Rijkswaterstaat
Ministry of Infrastructure and Water Management

RWS INFORMATION

Marine Strategy Framework Directive descriptors in relation to OWFs and Framework for Assessing Ecological and Cumulative Effects (KEC 5.0)

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Contents

1 Introduction and scope

This chapter describes the development directions concerning the effects of offshore wind on the 11 Marine Strategy Framework Directive (MSFD) descriptors. The main question is whether there is sufficient knowledge to verify any possible effects on the 11 MSFD descriptors and associated criteria. Additionally, if effects cannot be verified suggestions for further research are indicated and specified where possible. For each criterion under the descriptors, it is mentioned what it contains, and how the Good Environmental Status (GES) is defined. The GES is the final state to be pursued.

. There are three phases in the 'life cycle' of an OWF, each with its potential effects. These are:

1. construction phase
2. operational phase
3. decommissioning phase.

For all descriptors, the key question is: is a potential effect (qualitatively) verifiable and if not, is additional research required?

2 Exploration by descriptor

2.1. D1 Marine biodiversity

Introduction

Descriptor 1 (D1) pertains to the biological diversity of marine ecosystems. Specifically, it focuses on the need to maintain biodiversity in the marine environment, ensuring that the quality and occurrence of habitats and the distribution and abundance of species are in line with the prevailing physiographic, geographic and climatic conditions. For all species groups mentioned the criterion D1C1 'Incidental Bycatch', in the context of offshore wind development, is considered neutral as offshore wind is not fishery.

Marine mammals

1) Conclusion

During construction the distribution and abundance of marine mammals can be substantially affected by underwater noise, and these effects must be minimalized to minimize the pressures on the populations of marine mammals. How operational wind farms affect the distribution of marine mammals and how it affects their habitat quality are essential questions that need to be answered. Additional research into these topics is therefore required.

2) Criteria

a) D1C1 Incidental bycatch

The development of OWFs is neutral for this criterion, as incidental bycatch of marine mammals is not expected to occur.

b) D1C2 Population abundance

GES definition: The population sizes of harbour porpoise, harbour seal and grey seal must meet favorable population size reference value from the Habitats Directive.

The development of offshore wind in the North Sea can affect the population abundance of marine mammals, both positively as well as negatively, although not all effects are fully understood yet. The potential negative effects on marine mammals during construction, as a result of underwater noise during piling, is covered in D11 (Energy supply, including underwater sound) and the underwater noise KEC document (Heinis *et al.* 2025). Both positive and negative effects might be expected because of changes in prey availability caused by offshore wind developments. Changes in prey availability are further covered in D1C5 (Habitat quality).

c) D1C3 Demographic characteristics

GES definition: No decline in pup production of the grey seal of more than 1% since the last assessment and no more than 25% decline since 1992.

It is currently unclear whether the construction or operation of OWFs positively or negatively affects the demographics of marine mammals. General studies have been performed that show demographic characteristics but these cannot be directly linked to OWF development. Additional research is required, as larger effects on specific demographics within a population can affect the long-term fitness and survival of the population.

d) D1C4 Distribution area

GES definition: The distributional range of harbour seal, and harbour porpoise meets the threshold value of the Habitats Directive.

The effect of OWFs on the distribution area of seals is unclear. Aarts (2021) made a distribution map for harbour and grey seals. The habitat model that underpins these seal distribution maps is based on tracking data. This model attempts to account for the fact that seal trackers were deployed opportunistically during a diverse array of projects resulting in data scattered across various regions and different time periods. Almost no seals have been tracked since 2019, apart from six juveniles released from a rehabilitation centre. It is not clear whether these are representative animals, because they were raised in a rehabilitation centre. These recent data from juveniles raise questions on the validity of the existing distribution maps for juveniles and the sparse observations also raise concerns about the validity of the maps for all other age groups (see Brasseur, S., Aarts, G., 2024). It cannot be excluded that the seals' foraging habitat may have changed because of natural and anthropogenic processes in the North Sea. As a result, the existing maps (Aarts 2021) may no longer represent current 2024 seal distribution. See also the Underwater noise KEC document (Heinis *et al.* 2024). In Scotland, harbour seals have been found to make targeted voyages to OWFs to forage (Russell *et al.* 2014). Currently there is a decline in harbour seal abundance observed in Dutch waters, what factors are responsible for this decline and whether offshore wind developments play a role remains unclear. All in all, the effect OWFs on the distribution of seals remains a topic of discussion.

For the distribution area of the harbour porpoise the maps of Gilles *et al.* (2020) provide the most recent overview of their distribution. In 2024 a preliminary distribution map was made, with data from SCANS 2022 (Geelhoed 2024). Geelhoed (2024) concludes that the harbour porpoises distribution has shifted northward since the publication of the Gilles *et al.* (2020) distribution maps, with consequences for the number of harbour porpoises that will be disturbed due to the construction of OWFs. As a result, modelled effects will be overestimated to the west of the Dutch coast, while they will be underestimated to the North of the Wadden islands (Geelhoed 2024). As a result, there is a lot of discussion with regards to the distribution of harbour porpoises and how OWF construction effects might be affected. For a detailed discussion, see the Underwater noise KEC document (Heinis *et al.* 2024). An observational study did find that harbour porpoises had a year-round presence in wind farm Borssele and did not significantly differ from the reference location. On some occasions harbour porpoises were found to forage inside the OWF even close to the turbines. However, generally harbour porpoises seem to avoid the turbines when turbines are placed to close together, the avoidance behaviour could result in some avoidance of the OWF by harbour porpoises (Leemans & Fijn 2024).

