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Impacts of OWF installations on fisheries: A Literature Review

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PEER REVIEW

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Comments

The paper summarize a potential environmental impacts of OWFs, recognized from a literature review and gives an comprehensive overview of these impacts on the fish communities during the pre-construction, construction and operation phase of OWFs. The most important benefit of this paper is conclusion that OWF, based on current results, is not believed to impose any significant negative effects on the fish fauna, which is of the outmost importance for a future application of OWFs and discussion on their impact on environment.

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ABSTRACT

There is an increasing demand for energy in the world. It is well known that non-renewable energy reserves will be irreversibly used at some point. The effects of climate change and limited fossil energy resources have led to an increasing interest in generating energy such as electricity from renewable energy resources. Wind energy is currently the most important renewable energy source for electricity generation which is rapidly becoming a key objective of most European and other countries due to a high demand, both economically and politically. Wind energy provides a safe, clean, sustainable and competitive alternative for conventional sources of energy. European countries like Germany, the Netherlands, United Kingdom, Denmark and Sweden are currently operating offshore wind farms (OWFs) and have plans to increase the production of electricity by wind power. The growth of OWFs has raised concerns about their impact on the marine environment. Focus of this review is to show possible impacts of OWFs on the physical and biological environment reviewing existing knowledge from the literature.

KEYWORDS

Offshore Wind Farms (OWF), Fish, Benthos, Ecological effects, Fishery

1. Introduction

The offshore wind-power industry is very young[1]. Offshore Wind Farms (OWFs) were the first time developed worldwide in Denmark in 1991[1,2]. OWFs are also of great importance for reaching the Dutch objective of providing 20% sustainable energy in 2020[3]. A significant expansion of wind energy is expected in Europe in the near future, with increasing emphasis on OWFs[4].

The share of renewable energy for electricity generation in Germany was about 14% in the year 2007 and target of the German Federal Government is to increase this to 30% by 2020[4]. Moreover, wind energy is currently the most important renewable energy source for electricity generation in Germany, with a total share of 6.4%[5]. The share of renewable energies in the entire EU was planned to rise to 20% by 2020[5]. It is also noted that OWFs will contribute as much as 50% of the total Danish national

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consumption of electricity by 2025[6]. The potential impacts of this exploitation on the marine environment are divided into preconstruction, construction and post–construction period with short and/or long term effects[2,7]. These may include disturbing effects from noise, emergence of shadow electromagnetic fields, changes in substrate structure, bottom living fish, invertebrates communities and texture, and changed hydrological conditions[4,6,8].

Effects of OWFs on local environments depend on the different periods of exploration and construction[2]. These effects were illustrated by Elliott and shown in Figures 1 and 2[9,10].

These illustrations indicate the major processes which can potentially result from the development of an OWF and they may impact the surrounding environment[7]. Wilson noted that without a clear understanding of the local conditions, poorly planned OWFs could have a highly detrimental effect

on the ecosystems into which they are placed[7].

Activities which cause short and long term impacts are shown in Table 1.

Table 1

The potential impacts of OWF on the marine environment with short and long term effects[7].

Short term impacts	Long term impacts
Seismic exploration to identify the most appropriate location;	Presence of structures;
Intense noise from ramming, drilling <i>etc.</i> ;	Operational noise and vibrations;
Increased vessel activity from exploration and construction;	Electromagnetic impacts;
Increased turbidity from cable laying;	Increased vessel activities for maintenance.
Decommissioning of wind farms.	

The key issues that will arise during the construction/ decommissioning and operational phase are summarized in Table 2[11].

