REPORT

Quick scan of effects from large upscaling of offshore wind (part C)

Opportunities for nature enhancement in offshore windfarms in the North Seas

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1 Introduction

1.1 Background and purpose

Growth of the offshore wind (OW) energy industry must be accelerated to meet global 2050 Net Zero Carbon commitments. The international ambitions to reach these goals include substantial upscaling of OW in the North Sea and Celtic Sea. At the European level, the ambition has been formulated for at least 60 GW offshore wind by 2030 and 300 GW offshore wind by 2050, excluding UK and Norway.. The spatial study North Seas 2030 – offshore wind development (Royal HaskoningDHV, 2022) shows that the ambitions of only the member states of the EU already add up to at least 62 GW at the North Seas by 2030. This is already more than the European ambition of 60 GW offshore wind. Together with the ambition of the UK (50 GW) and Norway (4,5 GW), this brings the ambition of OW in the North Seas in 2030 up to at least 117 GW. These results show that up to 2030 and 2050, the North Seas will be changing, as a large increase of OW can be expected.

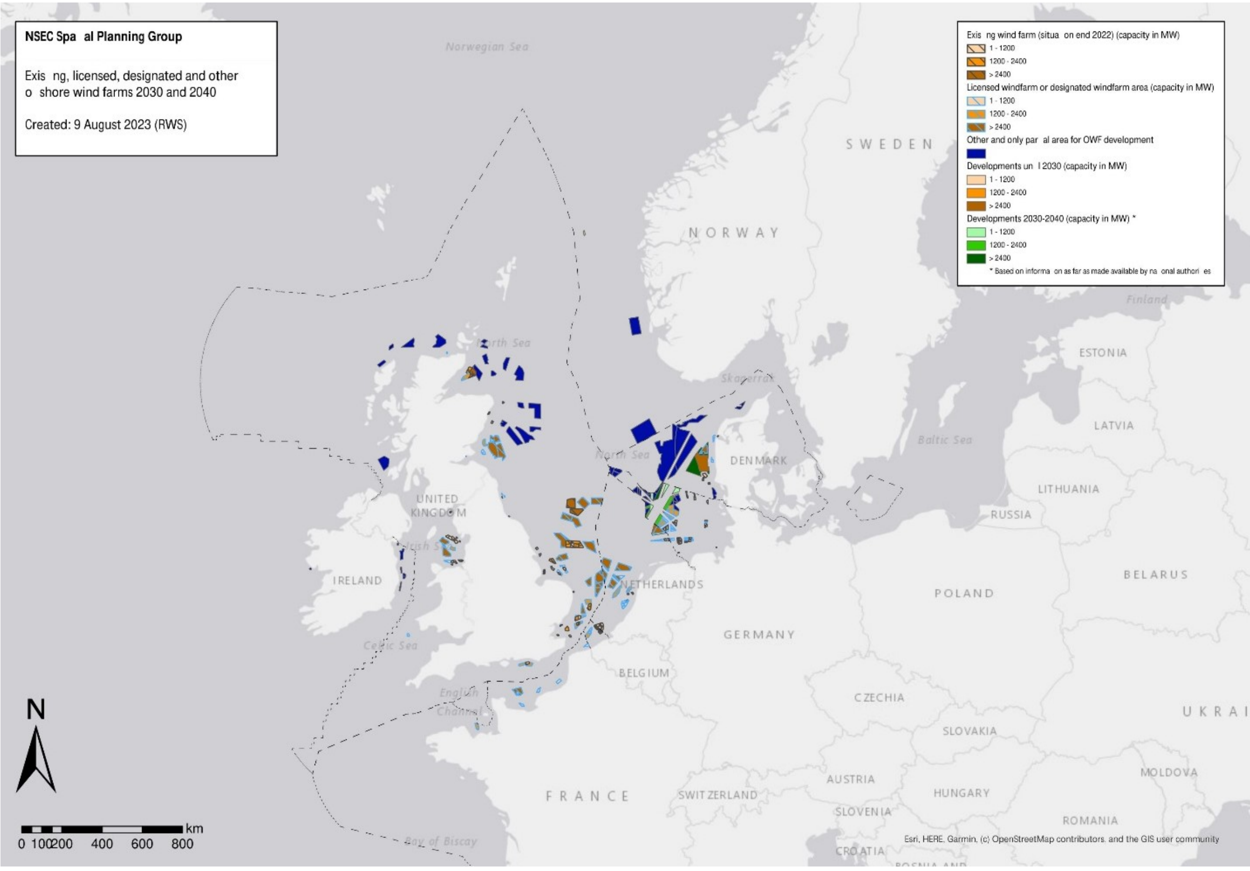

Figure 1. Map of the North Sea and Celtic Sea with an overview of the existing, designated and planned offshore wind park developments (RWS from input from NSEC parties, 2023).

Since the construction of the first windfarms, there have been concerns about their effects on nature. The presence of offshore wind farms (OWFs) in the North Seas changes the local environment both above and below water. Impacts of OWFs appear in multiple stages of construction, operation, and decommissioning. The main impacted species groups are birds, bats, marine mammals, fish, and benthic marine organisms. In addition, significant impacts are expected on ecosystem processes through the alteration of abiotic processes like stratification and its effect on primary production. However, besides negative impacts, OWFs might also offer opportunities for nature enhancement.

To support international discussion and decision-making around the spatial aspects of future upscaling of offshore wind, a quick scan on the effects from the large upscaling of offshore wind has been commissioned by Rijkswaterstaat as delegate of the North Sea Energy Coalition (NSEC). The spatial area of this study considers the North Sea and the Celtic Sea (OSPAR regions II and III respectively).

The quick scan contains the following components:

A. Cumulative effects from OW developments on species and habitats
B. Cumulative effects from OW developments on ecosystem processes
C. Opportunities from OW developments

This report contains the outcomes of part C from this quick scan and provides a high-level overview of published research of the opportunities for nature enhancement from offshore wind farms (OWFs). The other components are described in separate reports. It should be noted that the focus of this study is on the effects on ecosystem processes during the operational phase of OW, not the construction or decomissioning phase.

1.2 Approach and input

This part of the quick scan focuses on the opportunities for nature enhancement in OWFs. This study is based on suggested literature from suggested by RWS (i.e. Blauwe Cluster) and the North Sea Foundation. For this literature review, the suggested literature was used as a starting point. Additional literature was used based on the topics and authors mentioned in the papers. To consolidate and deepen the insights from this synthesis, interviews were conducted with the North Sea Foundation, the Rich North Sea program[1] and Deltares[2].

It should be noted that this literature review and interviews might not include all available knowledge on this topic and is therefore not fully comprehensive and should be considered a ‘quick scan’.

Who?	Where?	When?
Eline van Onselen and Renate Olie (North Sea Foundation and Rich North Sea program)	Head office North Sea Foundation, Utrecht, The Netherlands	13-04-2023
Luca van Duren (Deltares)	Microsoft Teams	17-04-2023 and 20-04-2023

1.3 Overview of opportunities

Opportunities, or potential positive effects, from OW developments can be divided into:

- Opportunities that occur from autonomous developments from the presence of OWFs (without taking additional measures). These are described in chapter 2.
- Opportunities that occur from additional efforts or measures to enhance nature in OWFs. These are described in chapter 3.

[1] The North Sea Foundation and Rich North Sea program are (respectively) a not-for-profit Dutch nature conservation organisation and a collaboration program between offshore wind developers, NGOs, scientific institutes, educational institutions and public authorities (https://www.derijkenoordzee.nl/en/)
[2] Deltares is an independent Dutch research institute working on innovative solutions in the field of water and subsurface (https://www.deltares.nl/en)

- Opportunities for multi-use in OWFs. These are also described in chapter 3.

