.87	1.75	1.19	No clear regime

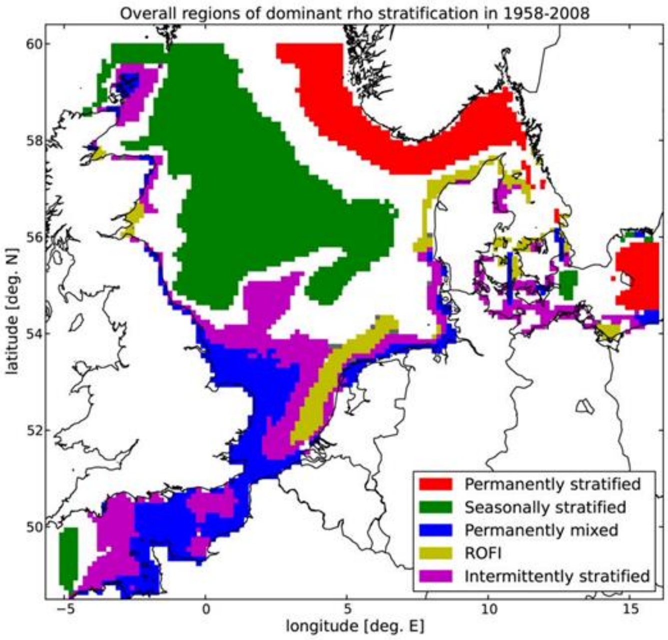

Figure 10. Modelled stratification regime in the North Sea (Van Leeuwen et al.*, 2015). The white areas indicate where the dominant regime occurs for less than 50% of the time (less visible due to minimal occurrence).*

Another issue regarding oyster restoration in relation to wind farms and food availability is potential competition with other bivalves such as mussels (*Mytilus edulis*) and possibly Pacific oysters (*Magallana gigas*). Currently (and in the past) mussel beds only occurred at the edges of the North Sea, in shallow areas such as the Wadden Sea and the Oosterschelde. However, mussels are observed on buoys throughout the North Sea (Steenbergen *et al*., 2005). In the current wind farms large concentrations of mussels are observed on the turbine piles, in the upper few meters. They generally occur at a depth of 2-5 meters, i.e. within the photic zone, but outside the major influence of breaking surface waves. A recent scenario study indicated that the potential biomass of mussels on the planned wind farms in the North Sea would have a major effect on chlorophyll levels (differences of >10%) and potentially even on primary production (Slavik *et al*., 2017). The carrying capacity of the North Sea for oysters in wind farms is clearly dependent on the competition with mussels. In order to assess what can realistically be expected in terms of carrying capacity for oysters in the current or the future North Sea with large scale wind farms present and the associated mussel population, very different model runs are required.

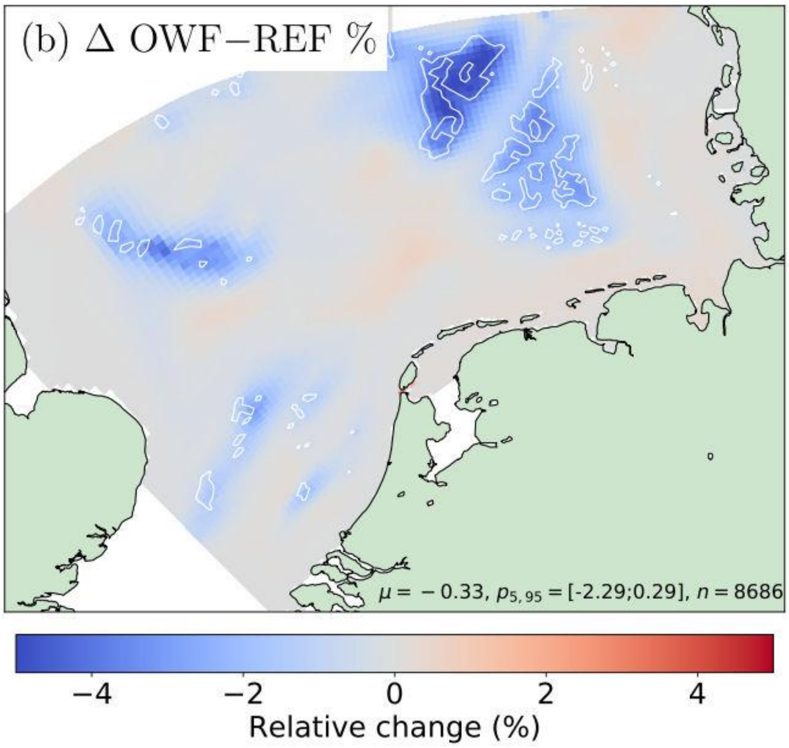

Figure 11. Effect of mussel biomass in wind farms on primary production (Slavik et al*. 2017).*

3.2.2 Larval retention

With the model assumptions, which do not take larval behaviour into account, the model predicts dispersal, but also retention of larvae in a certain area. Dispersal can be important for seeding other areas while retention is important to ensure maintenance of the introduced population. Due to the effect of the 'coastal river', the northward residual flow along the Dutch west coast, larval dispersal is larger in northerly direction than in southerly direction. This effect is stronger closer to the shore than off shore. Larval retention is low at Hollandse Kust West 4, IJmuiden Ver location and CP4 (Fig. 12C,D,E). Moderate larval retention is observed at CP5, CP11 and Borkum Reef Ground. All other locations show high larval retention, which makes them suitable for oyster restoration for this aspect. Larvae from Borkum Reef Ground and TNvW (Fig. 12H) can reach the German part of the North Sea. It is important to realise that model resolution does not resolve local hydrodynamic features. Due to the complex local topography it is possible that larvae are retained more in the vicinity of the release location due to local hydrodynamic features such as eddies. Also, the fact that larval behaviour is not taken into account may lead to differences. If larvae actively influence their position in the water column near the bottom dispersal may be reduced (Jonsson *et al*., 1991). The dispersal patterns produced by the model are likely maximum ranges (with the assumption of a larval stage of 10 days).