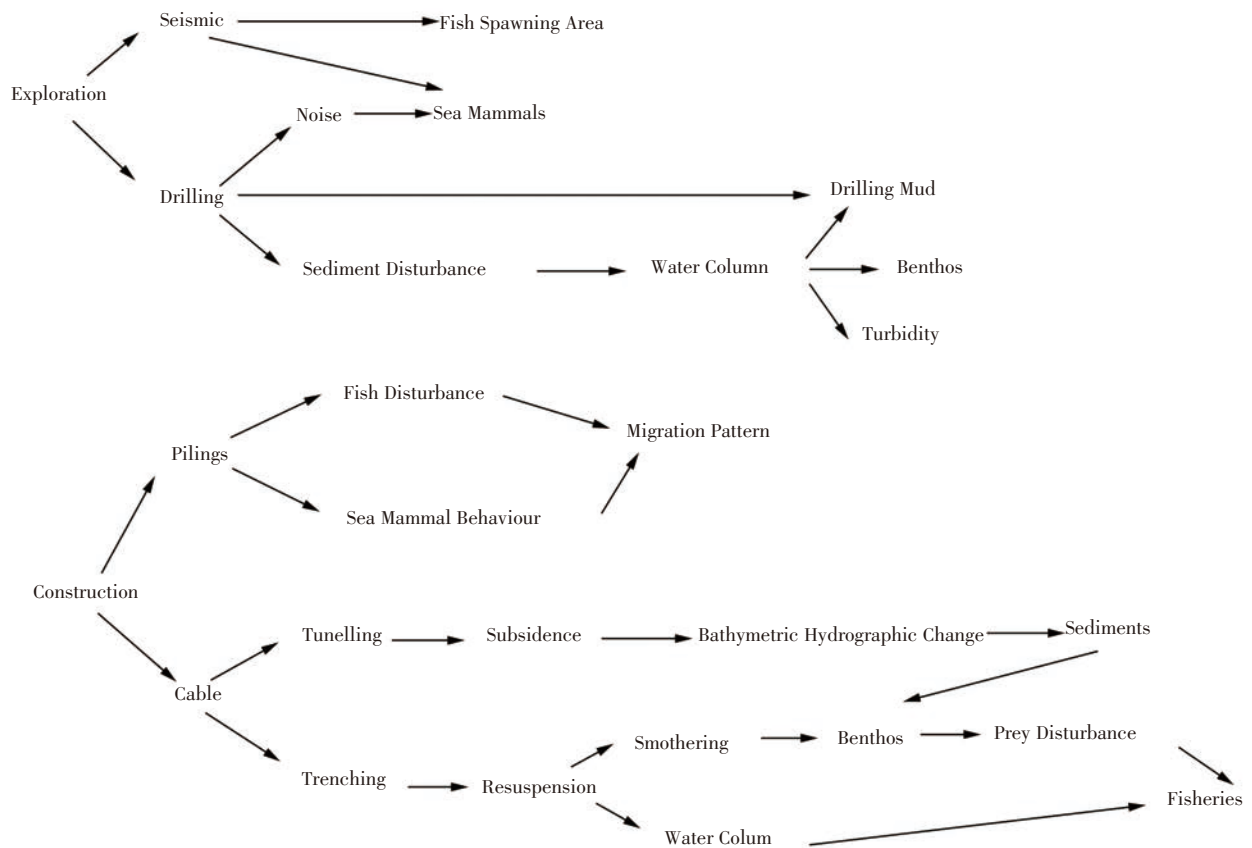


Figure 1. Consequences from the pre–construction/exploration and construction period of an OWF[9,10].

Table 2

Potential environmental impact during the construction/decommissioning and operation phases[11].

Phase	Potential impact
Construction activities:	Noise disturbance from piling on fish populations and spawning/nursery grounds during installation of pile foundations, increased suspended sediment, scour and sedimentation arising from installation (or removal) of turbine foundations and cable, temporary and met mast installation, and presence of disturbance/loss of fish and shellfish habitat under inter–array cables, prepared ground and construction plant movements.
Decommissioning: (Dredging, cable laying, turbine, offshore substation and met mast installation, and presence of construction plant)	
Physical presence:	Noise and vibration, electromagnetic fields, disturbance–maintenance activities, permanent loss of fish and shellfish sea bed habitat and creation of new habitat due to the presence of turbines, met masts and substation foundations and scour protection, barrier effects (fish migration, spawning <i>etc.</i>), hydrodynamics, sediment transport, other users (access and navigation).
Operation: (Presence of turbines, foundations, scour protection and substations)	