For both species groups, additional research is required to be able to draw solid conclusions on how OWFs might affect the distribution area.

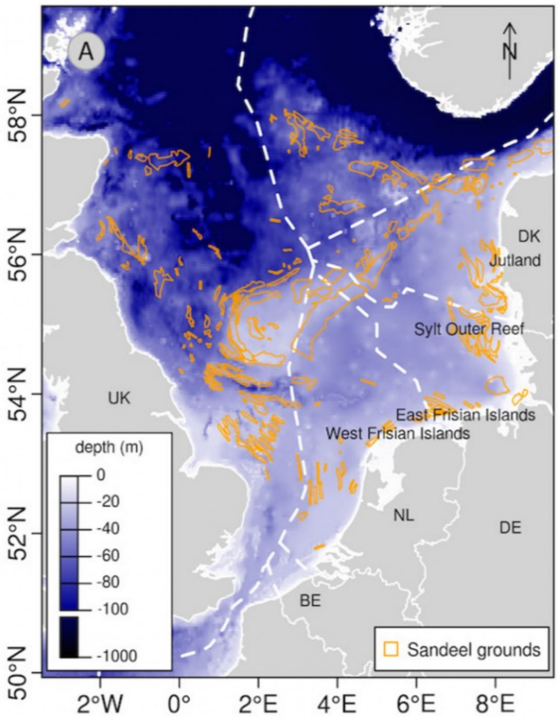

Figure 1. The water depth and distribution of sandeel spawning grounds in the North Sea. Adopted from Gilles et al. (2016).

e) D1C5 Habitat quality

GES definition: Maintain the extent and quality of habitat for grey seal, harbour seal and harbour porpoise;

During construction, the habitat quality of the OWF development area is significantly reduced for marine mammals because of the disturbance from underwater noise. Furthermore, underwater noise generated by operational turbines and the presence of maintenance vessels might also significantly affect the underwater sound landscape and thus the habitat quality for marine mammals. This is further discussed under Descriptor 11.

During operation the habitat quality could be improved due to increased food availability, the reef function of monopiles and scour protection and the larger abundance of prey fish around the structures. Both harbour porpoises (Leemans & Fijn 2024) and seals (Russell *et al.* 2014) have been found to forage in OWFs. On the other hand, forage fish, such as sandeel, herring and sprat, are important prey species for marine mammals (Brasseur *et al.* 2004; Leopold 2015). How the development of offshore wind affects the survival, fitness, or distribution of forage fish remains largely unknown and could significantly influence the habitat quality for marine mammals. For instance, some parts of sandeel grounds are possibly destroyed by the construction of OWFs. Additional research is required to understand the full impact of OWF development on the habitat quality, mainly focusing on forage fish as important prey species for marine mammals.

Birds

1) Conclusion

Many potential impacts of the construction and operation of OWFs are already covered in other chapters of KEC 5.0. Nonetheless, not all potential effects of the roll out of offshore wind have been assessed. It is especially important that the effects of habitat loss, barrier effect and habitat quality are investigated so that potential effects can be considered in the future developments of OWFs.

2) Criteria

a) D1C1 Incidental bycatch

The development of OWFs is neutral for this criterion, as incidental bycatch of birds is not expected to occur.

b) D1C2 Population abundance

GES definition: The population abundance of marine species indicates healthy populations and meets OSPAR threshold values in the International North Sea.

A side note to this GES is that some criteria associated with this GES are considered more important than others, partly due to measurability. This has not (yet) been taken into account in this assessment.

There are multiple ways in which OWFs can negatively affect the population abundance of seabirds. First, birds can collide with the blades of the turbine, which will be fatal. The species that are susceptible to such collisions, the number of individuals that are considered per species and the measures that could be taken to reduce collisions are extensively described in KEC 5 (IJntema et al, 2025). Second, some species are susceptible to the construction and operation of OWFs, as they will avoid OWFs altogether. The macro-avoidance of certain seabirds forces them to forage in regions with lower habitat quality or into areas with higher competition for resources resulting from the displacement. Both will lead to an increased mortality rate among the impacted seabirds. The specific species that are most susceptible to habitat loss and the mortality rates that can be expected per species are addressed in parts B of this KEC 5. Third, barrier effects because of the establishment of OWFs forces seabirds to adjust their route and go around the OWF. Consequently, foraging sites on the other side of OWFs become inaccessible and longer travelling times are needed. The subsequent increased energy use for travelling and the reduced foraging time can increase the mortality of certain seabirds. A more elaborate explanation is given in the habitat loss report (Soudijn et al, 2025) of KEC 5.

Something to keep in mind is that the analysis performed in KEC 5 regarding bird collisions, habitat loss and barrier effects all consider the Acceptable Levels of Impact (ALI) to determine the effect of OWFs on seabird populations. The reports part B about collisions and habitat loss (Ijntema et al, 2025 and Soudijn et al, 2025)gives more insights about this.

c) D1C3 Demographic characteristics

GES definition: For each species, lack of breeding success should not occur in more than three out of six years (OSPAR assessment value)

It remains unclear if and how the operation of OWFs affects seabirds with varying demographic backgrounds differently, and whether such differences should be considered in the future design of OWFs. Most research into the demographic characteristics of seabirds has been performed on colonies, particularly considering the breeding success in response to multiple stressors. While research that investigates the susceptibility of different demographic characteristics of seabirds to OWFs is interesting, other research areas are more urgent, such as the research into habitat loss and barrier effect resulting from the construction and operation of OWFs.

d) D1C4 Distribution area

The construction and, more importantly, operation of OWFs can cause some seabird species to avoid them. Seabirds can be susceptible to collision, barrier effects or habitat loss when encountering an OWF. Both barrier effects or habitat loss can result in a shift in the distribution area of certain seabird species. As a result, the survival of these birds can be impacted, ultimately leading to a reduction in the population abundance (D1C2). The consequences of habitat loss are covered in Soudijn *et al.* 2025. The consequences of barrier effects are still a knowledge gap. Additional research into the cumulative effects of habitat loss and barrier effects are needed to fully comprehend the effect OWFs have on the long-term survival of seabird species.

e) D1C5 Habitat quality.