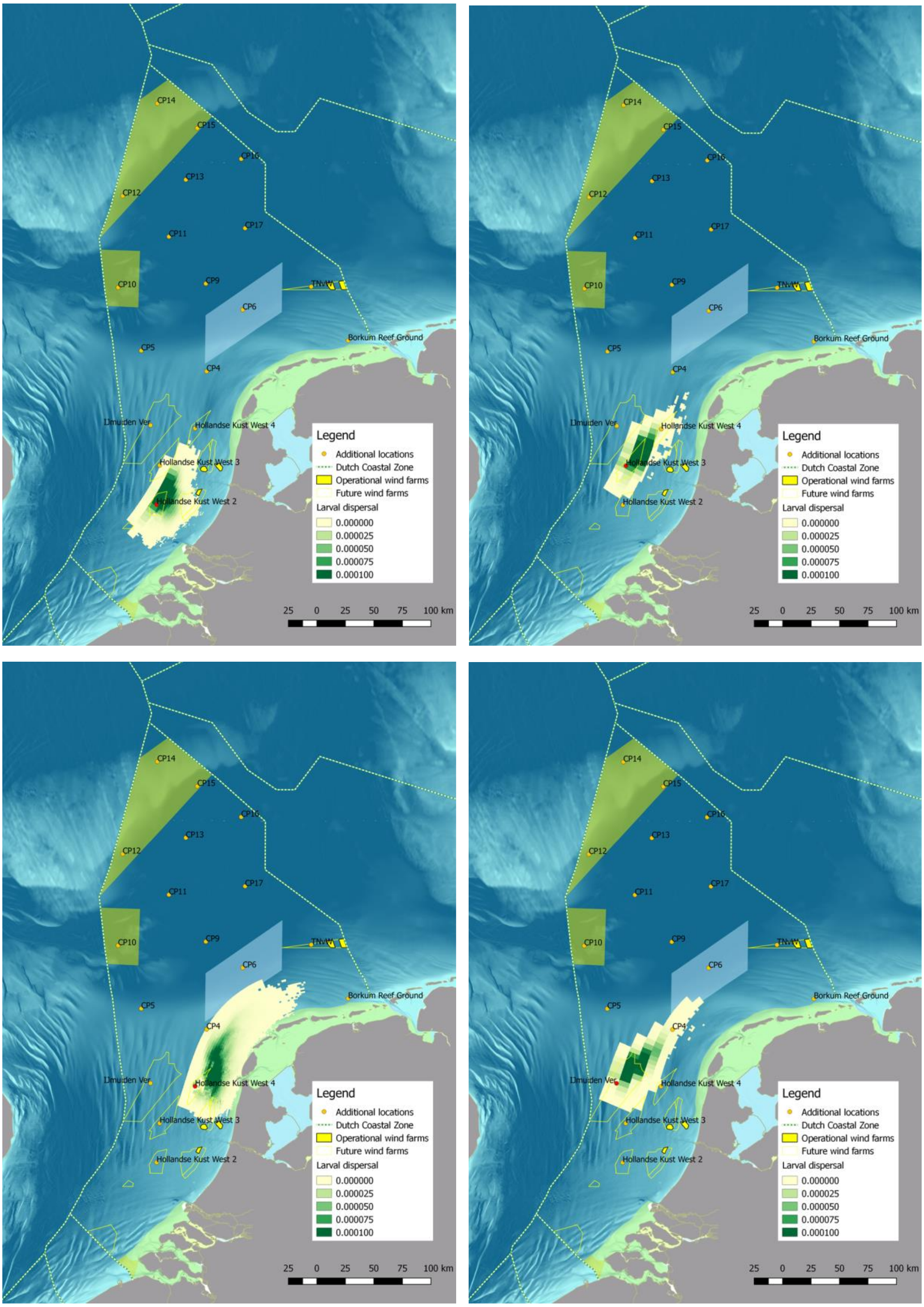

Figure 12 A-D. Larval dispersal from release locations indicated with red dots.