Chapter 4 of this report contains the most relevant knowledge gaps and recommendations based on this study.

In Table 1 a summary and overview are presented of the opportunities for nature enhancement as described in the chapters below. With these opportunities there are also risks (or potential negative effects) which have been included in table 1.

Table 1 Summary of opportunities for nature enhancement

Topic	Ecosystem component	Effect (opportunity/risk)	Spatial extent	Source
Artificial reef effect of foundation and scouring protection	• Benthic and biofouling communities • Fish • Marine mammals • Birds	Opportunities • Habitat gain for species that prefer hard substrate → can lead to biodiversity hotspots and the *steppingstone effect* • Biofilter effect • Altered food availability Risks • Habitat loss for soft sediment species • Potential spread of invasive species • Altered food availability • Loss of habitat after decommissioning • Collision of birds	Inside windfarms	Degrear et al. (2020); Glarou et al., 2020); the North Sea Foundation (2022)
Exclusion of fisheries	• Benthic communities • Fish • Marine mammals	Opportunities • Bottom rest for benthic species; increasing habitat complexity, benthic biomass, and benthic biodiversity • Provision of shelter for fish and potential increase in biodiversity • Potential spill-over effect Risk • Increase in fishing around OWFs putting pressure on fish growth and productivity, and biodiversity • Spatial redistribution of fishing efforts (fisheries displacement effect) leading to adverse interactions with other previously less impacted sensitive habitats	Inside and outside windfarms	Gill et al. (2020)

Nature-inclusive design: scour-protection,	• Benthic communities • Marine mammals • Fish • Bivalves	<u>Opportunities</u> • Nature-inclusive • Restoration of oyster beds • Marine mammal feeding grounds <u>Risks</u> • Lack of ecological success • Settlement and distribution of invasive species • Competition between target species • Absence of target species • Loss of habitat after decommissioning	Inside windfarms	Lengkeek et al. (2017); Kamermans et al. (2018); Hermans et al. (2020)
Multi-use: mariculture (seaweed farming)	• Benthic communities • Fish • Marine mammals	<u>Opportunities</u> • Provision of shelter for fish and potential increase in biodiversity • Using seaweed for the bioremediation of contaminants <u>Risk</u> • Potential decrease in primary production	Inside windfarms	Van den Burg et al., (2020)
Multi-use: aquaculture (mussel/shellfish)	• Benthic communities • Fish • Marine mammals	<u>Opportunities</u> • Shellfish provide additional habitat complexity favouring increased biodiversity • Shellfish provide ecosystem services, such as climate and water regulation and purification <u>Risk</u> • Potential disturbance by maintenance and operational vessels • Potential decrease in primary production	Inside windfarms	Jansen et al. (2016)

2 Nature enhancement opportunities from presence of OWFs

OWFs can affect benthic communities and demersal and benthopelagic fish. These changes occur mainly below the sea surface and are referred to as the *artificial reef effect.* Artificial reefs are man-made structures that are placed in the seabed and mimic characteristics of natural reefs. Sometimes, these structures are purposely deployed to improve biodiversity. However, artificial reefs are not always placed for this purpose. Today, such structures are a side effect of *ocean sprawl*. Ocean sprawl reflects the large increase of man-made structures in the sea, such as OWFs (Degraer et al., 2020). In this section, the opportunities and risks of such artificial reefs for nature enhancement are summarized.

2.1 Habitat gain

As OWFs foundations (fixed turbines) are made of hard substrate, they offer new habitat opportunities for hard substrate species (Degraer et al., 2020; Glarou et al., 2020). Originally, there were some types of native hard substrate in the Southern North Seas (e.g., mussel banks, oyster reefs and polychaete (*Sabellaria*) reefs), but they have almost all disappeared as a result of demersal fisheries (bottom trawling). Hard substrates increase habitat complexity, attachment opportunities and the availability of shelter and thereby attracting many species (North Sea Foundation, 2022). OWF structures often provide two types of artificial habitats: 1) hard vertical substrates and 2) a complex range of horizontal habitats, depending on the type of foundation and degree of scour protection (see **Error! Reference source not found.**).

After monopiles are placed, a rapid colonization of all submerged parts by a variety of fouling organisms starts. In general, biofouling communities on offshore installations are dominated by macroalgae, mussels and barnacles near the water surface; filter-feeding arthropods at intermediate depths; and anemones in deeper locations (see Figure 2). Additionally, larger species such as lobsters and crabs seem to benefit from the presence of the structures and the biofouling community. In the study of Rumes et al. (2013) a substantial increase in autumn biomass is shown. However, besides the opportunities for habitat gain, there is also the loss of soft sediment habitats. Windfarms are often developed in a soft sediment environment, and therefore are introducing hard substrate to this environment. It is expected that the introduction of new habitats is beneficial for some species but can be at the cost of others (North Sea Foundation, 2022). To determine the (long-term) effects of habitat gain from OWFs, more research and monitoring through experimental pilot projects is needed.

An additional risk that should be considered is that the positive effects from habitat gain are lost after decommissioning of the OWF.