GES definition: The spatial extent and condition of the habitat are suitable for marine bird populations in the Dutch part of the North Sea.

By constructing an OWF in an otherwise empty sea can have serious implications on the habitat quality of seabirds, but for most hypothesized effects knowledge is still lacking. Additionally, whether these implications are positive or negative is dependent on the species that is considered, and effects are not expected to have a proportionate effect on seabirds.

Forage fish, such as sandeels, herring and sprat, are important prey species for seabirds. The current and future roll-out of offshore wind can affect the abundance and distribution of these fish species. For instance, the spawning grounds of sandeels overlap for a large part, with the current focus on offshore wind development on sandy bottoms in the southern North Sea (see Fig. 1). Any effects of the development of offshore wind in their spawning grounds could affect seabirds. Furthermore, pelagic herring and sprat might be affected by the hydrographical changes caused by the presence of turbines in the water column (See D4 and D7). While the indirect effects of the presence of monopiles on forage fish remains unknown, the direct effects could be a loss of habitat or reduced habitat quality for forage fish.

For instance, birds that predominantly forage on fish that can be found on sandy bottoms, such as sandeels, might be impacted by the development of an OWFs in this habitat as sand eels depend on sandy bottoms. Additional research is required to understand the full impact of OWF development on the habitat quality, mainly focusing on forage fish.

Fish

1) Conclusion

The effect of the construction and operation of OWFs on fish is multi-faceted. Both positive as well as negative effects can be expected, and knowledge gaps remain to be filled. The effect OWFs have on reef dwelling and benthopelagic species has been sufficiently covered in research, but how OWFs affect sand dwelling and pelagic species remains largely unknown. There are some upcoming research programs that could help fill this knowledge gap. Furthermore, the effect of the roll out of offshore wind on migratory fish remains unknown.

2) Criteria

a) D1C1 Incidental bycatch

The development of OWFs is neutral for this criterion as incidental bycatch of fish is not expected to occur in wind farms. Passive fishing is currently permitted in wind farms but it will not be discussed further here since it is co-use.

b) D1C2 Population abundance

GES definition: Improve population size of sharks and rays in the North Sea and especially in the coastal zone

As a result of the introduction of hard substrate into an otherwise soft sandy bottom habitat, the conditions and/or habitat for reef-dwelling species, such as goldsinny wrasse (*Ctenolabrus rupestris*), and benthopelagic species, such as cod (*Gadus morhua*) and pouting (*Centropristis striata*) are improved (Degraer *et al.* 2020). But also elasmobranchs, such as sharks and rays, can benefit from the artificial reefs that are established within OWFs (Bos & Tamis 2020). The abundance of these species is therefore expected to increase as a result of the OWFs that already have been developed, are currently under construction, and those that will be developed as part of the roll-out of offshore wind energy in the North Sea (Bergström *et al.* 2013; Reubens *et al.* 2014). However, it should be stated that the effects of EMF, on for instance elasmobranchs, are currently not yet well understood. These effects should also be taken into account and not be neglected. Additionally, bottom trawling fishery activities are currently not allowed in OWFs developed in the Dutch North Sea. It is important to note that the reef-dwelling and benthopelagic species are not only attracted to OWFs, but also forage at the artificial structures and thus OWFs may serve as a production and spawning site (Mavraki 2020; Gimpel *et al.* 2023). Some demersal fish, such as flat fish, also seem to be attracted to OWFs. Yet, they solely seem to aggregate around hard substrates, with no observed increase in their abundance (Degraer *et al.* 2020; Buyse *et al.* 2022; Buyse *et al.* 2023).

Many migratory fish species are protected under the MSFD and OSPAR. Up-to-date data on knowledge on the population abundance of migratory fish is lacking. Whether OWFs affect the survival of these species is unknown. However, it is expected that barriers in upstream rivers mainly affect the survival and fitness of migratory fish species (Bos & Tamis 2020).

The effect of the development of OWFs on the abundance of pelagic species remains largely unknown. Pelagic species could be affected by changing hydrographical conditions (see D4 and D7), but whether these changes will be positive or negative is unclear. Additional research is required.

c) D1C3 Demographic characteristics

The demographic characteristics of fish in and around OWFs remains largely unknown. Only for the benthopelagic species cod and pouting it was found that especially younger individuals were attracted to OWFs (Reubens *et al.* 2014) and that for cod reproduction is hypothesized and observed (Gimpel *et al.* 2023). A possible cue for this could be the continuous noise produced by the operating OWF (Cresci *et al.* 2023). The attraction of younger (i.e. smaller) individuals to OWFs might be caused by the increased availability of hiding places.

Additional research into the demographic characteristics of fish species affected by OWF development is required.

d) D1C4 Distribution area

GES definition: The distributional range of migratory fish in the Dutch part of the North Sea meets the threshold value of the Habitats Directive.

For some species information is available about the distribution of fish outside OWFs. There are knowledge gaps about species inside OWFs and if OWFs have a significant (cumulative) effect on the distribution of fish. In the Wozep/MONS program, research is proposed that investigates pelagic fish species within OWFs. It is uncertain if the proposed research is sufficient to provide unequivocal conclusions on the distribution of fish species.