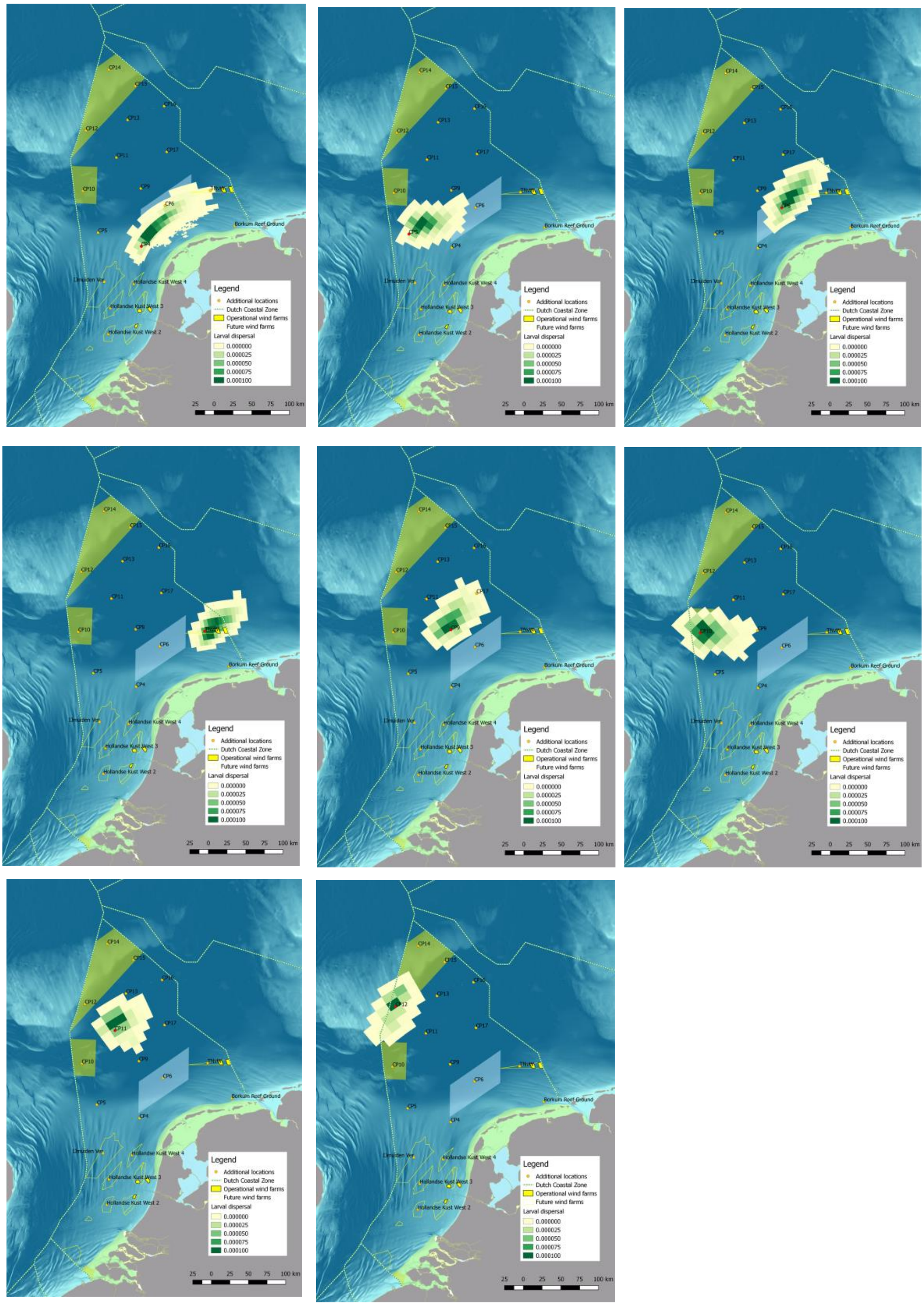

Figure 12 E-L. Larval dispersal from release locations indicated with red dots.