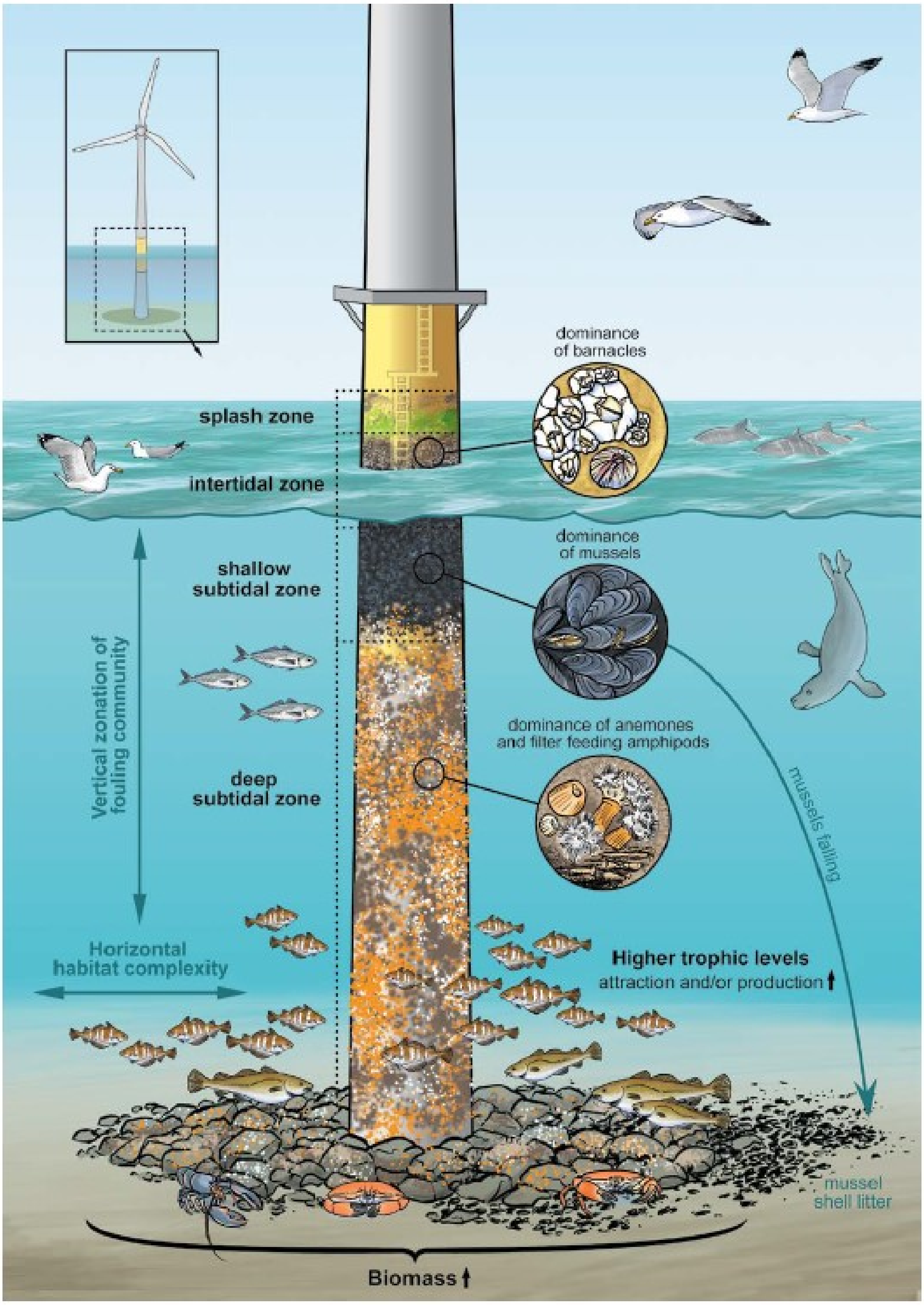

Figure 2 OWF structures offer an introduced habitat type for invertebrate organisms that grow on turbine foundations and attract other species, including crustaceans, fish, crustaceans, fish, marine mammals, and seabirds (Degraer et al., 2020).

2.2 Biodiversity hotspots

As described in the previous paragraph, the presence of OWF foundations introduces new habitat by the growth of new flora and fauna. This addition of new habitat may enhance settlement, survival and/or growth and therefore increase production (Degraer et al., 2020). As a result of the attraction of many different species to the new habitats, *biodiversity hotspots* may arise. This is further explained in this paragraph.

The placement of OWFs will create settlement opportunities for epibenthic fauna and thereby create biodiversity hotspots (Bureau Waardenburg, 2020). OWFs offer new habitat opportunities for invertebrates, such as mussels, starfish, hydroids and crustaceans. As a consequence, this change in habitat also provides opportunities for other species, like hard substrate associated fish species. For instance, the increase in fish abundance can be caused by an attraction of individuals that aggregate near hard structures. Van Hal et al. (2012; 2017) shows that five years after constructing an OWF, catches indicated pouting, long spined-sea scorpion, common dragonet, cod and bullrout that were attracted to the hard substrate. Also, species not caught in the area before were found, like goldsinny wrasse and grey triggerfish (North Sea Foundation, 2022). In this study, there were high abundances of fish some days, while during other days, the fish were spread more equally throughout the OWF. In addition, seasonal patterns were found in the aggregation level of fish. In general, three types of fish species that are attracted to OWFs can be observed: 1) species that predate the biofouling community for a prolonged period (such as the Atlantic cod); 2) species that are attracted for non-trophic reasons, such as finding shelter or mating partners (such as the Atlantic mackerel) and; 3) species that occasionally predate the biofouling community (such as the Atlantic horse mackerel) (Degraer et al., 2020). The survival and/or growth rates of these species are often higher in hard substrate habitats, as they have higher complexity and provide more shelter against predation in comparison to sandy habitats (Schwartzbach et al, 2020).

The increase of hard substrate in an environment that largely consists of soft substrate can lead to the spread of hard substrate species by facilitating migration and creating new dispersal pathways. This is called the *steppingstone effect*. The *biodiversity hotspots* that are created can act as *steppingstones* for species distribution. Distribution of species to other areas will be easier and potentially further offshore than they would normally reach. This provides opportunities for indigenous (native) as well as non-indigenous (invasive) species. Therefore, besides being an opportunity (potential positive effect), this can be considered a risk (potential negative effect) (North Sea Foundation, 2022; Slavik et al, 2018). An example of an invasive non-native species in some areas is the Pacific oyster. In some areas the Pacific oyster competes with the native blue mussel and thereby poses a threat to blue mussel beds (North Sea Foundation, 2022).

Besides opportunities (and risks) for nature underwater, there are also opportunities (and risks) above water. In general, birds are expected to suffer more from habitat loss than other species groups. However, some birds have shown to be attracted towards OWFs. This is often linked to the enhanced food availability or roosting possibilities due to the artificial reef effect or the colonization of the intertidal zone of the foundation by benthic communities. Examples are the great back-backed gull and the great cormorants (North Sea Foundation, 2022). Unfortunately, the downside of this attraction is the substantial risk of collision.

Overall, OWFs contributes to the number, size and geographical distribution of artificial reef habitats, and species with affinity to hard substrate are likely to occupy this habitat (Degraer et al., 2020). When decommissioning OWFs, this can lead to loss of hard substrate, removal of no-take zones around the OWFs and the loss of biological communities that have developed on the infrastructure (Fowler et al., 2020). Therefore, understanding the role of this kind of artificial habitats in maintaining local populations of species is important.

2.3 Altered food webs and ecosystem processes

Monopiles in the North Sea and Celtic Sea are mainly colonized by high densities of suspension (or filter) feeders, predominantly blue mussels. Suspension feeders filter the water by removing particles from the water column, resulting in lower turbidity, and increased light penetration. They consume and grow by filtering edible and organic particles from the water column, including primary producers, and excrete the inedible and excess particles as faecal pellets. This excretion provides a food source for pelagic species and enriches the soft sediment surrounding the turbines in an OWF, thus providing a source of nutrients and food for other marine organisms, stimulating secondary and tertiary production. This *biofilter effect* (illustrated in Figure 3) is demonstrated on a local scale and in laboratories and might result in large-scale effects with the upscaling of OW. Over 95% of the biomass on artificial structures can be composed of a variety of suspension feeders. Several are very resource flexible and can switch between suspended food sources. However, a thorough understanding of the biofilter effect is still lacking (Degraer et al., 2020).