With the introduction of artificial hard substrate through the construction of OWFs, the area to which species that depend on hard substrate in (part of their) life, is expanded. Already for some benthopelagic species a production effect has been found (Reubens *et al.* 2014). For demersal species, it seems they only aggregate around monopiles, without any effect on the population abundance (Degraer *et al.*

2020). It could be that this affects the distribution of demersal species, such as flatfish, where it is more centered around (artificial) hard substrates, such as OWFs (Buyse *et al.* 2022; Buyse *et al.* 2023). Also nature inclusive building can change the the environment for some species, as shown in Berges et al 2024 (Strong site fidelity, residency and local behaviour of Atlantic cod (Gadus morhua) at two types of artificial reefs in an offshore wind farm).

For migratory fish the infield cables (and export cables) and their electromagnetic fields could affect their distribution area. There are a lot of knowledge gaps about EMF on fish, migratory fish and elasmobranchs. The effect EMF might have on these species is further elaborated on in D11 (Energy supply, including underwater sound).

e) D1C5 Habitat quality

GES definition: Reduction of barriers in migratory routes so that by 2027 they are not an obstacle to sustainable populations in the catchment area.

During the construction phase of OWFs the habitat quality is impacted by the input of underwater noise, which is further described in D11 (Energy supply, including underwater sound). Additionally, destruction of habitat may occur due to the installation of hard structures such as monopiles, scour protection, cables and cable crossings. On the other hand, a new type of habitat becomes available namely hard substrate habitat and even additions based on nature inclusive design (Werner *et al.* 2024). If and how the hard substrate positively influences the habitat is largely unknown. For reef dwelling and benthic species it has been shown that the habitat quality increases. However, for pelagic species no significant positive effects has been found. Additional research into the effects on pelagic and benthopelagic species is required.

During the operation of the OWF EMF are emitted into the environment. This impact and remaining knowledge gaps are further discussed in D11 (Energy supply, including underwater sound).

f) D1C6 Pelagic habitats

The effect of the development of offshore wind in the North Sea is covered in D4 (Food web). These effects are partly addressed in the ecosystem report as part of KEC 5.0 (van Zijl, et al, 2024).

2.2. D2 Non-indigenous species

1) Introduction

Descriptor 2 (D2) focuses on non-indigenous species, which are species that have expanded their typical geographical distribution. They become 'invasive' when they threaten locally occurring marine biodiversity. The development of OWFs provide foreign hard substrate structures. It is hypothesized that the hard substrate structures serve as steppingstones that aid in the expansion of non-indigenous species that could possibly threaten the locally occurring marine biodiversity.

2) Conclusion

Currently, the construction and operation of OWFs is expected to have limited impact on the abundance of non-indigenous species, although there are still knowledge gaps. However, there should be an obligation to stay up to date on the notifications of ongoing research on the scour protection and launch a new North Sea wide monitoring program to study non-indigenous species.

3) Criteria
The development of OWFs results in the creation of an intertidal zone offshore, which can be a settlement site for non-indigenous species. However, marine larvae that are already present in the water column can spread over tens to hundreds of kilometers, by which every corner of the Greater North Sea can be reached over time. OWFs merely provide new substrate on which non-indigenous species can settle.

Before the international roll-out of offshore wind energy, some structures were already available in the North Sea that provided an intertidal zone, such as oil and gas platforms and buoys. While baseline monitoring has been performed on the diversity and abundance of the benthic communities of monopiles (Bouma & Lengkeek 2013; Coolen 2017), no structural and long-term monitoring programs exist today. Therefore, to stay updated on the presence of invasive species and investigate this criterion, a North Sea wide monitoring program could be launched of which monitoring of OWFs should be part. When monitoring OWFs, it should include the intertidal zone of the monopile, with a lesser focus on the scour protection surrounding monopiles.

Scour protection also serve as a potential settlement location for invasive species. However, it is assumed that these structures have a less profound effect as this habitat is also present in its natural form surrounding shipwrecks and oil and gas platforms. Furthermore, diverse monitoring programs already study the benthic communities of the scour protection, from which the settlement of non-indigenous species can be deduced if part of the monitoring scope.

2.3. D3 Commercial fish and shellfish

1) Introduction
Descriptor 3 (D3) of the MSFD sets out that populations of commercial fish and shellfish have full reproductive capacity to maintain stock biomass and that the proportion of older and larger fish/shellfish should be maintained (or increased), which is an criterion of a healthy stock. Both criteria, D3C1 and D3C2, must meet the thresholds set by the CFP. Criterion D3C1 is not applicable for OWFs.

2) Conclusion
Wind farms are neutral regarding Commercial Fish Stock, OWFs do not actively change these stocks. By providing shelter potentially the spawning stock biomass and species composition can change.

3) Criteria

At this moment displacement of fishery and impacts of that is not taken into account with the assessments.

a) D3C1 Mortality of commercially exploited species

GES definition: the fishing mortality of each commercially-exploited stock in the International North Sea meets the threshold value based on the CFP.

Criterion D3C1 specifically addresses mortality caused by fishing. As the development and operation of OWFs does not include any fishing activities, this criterion is not applicable in the current assessment.

b) D3C2 Spawning stock biomass of commercially exploited species

GES definition: the spawning stock biomass of each commercially-exploited stock in the International North Sea meets the threshold value based on the CFP.

With current knowledge regarding D3C2, OWFs seem to have no negative effect on the spawning biomass of commercial fish species. A positive effect could be possible, due to the provision of shelter near the scour protection.