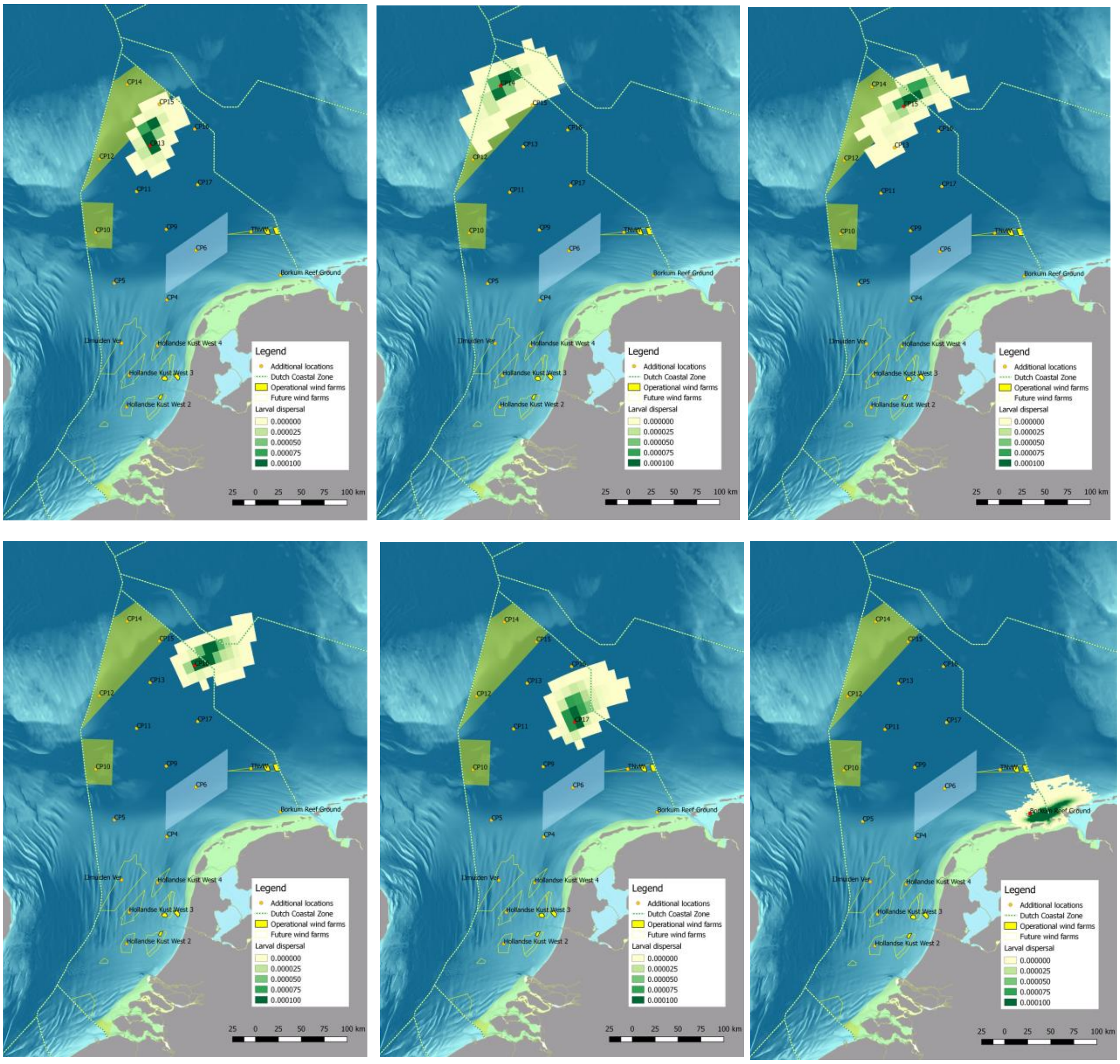

Figure 12 M-R. Larval dispersal from release locations indicated with red dots.

3.3 Historical occurrence

Historically dense aggregations of oysters used to occur on the so-called "Oyster Grounds". The current Gemini wind farm (i.e. "Buitengaats" and "Zee-energie") and potential location TNvW are located right in the middle of this area that also includes locations CP6 and CP9 (Fig. 13). CP17 and the location on the Borkum Reef Ground are located at the edge of the oyster grounds in an area where oysters appeared to occur regularly, though more patchily. CP4 and CP5 are located just outside the main area for oysters. Another area with high densities of oysters was located just south-west of the Doggerbank. The largest part of this area is part of the British North Sea, but a small part extended in the Dutch Continental Shelf. Location CP10 is relatively close. The other current wind farms as well as the concession areas that are currently under investigation, as well as locations CP11 – CP16 are all in areas where oysters have never been observed to be dominant.

It is noteworthy that the Olsen map is not comprehensive. As mentioned in Smaal *et al*. (2017) there are also anecdotal historical references to small oyster beds in the vicinity of the Borssele Wind Farm Zone, and in front of the Scheveningen coast. However, these were not the large continuous aggregations, as indicated in the Piscatorial Atlas by Olsen (1883).