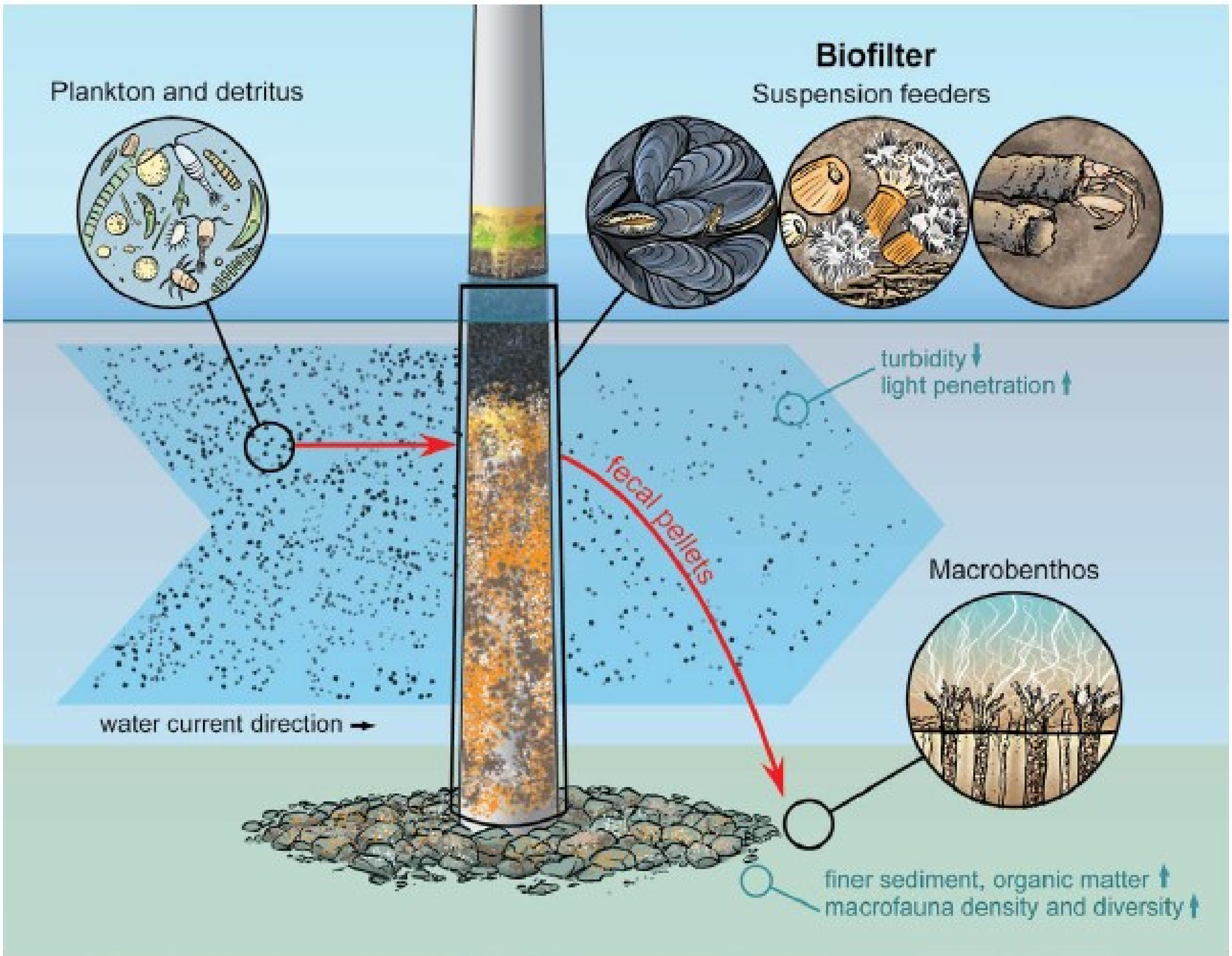

Figure 3 Biofilter effect (Degraer et al., 2020).

2.4 Exclusion of fisheries

Current national legislations do not allow commercial fishing or shipping within OWFs in most North Seas countries for safety reasons (Bergström et al., 2014). In the UK, commercial fishing inside OWFs is allowed, taking safety zones around turbines and periods of maintenance into consideration. The exclusion of fisheries could have both positive and negative effects. It is suggested by some (Ashley et al., 2013; Slavik et al., 2018) that by excluding fisheries from OWFs, it could lead to these areas functioning as marine protected areas (MPAs). However, OWFs are not designed as 'conservation management tools' and therefore lack the design elements of MPAs that have successfully contributed to enhanced fishery resources in other areas (Gill et al., 2020).

As a result of fishery exclusion from OWFs, species that have limited local production because of bycatch mortality or commercial fishing might increase in size, biomass and numerical density. In addition, *spill-over effects* are possible, depending on the degree of overfishing of the resource in general and spatial scale of the closed areas. The *spill-over effect* means that species grow so well in a no-take zone, that they start to exist outside this zone as well. Furthermore, excluding bottom-towed gear (dredges and trawls) from fishing activities will reduce the impacts on habitat complexity, benthic biomass and biodiversity, which potentially have positive impacts on managed fish populations and the overall occurring biodiversity (Gill et al., 2020). In the interview with Deltares, the exclusion of fisheries was mentioned as probably the largest opportunity for nature enhancement in OWFs, as it provides a change for species to recover and allows for the succession of the marine ecosystem. In a study of Püts et al. (2023) one example is mentioned where closed areas had a positive impact on the local biomass of benthic species. In Georges Bank on the U.S. and Canadian coast, large-scale areas were closed to protect spawning habitats of bottom-dwelling fish after being heavily exploited in the decades before. As a result, these closures led to an increase in the yellowtail flounder, cod, haddock population and scallops.

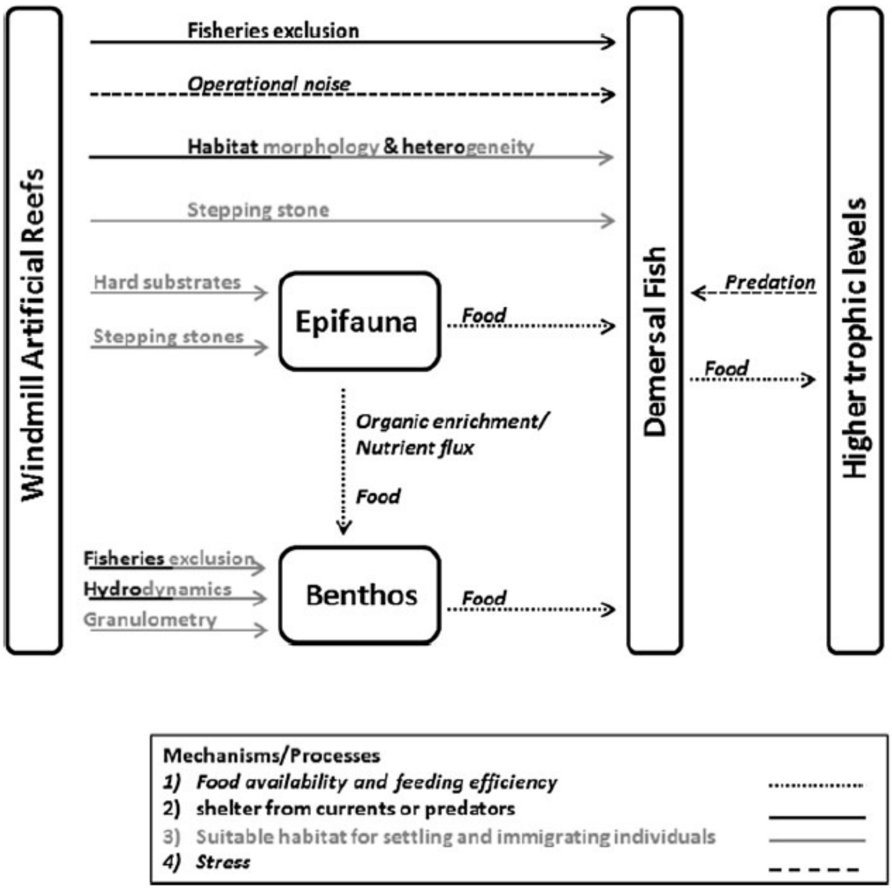

Figure 4 Schematic overview of the most relevant reef effects influencing fish production at OWFs (Reubens et al., 2014)

On the other hand, the exclusion of fisheries within OWFs can also lead to an increase in predation risk by attracted predators, e.g., seabirds. Subsequently, seabirds are at risk of mortality through collision with the OWFs. Additionally, there could be increasing fishing pressure from attracted fisheries just outside the OWFs (Gill et al., 2020). The model results in the study of Püts et al. (2023) show that fishing effort redistribution increased fishing pressure outside the closed areas (and especially at MPA borders) as a consequence of *spill-over* of fish biomass in the model. The reduction of fishing activity within the OWF might additionally lead to spatial redistribution in fishing effort to areas outside the windfarm, potentially leading to unintended negative impacts on previously less impacted sensitive habitats (Gill et al., 2020).

2.5 Sphere of influence

Frequently, research on ecosystems is performed on a small scale. Also, with respect to the artificial reef effect, the changes are most obvious at the scale of the turbine and its surrounding area. In the context of ecosystems, these first-order effects could be considered trivial, but small-scale changes can be the start of large-scale changes. These changes can result in potential regional effects on ecosystem processes and the marine food web. Subsequently, these changes can lead to effects on components important to ecosystem services such as commercial fisheries.