To maintain a healthy spawning biomass, it is important that the proportion of adult fish does not fall below certain reference levels. OWFs have the opportunity to provide more shelter and increase food availability, possibly increasing the abundance of larger adult fish. The larger the fish, the more spawning mass. OWFs may have more effect on certain fish species than on other species in this respect. So, there could potentially be an increase in biomass and a local shift in species.

2.4. D4 Food web

1) Introduction

Descriptor 4 (D4) specifically addresses the food web. Understanding the complex interactions within the marine food webs is crucial for assessing ecosystem health and resilience. As the development of OWFs continues, it is imperative to investigate their effects on marine food web components, to fulfill the objectives of D4 and ensure the sustainability of the North Sea ecosystem.

2) Conclusion

The current understanding of the North Sea food web is significantly limited by a lack of comprehensive monitoring data, particularly regarding the impact of OWFs. Additional research is required to effectively assess the effects of OWFs on the food web, which should include targeted monitoring programs focusing on phytoplankton, zooplankton and higher trophic level. These initiatives will contribute to laying the groundwork for future research into the dynamics of the North Sea ecosystem and the impact of OWF development.

GES definition: The effect of human interventions on interactions between different trophic levels in the food web is reduced.

3) Criteria

There is a substantial knowledge gap concerning the North Sea food web. Monitoring data of (specific species (groups) within) the food web is mostly lacking.. How the development of offshore wind affects the elements of the marine food web remains largely unknown. As such, the KEC5.0 will not go into the specific criteria of descriptor 4, as no detailed conclusions can be drawn.

It is difficult to draw conclusions for this criterion. This is more straightforward in the case of criterion D4C4 – Productivity of trophic guilds the primary production in the southern North Sea ecosystems has been regularly monitored. As such, the impact of the presence of monopiles (through the disruption of stratification) has been assessed by Deltares (van Duren et al. 2021). Yet, this analysis only shows the effect of OWFs on a raster of 25 km by 25 km, which is too rough. The effects (positive or negative) of OWFs on stratification are expected to be on a much smaller scale than this raster. Furthermore, the distances between turbines, as well as the size of an OWF is much smaller than the raster used in the study of Deltares. And lastly, the results in the study remain to be validated.

Before impacts of OWFs on the food web can be assessed, data is required, for which (basic) monitoring programs must be initiated. Some species groups can be relatively easily monitored, providing insights into the functioning of the food web. For starters, the phytoplankton diversity and biomass should be monitored to understand the primary production in the North Sea and how OWFs might affect this primary production. Subsequently, the zooplankton community should be monitored. The zooplankton prey on the phytoplankton, but are themselves preyed upon by higher trophic levels, and therefore play an essential role in the food web. Both the phytoplankton and zooplankton of the North Sea will be investigated as part of a MONS research program in which 7 PhDs are dedicated to understanding the basis of the food web. These studies will not necessarily research how OWFs then affect the food web, but they can serve as a knowledge basis. Dedicated research programs that study the effect of OWFs based on the food web must then still be initiated.

Apart from the basis of the food web, higher trophic levels can be researched to understand the health of the food web. Some forage fish prey on phytoplankton or zooplankton and are potentially (positively or negatively) affected by the disruption of the primary production caused by stratification. Other forage fish might be positively affected by OWFs through the introduction of hard substrate in areas that are generally characterized by soft sandy bottoms (Reubens *et al.* 2014). Lastly, the apex predators, such as seabirds and marine mammals, that prey on the forage fish can be indicative of the health of the entire food web (Fijn 2024). A basic monitoring program covering the abundance, survival and fitness of these apex predators serve as important input to assess the food web condition.

2.5. D5 Eutrophication

1) Introduction

The Marine Strategy Framework Directive (MSFD) Descriptor 5 addresses "Eutrophication," focusing on the levels of nutrients in marine waters and their impact on ecosystems. It aims to assess and manage the risks of nutrient enrichment, which can lead to excessive growth of algae (blooms) and subsequent oxygen depletion, negatively affecting marine life and habitats.
This descriptor is important because eutrophication can disrupt marine ecosystems, harm fish populations, and lead to detrimental effects on water quality and biodiversity. By monitoring nutrient levels and their effects, Descriptor 5 helps ensure the sustainability of marine environments and the health of fisheries, contributing to the overall goal of maintaining healthy oceans for future generations.

Descriptor 5 (D5) addresses eutrophication, focusing on the levels of nutrients in marine waters and their impact on the ecosystem. Eutrophication is a process driven by the enrichment of water by nutrients, usually from agriculture or urban discharges. Dissolved nitrogen and phosphorous are the main inorganic nutrients in the water column responsible for the eutrophication of marine waters. Nutrient enrichment can lead to excessive growth of algae (blooms) and subsequent oxygen depletion, negatively affecting marine life and habitats.

Based on the above description, the development of OWFs on its own does not lead to an input of nutrients into the water. Therefore, this descriptor is considered neutral for OWF development.

Lastly, it should be noted that other factors indirectly related to the process of eutrophication, such as chlorophyll a and stratification, are assessed in the KEC report on potential ecosystem effects (Zijl et al, 2024) as a result of the development of OWFs.

2.6. D6 Seafloor Integrity

1) Introduction

Descriptor 6 (D6) reflects the safeguarding of the characteristics (physical, chemical and biological) of the seafloor, including natural spatial connectivity, upon which a healthy structure and functioning of marine ecosystems depend. The seafloor constitutes a key compartment for marine life. A broad variety of habitats exist both inside and above the seabed, depending on substrate nature, depth, hydrodynamics and other local environmental conditions. This patchiness is reflected on the variety of associated species. Because of the importance the seafloor provides, maintaining its integrity is necessary to preserve marine biodiversity and living resources.