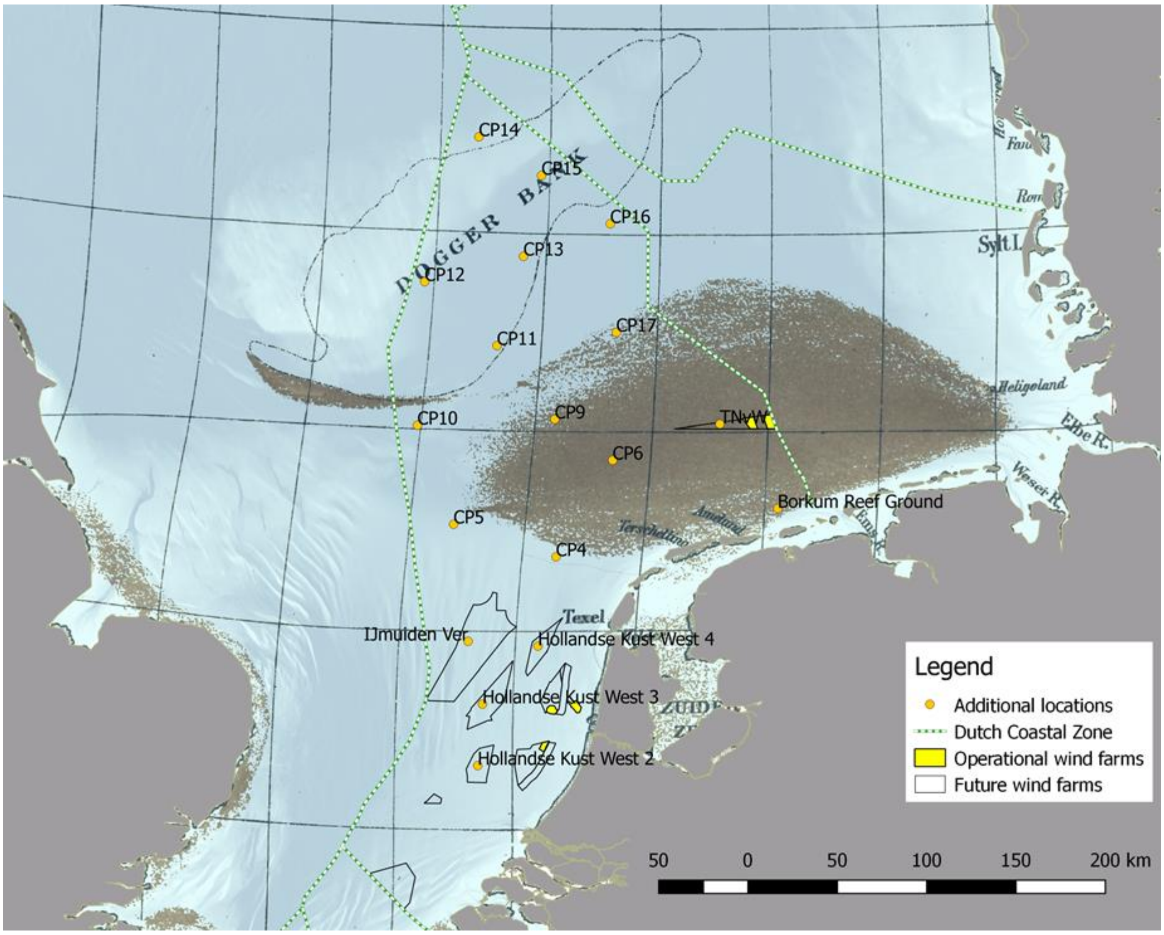

Figure 13. Historical distribution of the European flat oyster (Ostrea edulis) in the North Sea, based on the map in the Piscatorial Atlas by Olsen (1883). The brownish grey colours indicate where oysters and oyster beds have been observed. Not this represents the former distribution of oysters, which is not entirely the same as the map indicating where in the North Sea the seabed consisted virtually completely of oysters.

4 Conclusions and recommendations

To determine the relative suitability for development of self-sustaining European flat oyster (*Ostrea edulis*) beds, the locations for Offshore Wind Energy and other parts of the Dutch EEZ were analysed following Smaal *et al* (2017). Biotic and abiotic factors of importance for *O. edulis* survival, growth, reproduction and recruitment were compared for the 8 locations of Smaal *et al* (2017) and 18 additional locations. For the locations on the Dutch part of the EEZ the following factors are important: shear stress, suspended sediment, larval retention, temperature, sediment composition and food availability. Presence in historic distribution area was used as verification. Table 4 summarises the results. Average shear stress, suspended sediment and temperature are within the range considered suitable for the development of an oyster bed for all locations. Thus, these factors do not discriminate between locations. Maximum shear stress is too high for the nature area location Borkum Reef Ground. However, this is a highly heterogeneous area with large stones present that may create local shelter from hydrodynamic forces. In addition, the sediment is too silty at Zee-Energie and the remaining lot of TNvW, CP5, CP6, CP11, CP13 and CP17. Oyster restoration efforts may make the environment more suitable, e.g. by placing shell material or 3D structures which elevate the oysters from the bottom.

Only 7 of the 26 studied locations overlap with the historic distribution of the oysters. These are Borselle, Buitengaats (Gemini) and Zee-energie (Gemini), the remaining lot of the North of the Frysian Islands (TNvW), CP6, CP9 and CP17. An overlap with the historic distribution is no guarantee that conditions are suitable today as well, because circumstances will most probably have changed. For example, removal of the oysters beds (and their filter feeding activity) will have changed sediment capture and resuspension in the area. In the present study, the most important discriminating factors are larval retention and food availability. Based on low food availability or stratification the off-shore locations CP10-17 are considered less suitable. When selecting locations with medium and high larval retention the following locations remain: Egmond aan Zee, Prinses Amalia, Luchterduinen, Borssele, Hollandse Kust (zuid), Hollandse Kust (noord), Buitengaats, Hollandse Kust West 2, Hollandse Kust West 3, CP9. In Hollandse Kust West 3 bed mobility is probably too high.

Based on the analysis described in this report we recommend to select one of the following locations that are suitable for flat oyster restoration (Fig. 14).

1. Best: Borssele Wind Farm Zone (Borssele), Buitengaats (part of Gemini wind park) and CP9 (within historic distribution and high larval retention);
2. Very good: Hollandse Kust (zuidwest) (Hollandse Kust West 2) (high larval retention);
3. Good: Offshore Windpark Egmond aan Zee (Egmond aan Zee), Princes Amalia windpark (Prinses Amalia), Windpark Eneco Luchterduinen (Luchterduinen), Hollandse Kust (zuid) Wind Farm Zone (Hollandse Kust Zuid), Hollandse Kust (noord) Wind Farm Zone (Hollandse Kust Noord) (medium larval retention);
4. Suitable: a remaining lot of the North of the Frysian Islands Wind Farm Zone (TNvW), Zee-energie (part of Gemini wind park), Borkum Reef Ground (within historic distribution, medium or high larval retention, but locally too high maximum shear stress or too silty);
5. Suitable with introduction of substrate: CP5, CP6 (medium or high larval retention, but too silty without the introduction of substrate).