The artificial reef effect is not restricted to the structure themselves, but extends in four dimensions (as illustrated in Figure 5): i.e., 1) the two horizontal dimensions (distance from source of disturbance); 2) the vertical spatial dimension (throughout the water column and in the air) and 3) time (seasonal and yearly variation) (Degrear et al., 2018). Understanding how these different temporal and spatial effects can be translated to the population dynamics of those species is key to understanding the impact of OWF artificial reefs on the ecosystem on a regional sea scale. However, this is not yet fully understood (Degrear et al., 2020).

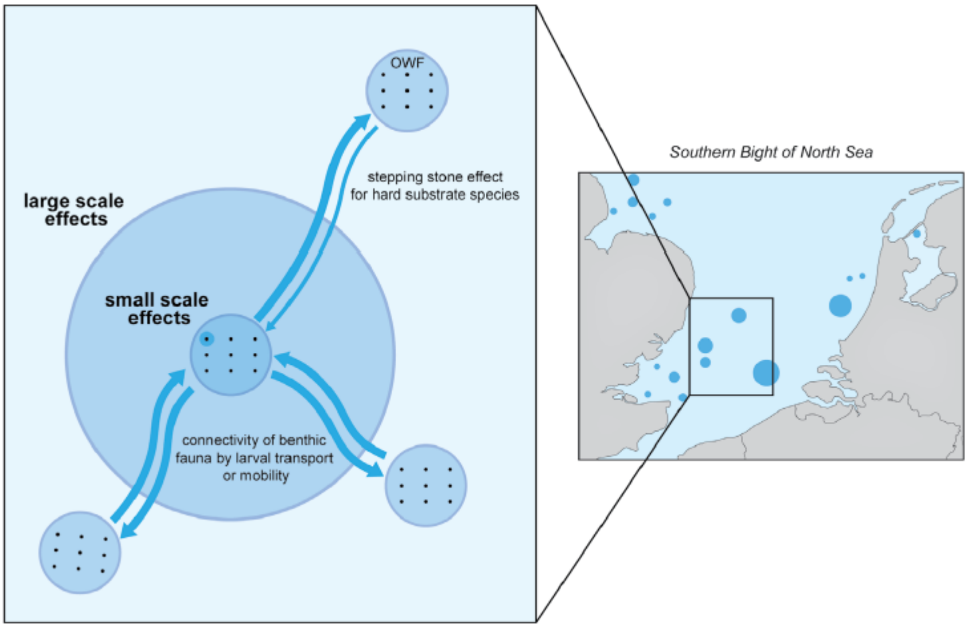

Figure 5 The artificial reef effect is particularly seen at the scale of the wind turbine and windfarm (small-scale), but some effects can extend well beyond the scale of a single windfarm (large-scale effect). This can be illustrated by the increased connectivity of hard substrate species (Degraer et al., 2020; Degraer et al., 2018).

3 Opportunities and risks from additional measures

Besides the opportunities (and risks) for nature through the presence of OWF structures, additional measures can be taken that offer opportunities for nature enhancement. In this section, nature-inclusive design (NID) is described as opportunity for nature enhancement and multi-use as additional opportunity.

3.1 Nature-inclusive design

Design principles

OWFs can be designed in a nature-inclusive way, in which the design and construction of windfarms include the potential to enhance natural resources, ecological functioning and biodiversity at the scale of a turbine (Lengkeek et al., 2017; Kamermans, 2018). Different studies (Glarou et al. (2020); Lengkeek et al. (2017); Hermans et al. (2020)) present a range of ecosystem functions that might be enhanced by modifying the scour protection and/or the OWF-foundations (see Appendix A1). Theoretically, the largest positive effects will be gained when the scour protection (or other design principles) are implemented at all suitable turbine locations in the OWFs (Lengkeek et al., 2017).

As described in the previous chapter, possible effects of successfully introduced new (hard substrate) habitats are increased population size and number of species and an increase in overall biodiversity (see Figure 6). An optimized scour protection to benefit nature will allow epifauna like mussels and anemones to attach themselves. This new habitat with smaller crevices provides food and shelter and will attract small and larger crustaceans like crabs and lobsters. This in turn will attract a variety of small and larger fish species, and ultimately also larger predators like sharks, rays, marine mammals and sea birds. Lengkeek et al. (2017) points out that 'the list of species is too broad and the information too sparse to design optimized scour protection for each species separately' (p. 79). By seeking common ground for a potential improvement for a large share of species, it might be feasible to increase the abundance of the focal species with limited effort (Lengkeek et al., 2017). To enable epifauna to attach themselves the chemical characteristics of the scour protection materials are critical (Ido & Shimrit, 2015). For instance, regular concrete is found not to be suitable for this purpose due to its high pH-value. Furthermore, non-indigenous (invasive) species are more likely to attach and settle on concrete than indigenous species (Airoldi et al., 2015; Glasby et al., 2007), providing a potentially negative effect.