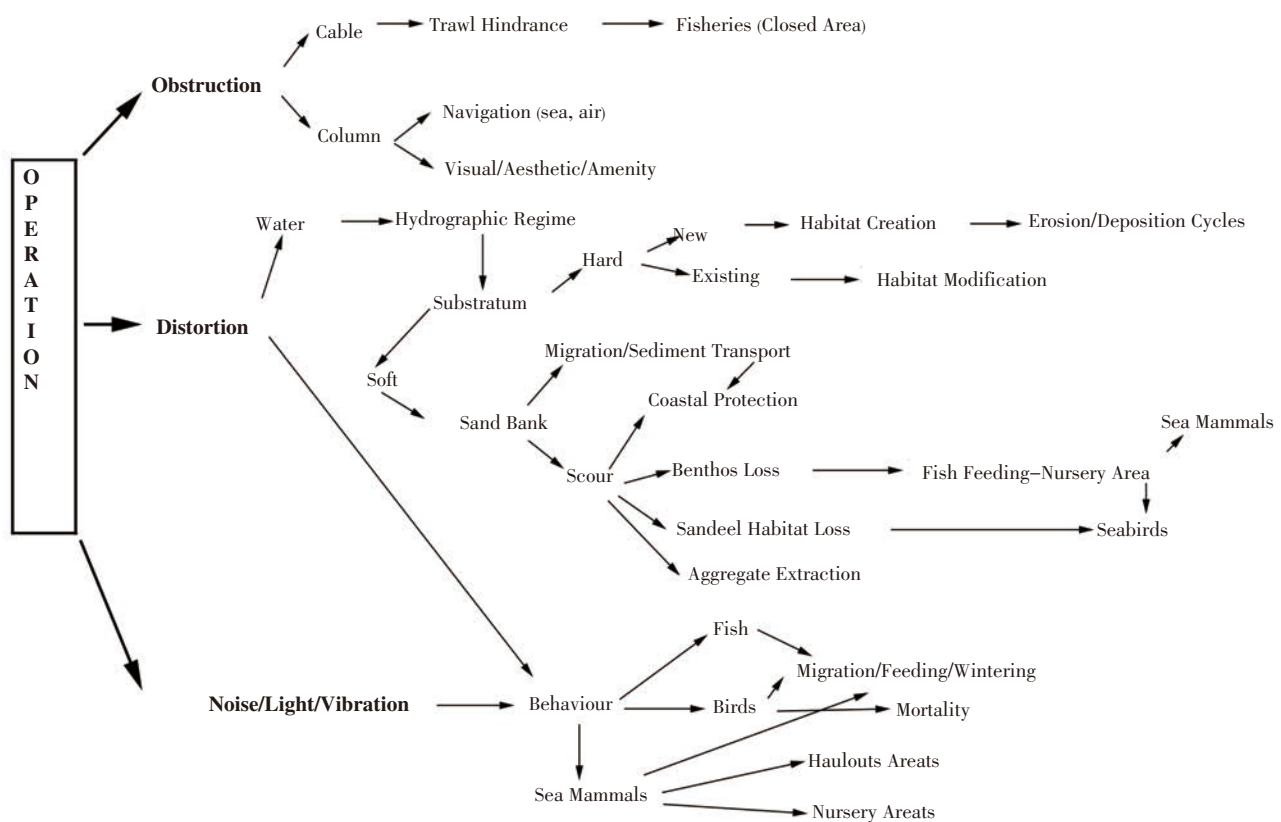


Figure 2. Consequences from an OWF while it operates[9,10].

2. Seismic shooting

Seismic shooting is performed during the pre-construction period[7] and is known to negatively affect the abundances of fish[2] and may cause catch reductions of 50%–80%[12]. No observations of increased mortality of the sandeel *Ammodytes marinus* (Raitt, 1934) were observed although a small decline in landings has been registered[13]. Moreover, Deltares[3] listed negative effects of seismic tests such as death of larvae, juveniles and adults due to underwater noise, secondary effects on population dynamics and feeding performance, disturbance by underwater noise, loss of feeding area, migration options, spawning grounds.

In general adult fish can avoid seismic sound waves, will seek some protection near the bottom, and will not be harmed[14]. Boertmann *et al.*[14] reported that in the shooting area within 18 nautical miles away, the fish catches did not return to normal levels within 5 d after shooting and the effect was more pronounced for large fish compared to smaller fish. It was concluded that there is a risk of reduced catches in areas with intensive seismic activity and this effect will only affect specific fisheries for a shorter period of time and it depends on the particular species with respect to anatomy, taxonomy and ecology[14]. In the same report it was also mentioned that the Norwegian studies showed an increased catch of Greenland halibut in gillnets and explained it most likely as the result of changed behaviour (more roaming movements) of the fish[14]. Similarly, low catch rates were observed 18 nautical miles from the seismic shooting area, but the most pronounced decrease of fish abundance occurred within the shooting area, where trawl

catches of *Gadus morhua* and *Melanogrammus aeglefinus* and longline catches of haddock were reduced by about 70% and the longline catches of cod by 45%[15].

3. Noise effects

Construction and operation of an offshore facility will generate noise and even low frequency sound will be emitted during the operation of the turbines[1]. Noise can affect reduction of the catch rate of commercially important species[15]. Engas *et al.* found that larger fish also had lower resonance frequencies than small fish and may therefore be more sensitive to sound at lower frequencies[15].