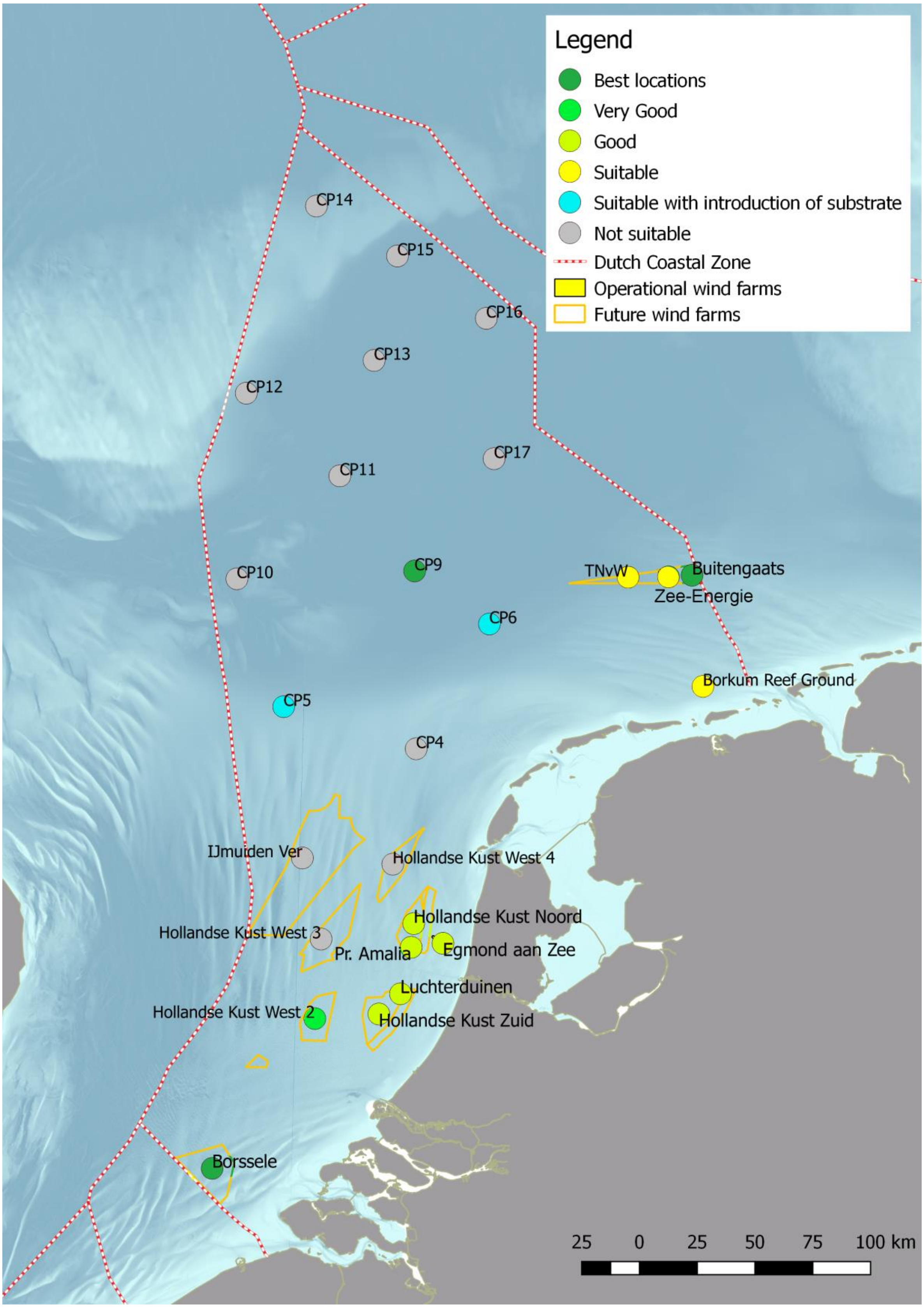

*Figure 14. Overall suitability of all wind energy at sea locations (including those analysed in Smaal et al., 2017) and other parts of the Dutch Exclusive Economic Zone for development of an European flat oyster (*Ostrea edulis*) bed.*

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Table 4. Summary of habitat characteristics for flat oysters based on shear stress (average and maximal tau in N/m²), suspended sediment (average in mg/l), larval retention, temperature (winter, Tmin ⁰C; summer, Tmax ⁰C), presence in historic distribution area, sediment composition and food availability.

location	shear stress avg.	shear stress max.	suspended sediment avg.	larval retention	Tmin	Tmax	historic distribution	sediment	food availability and oxygen
OWEZ (Egmond aan Zee)	0.8	8.7	20	medium	3	20	no	fine sand	OK
Prinses Amalia	0.6	7.1	10	medium	3	18	no	fine sand	OK
Luchterduinen	0.6	6.7	10	medium	3	20	no	fine sand	OK
Borssele	0.6	3.4	10	high	4	20	yes	coarse to fine sand	OK
Hollandse kust zuid	0.5	5.9	10	medium	4	18	no	fine sand	OK
Hollandse kust noord	0.6	6.8	10	medium	4	18	no	fine sand	OK
Gemini: Buitengaats	0.3	6.0	10	high	3	18	yes	fine sand	OK
Gemini: Zee-energie	0.3	5.6	10	high	3	18	yes	silty sand	OK
Hollandse Kust West 2	0.5	4.2	5-10	high	4	18	no	fine sand	OK
Hollandse Kust West 3	0.5	4.7	5-10	high	4	18	no	coarse sand	OK
Hollandse Kust West 4	0.5	6.2	5-10	low	4	18	no	coarse sand	OK
IJmuiden Ver	0.5	5.2	5-10	low	4	18	no	coarse sand	OK
CP4	0.4	6.6	5-10	low	4	18	no	fine sand	OK
CP5	0.2	4.5	0-5	medium	4	18	no	silty sand	OK
CP6	0.2	4.1	5-10	high	4	18	yes	silty sand	OK
TNvW	0.3	5.1	5-10	high	4	18	yes	silty sand	OK
Borkum Reef Ground	0.6	11.6	10-15	medium	4	18	no	fine sand	OK
CP9	0.1	3.2	0-5	high	4	15	yes	fine sand	OK
CP10	0.1	2.6	0-5	high	4	15	no	gravel	low food in spring
CP11	0.1	3.9	0-5	medium	4	15	no	silty sand	low food in spring
CP12	0.3	6.7	0-5	high	4	15	no	fine sand	low food in spring
CP13	0.1	3.7	0-5	high	4	15	no	silty sand	low food in spring, stratification in summer
CP14	0.2	5.6	0-5	high	4	15	no	fine sand	low food in spring
CP15	0.2	5.8	0-5	high	4	15	no	fine sand	low food in spring, stratification in summer
CP16	0.2	4.3	0-5	high	4	15	no	fine sand	low food in spring, stratification in summer
CP17	0.1	3.5	0-5	high	4	15	yes	silty sand	low in spring

5 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2008 certified quality management system (certificate number: 187378-2015-AQ-NLD-RvA). This certificate is valid until 15 September 2018. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V.