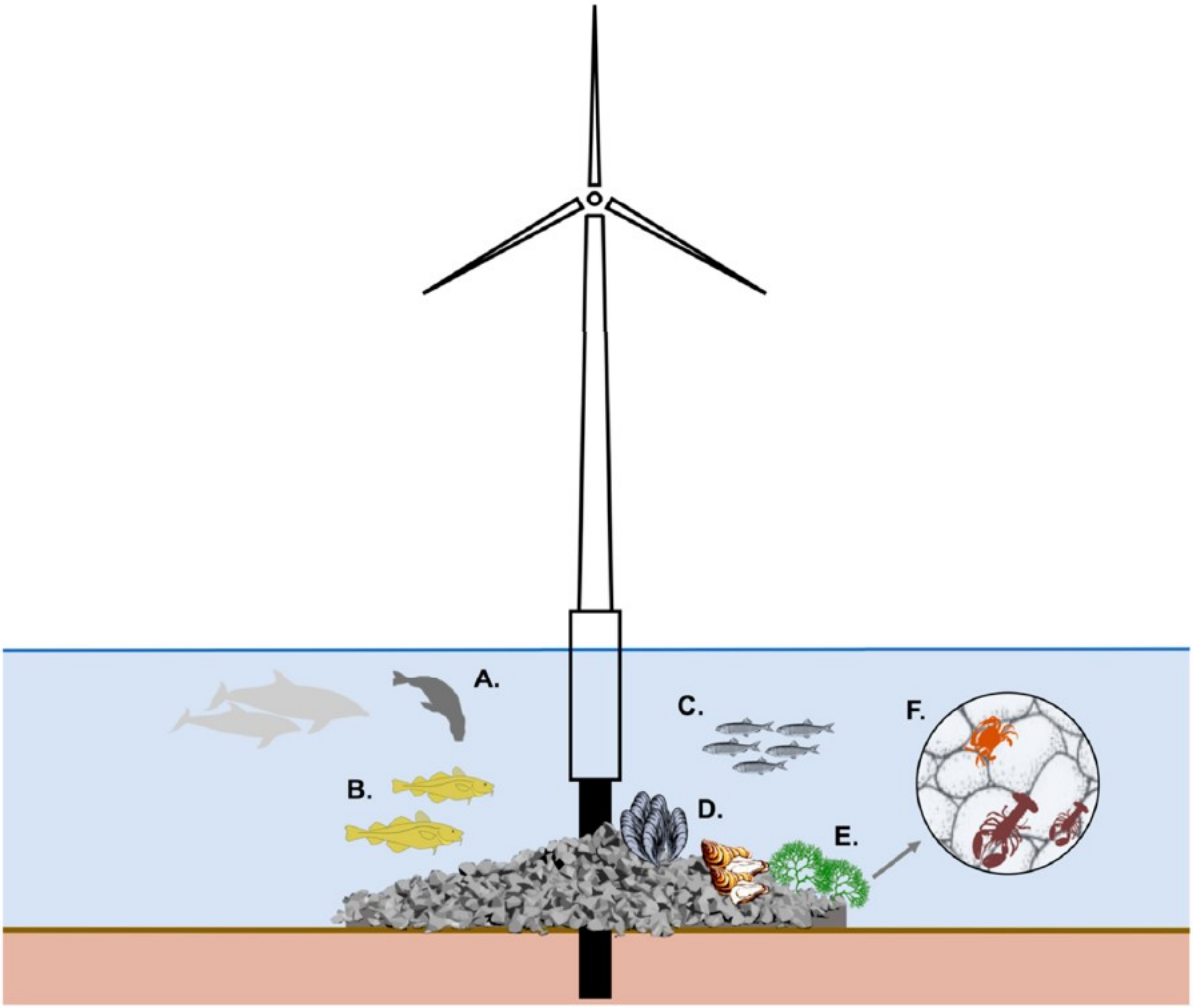

Figure 6 Conceptual illustration of offshore wind turbine and proposed ecological functions of scour protection. Reviewed evidence reveals that scour protection may provide food, shelter, and reproduction grounds for fish, as well as settlement grounds for bivalves and macroalgae. Examples show species that could benefit from improved scour protection designs: (A) Marine mammal feeding grounds; (B) Atlantic cod, utilizing scour protection structures; (C) Atlantic herring, utilizing scour protection for spawning; (D) Mussel and oyster banks; (E) Macro algal restoration; (F) Shelter for shellfish (Glarou et al., 2020).

Additionally, there are opportunities to further enhance nature and biodiversity at the site of an OWF by adding additional artificial reefs, like reef balls (The Rich North Sea, 2018; van Duren et al., 2016; VLIZ, 2023).

The expected benefits of nature-inclusive design options are to increase the numbers of biomass of species and increase biodiversity. However, it should be noted that the ecological benefits of the proposed nature-inclusive design options have not yet been researched and quantified in the field. Therefore, it cannot be stated to what extent these principles are contributing to nature (Hermans et al., 2020).

In addition, besides opportunities, the implementation of nature-inclusive designs has both ecological and technical risks. Examples of (theoretical) ecological risks are: 1) lack of ecological succession; 2) Settlement of non-indigenous species; 3) competition between target species; 4) absence of target species and 5) food limitation for target species.

Figure 7 below shows an overview of the top five technical and ecological risks associated with nature-inclusive design resulting from expert consultation (Hermans et al., 2020).

#		Risk description	Cause	Consequences	Likelihood	Technical impact	Potential ecological impact	Risk	Mitigation measures
T-1	Technical	Structural failure of primary structure	Uncertainties in the environmental loads	(Temporary) loss of function	2 small	5 very high	1 neutral	Medium	Periodic inspection and scheduled maintenance
T-2	Technical	Structural failure of NID	Uncertainties in the environmental loads	Damaging primary structure	3 average	4 high	3 negative	High	Periodic inspection, repairments, removal of NID
T-3	Technical	Biofouling	Settlement of non-organisms on structures	Additional drag, blocking of habitat by non-target species	4 high	4 high	2 small negative	High	Account for in design, periodic inspection and removal of NID if required
T-4	Technical	Design failure in placement phase	Environmental circumstances different than expected, use of sub-optimal equipment	Damage to primary structure, improper placement	2 small	4 high	2 small negative	Medium	Correct weather window, detailed morphological survey, optimal equipment
T-5	Technical	Unforeseen costs	Uncertainties, lack of experience	Overdimensioning	4 high	1 neutral	1 neutral	Low	Interdisciplinary collaboration, contact regulatory bodies, financial buffer
E-1	Ecological	Lack of ecological success	Uncertainties, lack of experience, unpredictable environmental factors	Resources wasted and NID reputation damage	4 high	1 neutral	3 negative	Medium	No regret measure, define goals of pilot accordingly
E-2	Ecological	Settlement of non-indigenous species	(non specific) artificial structures	No or smaller population of indigenous (target) species	4 high	1 neutral	3 negative	Medium	Specify design for target species, stock enhancement of target species
E-3	Ecological	Competition between target species	Overlapping habitat, predation	Increased mortality target species	4 high	1 neutral	1 neutral	Low	Gain experience
E-4	Ecological	Absence of target species	Lack of stock population, unsuitable environment, lack of settlement cues from environment	Limited biological impact	4 high	1 neutral	1 neutral	Low	Site assessment, stock enhancement
E-5	Ecological	Food limitation for target species	Competition for food, limited biological activity	Decreased settlement success	3 average	1 neutral	3 negative	Medium	Site selection, baseline monitoring

Figure 7 Top five technical and ecological risks associated with nature-inclusive design.

A more elaborate list of nature-inclusive design options and potential risks is included in **Error! Reference source not found.**. An additional risk to be considered is that potential positive effects from nature-inclusive design are lost after decommissioning of the OWF.

3.2 Restoration of flat oyster beds

Besides technical interventions, the restoration of flat oyster beds is a promising opportunity for nature enhancement in OWFs. Once, the North Seas contained large areas with European (native) flat oyster reefs (*Ostrea edulis*). Oyster beds are one of the most striking structures in soft-sediment environments and provide many ecosystem services, such as: pelagic-benthic ecosystem coupling, providing habitat, water quality regulation and shoreline stabilization (Kamermans et al., 2018). Several windfarms in the North Sea are suitable locations for the development of flat oyster beds (Figure 8) (Herman & van Rees, 2022). The scour protection around the wind turbines can be made suitable for the settlement of flat oysters (see treatment 4 in Figure 9) (Lengkeek et al., 2017). Subsequently, the oyster beds provide food and shelter for mobile invertebrates, settlement substrate for flora and fauna. Additionally, fish can use the beds as spawning grounds and for shelter (Kamermans et al., 2018). This can offer support for the restoration of ecosystem functioning, the achievement of biodiversity goals and enhancement of ecosystem services (Glarou et al., 2020).

Figure 8 Shells of the European flat oyster provide habitat for epibenthic flora and fauna (Kamermans et al., 2018)

The reason that OWFs offer such great potential for the restoration of oyster beds is the fact that in the current regulatory framework, OWFs are free from seabed-disturbing activities. This is regarded as a major precondition for the restoration of oyster beds (Kamermans et al., 2018). Other crucial (habitat) factors for the development of flat oyster beds in OWFs in the North Sea: 1) sediment composition; 2) large scale and small-scale seabed dynamics; 3) suspended particle levels in the water column and 4) the possibility of successful recruitment (Smaal et al., 2017). As the introduction of more hard substrate to the North Seas seems promising, soft bottom species might be vulnerable when hard substrate is introduced in their ecosystem, as soft-bottom habitat is eliminated. However, more studies are needed to determine the effect of the development of hard substrate on the protection on soft bottom species (Glarou et al., 2020).

3.3 Multi-use

Besides opportunities to enhance nature within an OWF, there are opportunities for multi-use. In multi-use scenario's two or more activities are developed together, or an activity is added to existing activities' (Steins et al., 2021, p.2). There are four different types of multi-use: 1) multi-purpose or multi-functional use, where different users operate in the same area, at the same time, with shared services and infrastructure; 2) symbiotic use, where users also operate in the same area, at the same time, but only share peripheral services and infrastructure; 3) co-existence or co-location, where users only share the same space at the same time; and, 4) subsequent use or repurposing, where uses take place in the same area, but in subsequent order (Steins et al., 2021).

Two forms of multi-use were mentioned that might offer opportunities for nature enhancement: mussel farming and seaweed production (pers. comm. North Sea Foundation and Luca van Duren, 2023).