2) Conclusion

OWF construction can have an impact on the seafloor integrity, as some seabed is lost, because of the installation of monopiles and the scour protection. During the operational phase, the effect on the seafloor integrity can be both positive and negative. Some underwater currents around the turbines can cause turbulence and therefore resuspension of the soil, negatively affecting the seafloor integrity. Yet, bottom-trawl fishing activity is currently not allowed within OWFs, leading to a higher soil integrity. Whether displacement of the fishing activity has an effect on other areas outside OWFs is being researched. Depending on the results of the MONS study, additional research is needed.

3) Criteria

a) D6C1 Physical loss of natural seabed

This criterion is input for D6C4 and D7C1. The physical loss of natural seabed is expressed in the percentage (%) lost in relation to the DCS. With regards to OWFs, this is the relative footprint of all the turbines on the DCS (58.000 km^2). For the Dutch KEC 5.0, a scenario with ca. 1742 turbines with ca 1.600 m^2 scour protection per turbine is used. This gives a total loss of 2787200 m^2 of natural seabed, which is 0,0048 % of the Dutch Continental Shelf (DCS).

b) D6C2 Physical disturbance of seabed

This criterion is input for D6C3. This is also a percentage (%) of the total DCS. Inside OWFs bottom trawling activities are currently not allowed, which greatly reduces the physical disturbance of the seabed.

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c) D6C3 Physical disturbance of habitat

The disturbance of seabed/habitats is larger than the loss of seabed/habitats. Where the installation of turbines and scour protection result in a loss of seabed and habitat, the burial of infield cables will only temporarily disturb the seabed and habitats. After the burial of the infield cables the seabed will restore over time.

However, currently no bottom trawling is allowed within OWFs. Currently it is foreseen that over the course of the lifetime of the OWF, the seabed inside the OWFs will not be disturbed, which will positively affect this criterion.

d) D6C4 Physical loss of habitat

GES definition: No significant loss due to human activities of the habitats described under the Marine Strategy Framework Directive.

This criterion pertains to the area loss per broad habitat type in the Dutch part of the North Sea. The lost seafloor surface due to the presence of objects and structures (e.g. pipes, platforms and wind turbines) and sand extraction is limited. Habitats with biogenic reefs have not yet been considered because their size and location are not yet sufficiently known. The physical loss from wind turbines and OWFs is limited.

2.7. D7 Hydrographical Conditions

1) Introduction

OWF development can have a substantial impact on the marine ecosystem, through bottom-up processes and changes in permanent hydrographical conditions. These have previously been researched in the Wozep and a modelling mechanism has been developed to investigate future offshore wind scenarios with respect to changes in hydrodynamics, suspended particulate matter (SPM) dynamics and ecological processes such as primary production. Additionally, this descriptor aims to provide insight into the spatial extent of each benthic habitat type adversely affected (physical and hydrographical characteristics and associated biological communities) due to permanent alteration of hydrographical conditions.

2) Conclusion

It is known that OWF development causes alteration of hydrographical conditions, and due to the relatively long operational phase these effects can be described as permanent. However, there is currently no knowledge available on how this alteration of hydrographical conditions according to the establishment of offshore wind farms does or does not adversely affect marine ecosystems. Therefore, additional research is needed to get insight in the impacts of these alterations on higher trophic levels and the marine ecosystem in general. Wozep, as well as MONS are dedicated to gain more insights on this matter with research into forage fish, zooplankton and Phytoplankton (see also D4 Food webs for research recommendations).

3) Criteria

a) D7C1 Extent of permanent changes in hydrographical conditions

The changes in hydrographical conditions have been modelled according to the currently foreseen cumulative OWF developments into 2031. See Zijl et al, 2024for a detailed description of the quantified effects of OWF development on hydrodynamics.

b) D7C2 Disturbed habitats through changes in hydrography.

Currently, there are many knowledge gaps surrounding the issue of translating the effects of the development of OWFs into disturbed habitats, because of changes in hydrographical conditions. Therefore, it is not yet possible to properly assess the fraction of disturbed habitats, quantitatively, as well as qualitatively. With the large ambitions for construction of offshore wind, this is a becoming a pressing issue that deserves attention. Wozep, as well as MONS and some other research programs are dedicated to gain more insights on this matter with research into forage fish, zooplankton and phytoplankton (see also D4 Food webs for research recommendations).

2.8. D8 Contaminants

1) Introduction

Contaminants are toxic and persistent chemical substances that degrade the marine environment and can cause serious damage. They mainly come from agricultural pesticides, paint coating on ships, pharmaceutical, industry and urban waste, including heavy metals. Implementing the measures under the various EU and global laws have led to a reduction of concentrations of these pollutants.

For priority contaminants there are EU threshold values, for other contaminants there are national threshold values (cf. Directive 2008/105/EC).

For offshore we investigate the emissions from the OWF itself, not any increased risk of collisions with ships, which could release any pollutants like oil spills.

There is a risk of emissions of substances during the use and maintenance of the wind farm, in particular from corrosion protection systems (coatings, sacrificial metals) of the monopile, erosion of wind blades and SF_6. Chemical contaminants that can occur include:

- Leaching of chemicals used to protect the pile against corrosion
- Incidents with contamination due to, for example, oil leaks and SF_6.
- Possible erosion of PFAS from the rotor blades
- Microplastics (from degradation the rotor blades) are treated under D10C2.