Furthermore, the chemical laboratory at IJmuiden has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2021 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation. The chemical laboratory at IJmuiden has thus demonstrated its ability to provide valid results according a technically competent manner and to work according to the ISO 17025 standard. The scope (L097) of de accredited analytical methods can be found at the website of the Council for Accreditation (www.rva.nl).

On the basis of this accreditation, the quality characteristic Q is awarded to the results of those components which are incorporated in the scope, provided they comply with all quality requirements. The quality characteristic Q is stated in the tables with the results. If, the quality characteristic Q is not mentioned, the reason why is explained.

The quality of the test methods is ensured in various ways. The accuracy of the analysis is regularly assessed by participation in inter-laboratory performance studies including those organized by QUASIMEME. If no inter-laboratory study is available, a second-level control is performed. In addition, a first-level control is performed for each series of measurements.
In addition to the line controls the following general quality controls are carried out:

- Blank research.
- Recovery.
- Internal standard
- Injection standard.
- Sensitivity.

The above controls are described in Wageningen Marine Research working instruction ISW 2.10.2.105. If desired, information regarding the performance characteristics of the analytical methods is available at the chemical laboratory at IJmuiden.

If the quality cannot be guaranteed, appropriate measures are taken.

References

Damen, J. M., van Dijk, T. A. G. P., and Hulscher, S. J. M. H. (2018). Spatially Varying Environmental Properties Controlling Observed Sand Wave Morphology. *Journal of Geophysical Research* 123, 19.

Duchêne J, I Bernard, S Pouvreau (2015) Programme d'Expérimentation et de recherche sur L'huître plate *Ostrea edulis* Vers un retour de l'huître indigène en rade de Brest. Version complète de l'article paru dans la revue Espèces n° 16 – 2015 aux éditions Kyrnos Publications.

Greenwood N., E. R. Parker, L. Fernand, D. B. Sivyer, K. Weston, S. J. Painting, S. Kroger, R. M. Forster, H. E. Lees, D. K. Mills, and R.W. P. M. Laane (2010) Detection of low bottom water oxygen concentrations in the North Sea; implications for monitoring and assessment of ecosystem health Biogeosciences, 7, 1357–1373,

Hijma, M., and Hoekstra, R. (2016). "IJmuiden Ver: Quickscan bathymetrie en morfo- en hydrodynamiek." Deltares, Delft.

Jonsson, P.R., C. Andre, M. Lindegarth (1991) Swimming flume behaviour of marine bivalve larvae in a boundary-layer flow: evidence for near-bottom confinement. Mar. Ecol. Prog. Ser.79: 67-76.

Knights, A., Crowe, T., Burnell, G., 2006. Mechanisms of larval transport: vertical distribution of bivalve larvae varies with tidal conditions. Mar. Ecol. Prog. Ser. 326, 167–174. http://dx.doi.org/10.3354/meps326167.

Lengkeek, W., Didderen, K., Teunis, M., Driessen, F., Coolen, J.W.P., Bos, O.G., Vergouwen, S.A., Raaijmakers, T.C., De Vries, M.B. & Van Koningsveld, M. (2017). Eco-friendly design of scour protection: potential enhancement of ecological functioning in offshore wind farms: towards an implementation guide and experimental set-up. Report nr 17-001 Bureau Waardenburg. Culemborg: Bureau Waardenburg; http://www.buwa.nl/fileadmin/buwa_upload/Bureau_Waardenburg_rapporten/17-001_Bureau_Waardenburg_report_EcoFriendly_design_scour_protection.pdf.

Ministerie van Economische Zaken [Min. EZ] (2014). Natuurambitie Grote Wateren 2050 en verder. Den Haag. https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/publicaties/2013/10/31/beleidsverkenning-natuurambitie-grote-wateren-2050-2010/natuurambitie-grote-wateren-2050-en-verder-dec-2014.pdf

Ministerie van Economische Zaken en Klimaat [Min. EZK] (2018). Brief van de Minister van Economische Zaken en Klimaat d.d. 27 maart 2018 over de routekaart windenergie op zee 2030. Tweede Kamer, vergaderjaar 2017–2018, 33 561, nr. 42. https://zoek.officielebekendmakingen.nl/kst-33561-42.html

Ministerie van Economische Zaken & Ministerie van Infrastructuur en Milieu [Min. EZ & Min. IenM] (2013). Brief van de Staatssecretarissen van Economische Zaken en Infrastructuur en Milieu, mede namens de Minister voor Buitenlandse Handel en Ontwikkelingssamenwerking, over de Uitvoeringsagenda Natuurlijk Kapitaal: behoud en duurzaam gebruik van biodiversiteit. Tweede Kamer, vergaderjaar 2012–2013, 26 407, nr. 85; https://zoek.officielebekendmakingen.nl/kst-26407-85.html.