The cultivation of seaweed in OWFs can have environmental effects. Opportunities for nature enhancement might include the use of the seaweed farm for providing shelter for species or using seaweed for the bioremediation of contaminants. However, seaweed farming might also have negative effects, such as potential changes to the ecosystem, a decrease in primary production (even with relatively moderate upscaling of seaweed cultivation (as was demonstrated in a data-modelling study by Vilmin & van Duren, 2021) or effects on biodiversity (introducing of invasive species) (van den Burg et al., 2020).

Second, mussel aquaculture has the potential to provide ecosystem services, such as climate and water regulation, waste assimilation and biodiversity. The most acknowledged ecosystem service from bivalve culture is the (top-down) control of eutrophication (Jansen et al., 2016). For the planning and up-scaling of mussel farming, it is necessary to provide insights into the maximum level that can be sustained in the given area. This can be done by conducting carrying capacity assessments (Jansen et al., 2016). Roycroft et al. (2006) show that the physical presence of suspended mussel culture does not seem to induce adverse effects on the numbers of seal and seabirds. Additionally, the presence of operation and maintenance vessels may cause disturbance, but it is assumed that this only has a minor impact (Jansen et al., 2016).

4 Conclusions and recommendations

This chapter contains a summary of the main opportunities, risks, and recommendations for nature enhancement from the development of OW. These are based on the reviewed literature, conducted interviews with subject matter experts and advice from the authors of this report.

4.1 Main opportunities, risks and knowledge gaps

The main potential opportunities for nature enhancement and their associated risks are:

- Strong potential for increased local biodiversity through the introduction of hard substrate.
  - Risk: It is likely that with the introduction of hard substrate in an otherwise soft sediment environment, non-indigenous (invasive) species will settle and spread.
- Improved local habitat complexity, benthic biomass, biodiversity and positive effects on fish populations (with potential *spill-over effect*) through the exclusion of fisheries inside OWFs.
  - Risk: Increased fishing pressure around OWFs.
- Nature inclusive design and the use of optimized scour protection offers potential in specific areas for the restoration of native (flat) oyster beds. See appendix A1 for additional nature-inclusive design options and risks.
  - Risks: Lack of ecological success, alternation of the marine food web and unknown ecosystem effects, spread of invasive species.
- Measures to increase nature enhancement often provide opportunities for some species but bring risks for other species.

OWFs also provide opportunities for multi-use. The main opportunities as identified through literature and consultation of subject matter experts are:

- Different types of energy production.
- Shellfish (mussel) cultivation.

Nature-inclusive design seems promising for nature enhancement within OWFs, but this has often not yet been tested and the effects on marine ecology are therefore often unknown. Initial knowledge and insights are developed through pilot projects and monitoring, however, this knowledge is often mainly on local and small-scale effects. Insights in ecosystem-scale effects, regional effects, and effects from the upscaling of OW are still limited. Hence it can be concluded that the full picture of potential opportunities and risks from the large upscaling of OW in the North Seas in the future (and in a changing environment) are not yet known.

4.2 Recommendations

4.2.1 Generic recommendations

- It is recommended to determine goals (or targets) for OWFs, e.g., as a site for energy production, nature restoration or enhancement, food production, or a combination of those. Goals should be set depending on the most appropriate location for its purpose, e.g., conduct oyster reef restoration where there is a likelihood of these reefs to naturally recover (without human intervention).

- It is recommended to consider the decommissioning of an OWF at an early (starting) stage of development. Preferably, plans for decommissioning and mitigating its effects on nature should be included in a tender bid.
- It is recommended to continue and accelerate international discussions on the legal implications and solutions for decommissioning to the benefit of nature.

4.2.2 Recommendations regarding multi-use

- It is recommended from an biodiversity perspective to exclude fisheries within OWFs since they have demonstrated to provide a refuge and foraging ground for several benthopelagic fish species. This potentially enables the recovery of exploited fish stocks and increase local biodiversity. This is supported by the following arguments (Reubens et al., 2014):
    - Dominance of juvenile fish inside the OWF (below landing size)
    - Seasonality in fish presence and abundance (demonstrating *spill-over effect* benefiting fisheries)
    - Scope for OWFs to function as fisheries closures (benefit of *de facto* MPAs generally leading to an increase in density, biomass, diversity, and individual fish sizes)
    - Lack of proof of production at regional scale (which can lead to overfishing since fish aggregate at OWF making them an 'easy target')
- Particularly active fishing techniques like demersal bottom trawling should (continue to) be excluded inside and around the close vicinity of OWFs. Potentially, passive fishing techniques can be allowed as multi-use function within an OWF. However, this should not work to counteract goals for nature enhancement (L. A. van Duren, personal communication, 17 April 2023).
- Note that OWFs provide areas of opportunity for fisheries exclusion, however this function depends on their location, since OWFs are not always in the most appropriate (natural) areas as fish habitat. More importantly, the designation of marine protected areas (MPAs) or marine reserves should be based on the natural importance of that region for a multitude of species and should be part of (inter)national marine spatial planning (MSP) (Reubens et al., 2014).

4.2.3 Recommendations for further research

- To stimulate more research on the understanding of the effects of nature enhancement opportunities and whether these are positive or negative (and for which species).
- To stimulate more pilots and extensive monitoring (including on a regional scale) to enable better judgement on the mentioned effects on marine ecology from OWF developments. The following topics of research are suggested as priorities.
    - restoration of oyster reefs
    - shellfish culture
    - carrying capacity
    - effects from the exclusion of fisheries on fish production incl. target species
    - different scour protection structures and materials
    - larvae dispersal
    - potential spread of invasives
- It is recommended to assess the effects from OW for each ecosystem component in cumulation with other anthropogenic pressures, preferably incorporating the effects from climate change. This should enable the assessment of the actual cumulative effects of all anthropogenic pressures on the various ecosystem components and its impact on the ecology in the North Sea and Celtic Sea. This assessment should include the level of impact from each anthropogenic pressure in order to prioritize measures and mitigations.

- It is important that the international collaboration on the effects from OWF on marine ecology is strengthened. Particularly the collaboration and knowledge sharing in research and mitigating measures and the collaboration in marine spatial planning by governments can be improved. It is recommended that an international research program is developed where cross-boundary research topics are jointly funded and coordinated by governments and knowledge gaps are addressed by a collaborating team of international scientists. (pers. comm. Luca van Duren, 2023)

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References / sources

Airoldi, L., Turon, X., Perkol-Finkel, S., & Rius, M. (2015). Corridors for aliens but not for natives: Effects of marine urban sprawl at a regional scale. Diversity and Distributions, 21(7), 755–768.

Bergström, L., Kautsky, L., Malm, T., Rosenberg, R., Wahlberg, M., Capetillo, N. Å., & Wilhelmsson, D. (2014). Effects of offshore wind farms on marine wildlife—a generalized impact assessment. *Environmental Research Letters*, *9*(3), 034012.

Bureau Waardenburg (2020). Options for biodiversity enhancement in offshore windfarms. Retrieved from Microsoft Word - 18-0660 The Rich North Sea- options for biodiversity enhancement in OWFs 07022020.docx kopie (buwa.nl)

Degraer, S., Carey, D. A., Coolen, J. W., Hutchison, Z. L., Kerckhof, F., Rumes, B., & Vanaverbeke, J. (2020). Offshore wind farm artificial reefs affect ecosystem structure and functioning. Oceanography, 33(4), 48-57.

Degraer, S., Brabant, R., Rumes, B., & Vigin, L. (2018). Environmental impacts of offshore wind farms in the Belgian part of the North Sea. Scientific Reports Series: Memoirs on the Marine Environment.