From Descriptor D8, D8C1 and D8C3 are therefore relevant for offshore wind energy.
Descriptor D8C2 is about effects of contaminant is relation to imposex of marine snails. This one is not applicable, since it is related to ships.

2) Conclusion

There are still many knowledge gaps regarding D8. On the one hand, it is unclear which substances are used in the manufacturing and operation of the wind turbines, and on the other hand, the degree of leaching and its effects on the environment is unknown.

3) Criteria

a) D8C1 Contaminants in water, sediment and biota

GES definition: The concentrations of contaminants relevant to the marine environment (UPBT and non-UPBT) meet the threshold values set at European (WFD, Dutch part of the North Sea) and regional level (OSPAR, Southern North Sea).

The monopiles are protected against corrosion, for example rust. This can be done, among other things, by using specific metal or epoxy coatings. The emissions of zinc, indium, lead and cadmium from sacrificial metals at offshore wind turbines are not harmful to people or the environment. The use of epoxy coatings can potentially be harmful. Whether this is the case in practice depends largely on the coating used. It differs per coating as to how many and which substances can be released.

Various points of interest were identified in the previously conducted quick scan into emissions of substances from offshore wind turbines (RIVM 2022). This concerned the leaching of the Substances of Very High Concern bisphenol A (BPA) and 4-tert-butylphenol (4-tbp) from epoxy-based coatings. There is currently no overview of whether and to what extent epoxy coatings are used in Dutch offshore wind farms. If epoxy coatings are not used at a wind farm, no risks due to leaching of BPA or 4-tbp are expected.
It is therefore important to get a better idea of which coatings are used in current offshore wind turbines. At this moment there is no overview of the coatings used on Dutch wind turbines. No conclusions can me made about this.

The use of heavy metals in sacrificial anodes used as cathodic protection is not permitted in the site decision. This prevents certain substances from ending up in the water.

In the EIAs calculations have been done about the increase in the concentration of zinc or aluminum due to any sacrificial anodes. The calculations showed this is negligible compared to the normal background concentration.

The RIVM report (2022) recommends that new wind turbines, as a precaution, use coatings from which no or few substances leak. This should be included in the site decisions.

The RIVM report (2022) indicates that PFAS may be used in wind turbine blades. It is unclear whether this happens and to what extent. PFAS may also enter the sea due to wear of the rotor blades and the falling of plastic particles into the sea. This is a point of attention that will need to be investigated further.

b) D8C3 Serious acute contamination

GES definition: significant pollution events in the Dutch part of the North Sea have been minimised.

D8C3 is about serious acute pollution. Occasionally hydraulic oil leaks occur. However, these are incidental and are avoided as much as possible.

Leakage of coolant, for example, may also occur. This concerns, for example, the gas sulfur hexafluoride (SF6, a so-called F-gas) that is used to insulate switching stations in the electricity network. SF_6 is not harmful to the ozone layer, but it is a very heavy greenhouse gas with a greenhouse gas effect. For this reason, SF_6 has been placed on the Kyoto list of substances whose use and emissions must be minimized. There are alternatives to SF6. These could be used.

Provisions are made in the wind turbines (including liquid-tight facilities and drip trays) to prevent environmental pollutants from entering the seawater. Any contamination of the water is therefore not expected.

2.9. D9 Contaminants in Seafood

1) Introduction

Pollutants in the sea ultimately contaminate seafood intended for human consumption. It is therefore important for both environmental and human health reasons to ensure that the levels of contaminants in the marine environment remain low and within safe limits.

2) Conclusion

For contamination from offshore wind farms see D8. The use of contaminants can be regulated in the site decisions.

2.10. D10 Marine Litter

1) Introduction

Descriptor 10 (D10) is about marine litter. Marine litter is harmful for the marine environment and can cause pollution, suffocation, starvation and entanglement of species and degradation of habitats. Here we only consider marine litter that comes from the OWF itself. Litter from shipping or maintenance vessels is not included here since regulation to prevent this is already in place.

Microplastics from degradation of rotor blades is, as far as we know, the only microplastic/litter that comes from an offshore windfarm. Therefore, only D10C2 is considered.

2) Conclusion

The input of micro waste into the marine environment due to OWF structures, remains greatly unknown. Additional research is required to be able to give insight into the risks of micro waste emissions from OWFs on the marine environment.

3) Criteria

a) D10C1 Amount of litter at sea (beach and seafloor)

Not applicable

b) D10C2 Micro waste (microplastics in seafloor sediment)

The RIVM estimates that the number of plastic particles that enter the sea due to wear of turbine blades is smaller than from other sources, such as Dutch shipping. The erosion of wind blades can largely be prevented by using modern wind turbines with leading edge protection (RIVM 2022).

The RIVM report indicates that wear on a wind turbine is estimated at 35.8 kg per turbine over the lifespan of a turbine (25 years) for turbines without so-called Leading Edge Protection (LEP), and only 78 grams per turbine over the lifespan. of a turbine with LEP. LEP are specially developed coatings or materials to protect the blades against wear, where a lot of development is taking place nowadays.

Due to the still great uncertainty in the quantity in kg and particle size of the emitted plastic particles, it is not yet possible to make a statement about the risks of the emission of plastic particles due to wear of turbine blades. Additional research is required.

c) D10C3 (Micro) waste absorbed by marine animals

Currently unable to assess.

2.11. D11 Energy Supply, including Underwater Sound

1) Introduction

Descriptor 11 (D11) is about impulsive and continuous sound. Criterion D11C1 concerns the effect of impulse sound on the harbour porpoise. D11C2 concerns the effect of continuous noise on marine mammals.