Ministerie van Infrastructuur en Milieu & Ministerie van Economische Zaken [Min. IenM & Min. EZ] (2014a). Noordzee 2050 Gebiedsagenda. Den Haag. https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2014/07/28/verslag-noordzee-2050-gebiedsagenda/verslag-noordzee-2050-gebiedsagenda.pdf

Ministerie van Infrastructuur en Milieu & Ministerie van Economsiche Zaken [Min. IenM & Min. EZ] (2014b). Rijksstructuurvisie Windenergie op Zee; Partiële herziening van het Nationaal Waterplan Hollandse Kust en Ten Noorden van de Waddeneilanden. Den Haag; https://www.noordzeeloket.nl/publish/pages/122850/rijksstructuurvisie_windenergie_op_zee_3390.pdf

Ministerie van Infrastructuur & Milieu & Ministerie van Economische Zaken [Min. IenM & Min. EZ] (2015a). Beleidsnota Noordzee 2016-2021. Den Haag. https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/beleidsnota-s/2015/12/14/beleidsnota-noordzee-2016-2021/nz-nl-beeldscherm.pdf.

Ministerie van Infrastructuur en Milieu & Ministerie van Economische Zaken [Min. IenM & Min. EZ] (2015b). Mariene Strategie voor het Nederlandse deel van de Noordzee 2012-2020, deel 3. Den Haag; https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/beleidsnota-s/2015/12/14/mariene-strategie-voor-het-nederlandse-deel-van-de-noordzee-2012-2020-deel-3/mariene-strategie-voor-het-nederlandse-deel-van-de-noordzee-2012-2020-deel-3.pdf.

Ministerie van Infrastructuur en Milieu & Ministerie van Economische Zaken, Landbouw en Innovatie [Min. IenM & Min. EL&I] (2012). Mariene Strategie voor het Nederlandse deel van de Noordzee 2012-2020, Deel 1. Den Haag; https://www.noordzeeloket.nl/publish/pages/122603/mariene_strategie_voor_het_nederlandse_deel_van_de_noordzee_2012-2020_deel_i_682.pdf.

Olsen, O.T., 1883. The Piscatorial Atlas of the North Sea and St. George's Channels. Taylor and Francis, London

Queste BY, L Fernand, TD Jickells, KJ Heywood, and AJ Hind (2016) Drivers of summer oxygen depletion in the central North Sea Biogeosciences, 13, 1209–1222.

Slavik, K., Lemmen, C., Zhang, W., Kerimoglu, O., K., K., and Wirtz, K. W. (2017). The large scale impact of offshore windfarm structures on pelagic primary production in the southern North Sea. *Hydrobiologia* in press.

Smaal, A., Kamermans, P., Kleissen, F., Van Duren, L. & Van der Have, T. (2017). Platte oesters in offshorewindparken (POP): mogelijkheden voor de ontwikkeling van platteoesterpopulaties in bestaande en geplande windmolenparken in het Nederlandse deel van de Noordzee. Rapport C035/17 Wageningen Marine Research; http://library.wur.nl/WebQuery/wurpubs/fulltext/412950.

Sociaal-Economische Raad [SER] (2013). Energieakkoord voor duurzame groei. Den Haag. http://www.ser.nl/~/media/files/internet/publicaties/overige/2010_2019/2013/energieakkoord-duurzame-groei/energieakkoord-duurzame-groei.ashx

Steenbergen J., M.C.J. Verdegem, J.J. Jol, J. Perdon, P. Kamermans, V.G. Blankendaal, A.C. Sneekes, A.G. Bakker, H. van 't Groenewoud, G. Hoornsman (2005) Verkenning van mogelijkheden voor mosselteelt op open zee & een mosselkansenkaart voor de Noordzee. RIVO Rapport C088/05

Van der Kaaij, T., Van Kessel, T., Troost, T., Van Duren, L. A., and Villars, M. T. (2017). "Modelondersteuning MER winning suppletie- en ophoogzand Noordzee 2018 – 2027; Modelvalidatie " Rep. No. 1230888-002. Deltares, Delft.

van Dijk, T. A. G. P., Van der Tak, C., De Boer, W. P., Kleuskens, M. H. P., Doornenbal, P. J., Noorlandt, R. P., and Marges, V. C. (2011). "The scientific validation of the hydrographic survey policy of the Netherlands Hydrographic Office, Royal Netherlands Navy.," Rep. No. 1201907-000-BGS-0008. Deltares, Delft.

Van Duren, L.A., Gittenberger, A., Smaal, A.C., Van Koningsveld, M., Osinga, R., Cado van der Lelij, J.A. & De Vries, M.B. (2016). Rijke riffen in de Noordzee: verkenning naar het stimuleren van natuurlijke riffen en gebruik van kunstmatig hard substraat. Delft: Deltares; http://publications.deltares.nl/1221293_000.pdf.

Van Leeuwen, S., Tett, P., Mills, D., and van der Molen, J. (2015). Stratified and nonstratified areas in the North Sea: Long-term variability and biological and policy implications. *J. Geophys. Res.* **120**, 4670-4686.

Vermaas, T., Hijma, M., and Hoekstra, R. (2017). "Quickscans wind zones Hollandse Kust West 2-4." Deltares, Delft.

VVD, CDA, D66 en ChristenUnie (2017). Vertrouwen in de toekomst. Regeerakkoord 2017 – 2021 https://www.kabinetsformatie2017.nl/binaries/kabinetsformatie/documenten/publicaties/2017/10/10/regeerakkoord-vertrouwen-in-de-toekomst/Regeerakkoord+2017-2021.pdf

Justification

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The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

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Date: 26 July 2018

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