Fowler, A. M., Jørgensen, A. M., Coolen, J. W., Jones, D. O., Svendsen, J. C., Brabant, R., ... & Degraer, S. (2020). The ecology of infrastructure decommissioning in the North Sea: what we need to know and how to achieve it. ICES Journal of Marine Science, 77(3), 1109-1126.

Gill, A. B., Degraer, S., Lipsky, A., Mavraki, N., Methratta, E., & Brabant, R. (2020). Setting the context for offshore wind development effects on fish and fisheries. Oceanography, 33(4), 118-127.

Glarou, M., Zrust, M., & Svendsen, J. C. (2020). Using artificial-reef knowledge to enhance the ecological function of offshore wind turbine foundations: Implications for fish abundance and diversity. Journal of Marine Science and Engineering, 8(5), 332.

Glasby, T. M., Connell, S. D., Holloway, M. G., & Hewitt, C. L. (2007). Nonindigenous biota on artificial structures: Could habitat creation facilitate biological invasions? Marine Biology, 151(3), 887–895.

Halouani, G., Villanueva, C. M., Raoux, A., Dauvin, J. C., Lasram, F. B. R., Foucher, E., ... & Niquil, N. (2020). A spatial food web model to investigate potential spillover effects of a fishery closure in an offshore wind farm. *Journal of Marine Systems*, *212*, 103434.

Herman, P. M. J., & Van Rees, F. F. (2022). Mapping Reef forming North Sea Species. 11207716-000-ZKS-0001, Deltares, Delft.

Hermans, A., Bos, O. G., & Prusina, I. (2020). *Nature-Inclusive Design: a catalogue for offshore wind infrastructure: Technical report* (No. 114266/20-004.274). Witteveen+ Bos.

Ido, S., & Shimrit, P.-F. (2015). Blue is the new green–ecological enhancement of concrete based coastal and marine infrastructure. Ecological Engineering, 84, 260–272.

Jansen, H. M., Van Den Burg, S., Bolman, B., Jak, R. G., Kamermans, P., Poelman, M., & Stuiver, M. (2016). The feasibility of offshore aquaculture and its potential for multi-use in the North Sea. Aquaculture international, 24, 735-756.

Lengkeek et al. (2017). Eco-friendly design of scour protection: potential enhancement of ecological functioning in offshore windfarms.

North Sea Foundation (2022). The potential ecological effects of habitat gain and loss posed by offshore windfarms.

Reubens, J. T., Degraer, S., & Vincx, M. (2014). The ecology of benthopelagic fishes at offshore wind farms: A synthesis of 4 years of research. Hydrobiologia, 727(1), 121–136. https://doi.org/10.1007/s10750-013-1793-1

Roycroft, D., Kelly, T. C., & Lewis, L. J. (2007). Behavioural interactions of seabirds with suspended mussel longlines. Aquaculture International, 15, 25-36.

Rumes, B., Coates, D., De Mesel, I., Derweduwen, J., Kerckhof, F., Reubens, J., & Vandendriessche, S. (2013). Does it really matter? Changes in species richness and biomass at different spatial scales. S. Degraer et al, 183-189.

Schwartzbach, A., Behrens, J. W., & Svendsen, J. C. (2020). Atlantic cod Gadus morhua save energy on stone reefs: Implications for the attraction versus production debate in relation to reefs. Marine Ecology Progress Series, 635, 81-87.

Slavik, K., Lemmen, C., Zhang, W., Kerimoglu, O., Klingbeil, K., & Wirtz, K. W. (2018). The large scale impact of offshore wind farm structures on pelagic primary productivity in the southern North Sea (arXiv:1709.02386). arXiv. http://arxiv.org/abs/1709.02386

Stichting de Noordzee (2023, April 13). *Interview cumulative ecosystem effects offshore wind* [Personal communication].

Van den Burg, S. W., Röckmann, C., Banach, J. L., & Van Hoof, L. (2020). Governing risks of multi-use: seaweed aquaculture at offshore wind farms. Frontiers in Marine Science, 7, 60.

Van Duren, L. A. (2023, April 17). *Interview cumulative ecosystem effects offshore wind* [Personal communication].

Van Hal, R., Couperus, B., Fassler, S., Gastauer, S., Griffioen, B., Hintzen, N., Teal, L., van Keeken, O., & Winter, E. (2012). Monitoring- and Evaluation Program Near Shore Wind farm (MEP-NSW)- Fish community (Issue December). https://edepot.wur.nl/251669

Van Hal, R., Griffioen, A. B., & van Keeken, O. A. (2017). Changes in fish communities on a small spatial scale, an effect of increased habitat complexity by an offshore wind farm. Marine Environmental Research, 126, 26–36. https://doi.org/https://doi.org/10.1016/j. marenvres.2017.01.009

Vilmin. L. & van Duren, L. (2021). Modelling seaweed cultivation on the Dutch continental shelf. 11205769-002-ZKS-0001, Deltares, Delft.

Vrooman, J. Schild, G., Rodriguez, A.G., van Hest., F. (2019). North Sea wind farms: ecological risks and opportunities. North Sea Foundation, Utrecht, the Netherlands. Carpenter, J. R., L. Merckelbach, U.

A1 Nature-inclusive design variables and risks

Lengkeek et al. (2017) defined four design variables for optimized scour protection (see Figure 9):
- Adding larger structures than conventional scour protection to create large holes and crevices, to provide shelter for large mobile species (treatment 1)
- Adding more small-scale structures than conventional scour protection to create more small-scale holes and crevices but also attachment substrate and settlement substrate (treatment 2).
- Providing or mimicking natural (biogenic) chemical substrate properties to facilitate species (treatment 3).
- Active introduction of specimens of target species to enhance establishment of new populations (treatment 4).

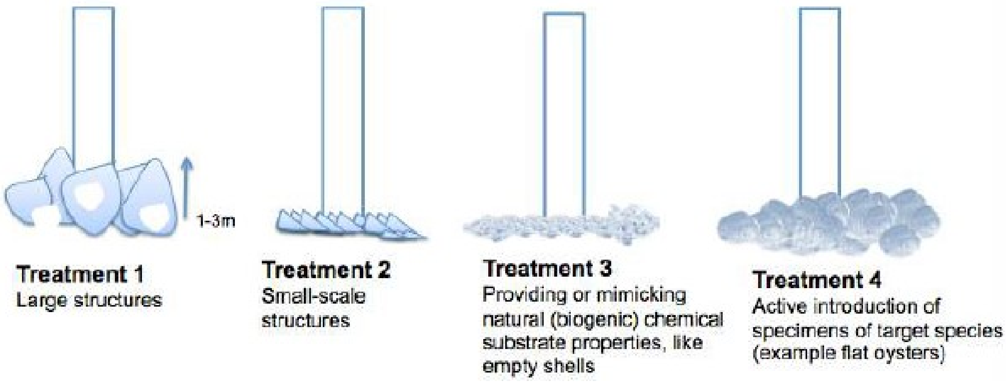

Figure 9 Example of experimental design for scour protection (Lengkeek et al., 2017). Treatments should not be mixed. For research purpose, adding a control treatment (treatment 5) would be beneficial to test the effect of the optimised scour protection.

The design variables for optimized scour protection are considered a first step in a process that should result in learning by doing.

Hermans et al. (2020) offers an overview of promising technological options for nature-inclusive designs. These nature-inclusive design options can be organized in three categories, based on the aspect of the offshore infrastructure they apply to. Next to an optimized scour protection layer, two additional forms of nature-inclusive designs are mentioned:
- Add-on options: this refers to structural additions in a design of an offshore substation (or a monopile) that enhance nature, thus making NID an integral element.
- Optimized cable protection layer: this refers to an optimization of a standard cable protection design for power cables or cable crossings that enhance nature.