In addition to the introduction of energy in the form of underwater sound, there is also the introduction of energy through Electro Magnetic Fields (EMF) and heat. This is caused by the array cables. EMF and heat have been added to this descriptor here, although they have not yet been added to the official European list but will be added to the Dutch list.

2) Conclusion

The assessment of D11C1 is described in the KEC report about underwater noise. D11C2 is still in the research-phase. Research is ongoing, a good assessment is not possible yet. For EMF and Heat some research is ongoing, but there are still a lot of knowledge gaps. A good assessment is not possible yet and more research is required.

3) Criteria

a) D11C1 Impulsive noise

GES definition: For harbour porpoises, reduction in population size is prevented by setting a limit on the number of porpoise disturbance days.

The effect of impulsive noise, i.e. pile driving, on the disturbance and distribution of marine mammals has been covered extensively in Heinis et al, 2025. It is assumed that marine mammals, especially harbour porpoises (Heinis et al, 2025), are the most sensitive to impulsive underwater noise. Measures that limit the negative effects of impulsive noise to harbour porpoises are thus expected to also have a positive effect on other species. The effect of impulsive sound on fish has also been studied. However, marine mammals and fish are able to move away from the source of the noise, even encouraged to do so by slow start that is generally used while pile driving. The benthos, on the other hand, is not able to do so. These species are fully exposed to the full force of the impulsive noise of pile driving. Potentially, the extreme vibrations of the sediment caused by pile driving might have a larger effect on the benthos that the underwater noise emitted during the activity. In het KEC document (Heinis et al., 2025) about underwater noise, an extensive assessment with regards to D11C1 is executed.

b) D11C2 Continuous Noise

Continuous noise consists of the noise and vibrations produced by turbines, and the noise of maintenance vessels in and around OWFs. Also, vibro hammers will produce continuous noise.

Continuous noise is produced, especially by vessels, during the construction and operational phases. There is not yet sufficient quantitative data available for this form of noise disturbance to be able to make statements about possible population effects. In the KEC document about underwater noise (Heinis *et al.*, 2025) an overview is provided of the most recent insights and developments with continuous noise. Continuous noise from operational wind turbines is generally only important when the ambient noise from wind and shipping is very low (Tougaard *et al.* 2020).

At this moment it is not possible to make a good assessment of the effects of continuous noise on marine mammals. Additional research is ongoing.
In the DEMASK project research will be investigating continuous noise of shipping and the vibration of operational wind turbines. In the tenders and SIMPLE-III project research will be investigating continuous noise of e.g. vibro piling or soil-fluidization. There will also be a study in the Wadden Sea about the relation underwater noise from shipping and harbour porpoises.

<u>EMF</u>

The electricity generated by the wind turbines is transported via so-called infield cables to the TenneT platform and from there via the export cables to the land. The alternating or direct electrical current running through the cables generates an electromagnetic field (EMF) around the cable. An EMF consists of a magnetic and an electric field. The electric field is shielded by the sheathing of the infield cables and is not released in the immediate vicinity of the cable. The magnetic field is not completely shielded and can be observed in the immediate vicinity of the cable. When organisms move through the magnetic field, a weak electric field is also generated, the so-called induced electric field (iE field) (Hermans & Schilt, 2024). The magnetic field therefore radiates to the environment (up to tens of meters outside the cable), and can therefore lead to effects on marine organisms, including marine mammals.

EMF could negatively affect migratory species (fish), harbour porpoises and elasmobranchs. It could affect behaviour, development in early stages of live and cause barrier effect. Research is carried out to quantify EMF effects. Recently, especially the effects on elasmobranchs are studied in the lab and mesocosms. Still there are a lot of uncertainties and knowledge gaps.

To gain more insight into the possible effects of EMF on marine organisms, more knowledge on the occurrence of EMF in the marine environment due to anthropogenic activities is required. This can be followed by a detailed assessment on the input of EMF from OWFs. The ultimate result could be a North Sea wide EMF map based on anthropogenic activities. More research is required, especially with a focus on true field studies.

<u>Heat</u>
The infield cables in the OWF can produce heat and thereby have effect on the seafloor and the species living in the seafloor. Only deep burrowing invertebrates are considered likely to be exposed to anything more than trivial heating effects from cable operation. In Germany the 2K principle is used with cables to prevent effects from heat to protect benthic life. This 2K principle is a requirement to achieve a burial depth which will result in a temperature elevation of not more than 2K at a depth of 0.2m within overlying sediments.

Heat and the effects of heat are still a topic with a lot of knowledge gaps. An assessment if, or if not, the OWFs will have effects on benthic species and fish, and by that influencing the food web, is not yet possible. The basis for this should be a map that showcases the input of heat into the marine environment by anthropogenic activities a.o. OWFs. Additional research into this abiotic parameter is required.

3 Conclusion

This assessment of the effects of offshore wind farm development in relation to the 11 Marine Strategy Framework Directive (MSFD) descriptors has been mainly focused on the question whether there is sufficient knowledge available to quantitatively or qualitatively verify potential effects on the MSFD descriptors and their underlying criteria. Furthermore, if knowledge proved to be insufficient or absent in order to verify potential effects, suggestions for further research were indicated and specified if possible.

This assessment can be used as a more thorough analysis and guideline on how to take the MSFD into account in assessing the effects of offshore wind farm development, for example in the assessment of a cumulative scenario, simultaneously identifying where scientific knowledge and frameworks are lacking, or are still absent and necessary to be developed, in order to be able to fully assess the effects for every descriptor and criterion.

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