4. Habitat changes

Before construction, core drilling will be done to get an overview over sediment layers in the OWF area[2]. Both seabed preparation and cable laying activities during the construction phase will result in temporary sediment re-suspension and thus in increased turbidity of the water, which may change sediment characteristics[16]. The fine particle component of the substrate may be the one most likely to be affected by the construction of an OWF since smaller particles are more easily suspended within the water column[1]. This will increase turbidity and is considered a short-term effect as shown in Table 1[7]. There will also be changes when placing the wind turbine fundament on the ground but the placing itself is considered as a short-term effect[2]. These actions can affect some benthic organisms

but the species are believed to return to the OWF again when the construction period is over^[2]. In case of re-suspension and turbidity it should be taken into account that depending on the local natural conditions in the marine environment, a natural re-suspension and (re)-sedimentation will take place^[16]. Similarly van Deurs *et al.*^[17] found that three species of sandeel altogether revealed a positive short-term effect on the densities of both juveniles and adults, which was consistent with a reduction in the fraction of silt and clay. However, a negative effect on juveniles was predicted in the long term. Wilhelmsson *et al.*^[18] assumed that OWFs may function similar as artificial reefs and fish may aggregate next to such structures, particularly small demersal fish.

5. Co-use and function of OWF

Meel^[19] suggested that OWF can be useful for aquaculture and this will compensated for possible negative impacts of OWFs on fisheries. SWOT (Strength, Weakness, Opportunity, Threat) analysis has been used to find out the opportunities for strategic action by aquaculture stakeholders and is shown in Table 3.

Unlike shipping and fishing, aquaculture is a static activity which will not interfere with the wind farm operation. Conflict with fishermen can be minimised as aquaculture can offer employment or income earning opportunities to the fishermen. OWFs might also have the potential for becoming marine protected areas as the unutilised waters between the wind farm piles would be taken up by aquaculture cages or rafts (long lines are fishing devices not applicable in aquaculture)^[19].

6. Step stones

Surrounding marine habitats of OWFs are assumed to have

some influence on the species diversity in the area. With a natural rock reef in close proximity, it is believed that the diversity and amount of fish will be quite large^[2]. Benthic species preferring hard substrate, such as epifauna, will easier, quicker and in a larger amount use the boulder in an OWF as a new habitat and use it as a stepping stone for further dispersal^[20].

7. Electromagnetic fields

During the construction and decommissioning the seabed will be disturbed when laying the foundations for the OWFs and associated substations. This also holds for underwater power cables within the OWF and from the farm transporting electricity to the main connection of the power grid at shore^[21]. Removal of sediments will lead to loss of habitat and turbidity will increase due to suspended materials. Resuspended sediments will be transported by prevailing water movements during construction, which may also mobilize contaminants from sediments^[21]. During the cable laying significant sources of noise would occur and this could cause damage to the acoustic systems of species within 100 m of the source, and are expected to cause mobile organisms to avoid the area^[22].

The electromagnetic fields created by cables have been reviewed in the literature^[21]. Two technologies can be used to transport electrical energy and connect wind farms to the grid: alternating current and direct current^[23]. They have the potential to interact with aquatic organisms that are sensitive to electric and magnetic fields^[21]. This affects both bony fishes and elasmobranch fishes^[2,21]. Elasmobranchs have the ampullae of Lorenzini which are considered to be the organ that perceive the electrical signal^[24] and it is, therefore, believed that elasmobranchs will be affected by the electromagnetic cables^[2]. Gill^[21] pointed out that magnetosensitive species occur in coastal waters worldwide (*e.g.* migratory fish, elasmobranchs, mammals,

Table 3
SWOT analysis for aquaculture in OWFs^[19].

Strengths	Weaknesses
Maximisation of production from unit area of sea is in the best interest of any nation.	No previous experience.
Reduction of the impact on fishermen’s livelihood from OWFs.	A legislative problem as the seabed owner (Crown Estate) prohibits any other income earning activity by the OWFs in the leased area.
Lack of aquaculture sites in inshore waters creates a requirement for new sites (Crown Estate website).	OWF development is looked after by offshore managers and environment managers who do not have specific domain expertise in aquaculture. Hence it is difficult for them to understand that aquaculture equipment need not to interfere with OWF operation.
Sustainability of OWF depends on co-existence with other profitable users of the sea.	Traditional aquaculture equipment is not well suited for OWF locations.
Opportunity	Threat
Example for the implementation of the ecosystem approach and marine spatial planning.	Conflict with fishing, shipping and other profitable users of the sea is imminent once aquaculture is allowed to take place within OWFs.
Income from the OWF lease can be increased.	This is a new concept which has to undergo semi commercial trials before full scale commercial production can be undertaken.
Objections to OWF development from the fishermen community can be managed by offering employment.	There is a legal void as the seabed owner (Crown Estate) does not have a policy for marine spatial planning and other economic activity within OWF locations.
Marine spatial planning requires the co-existence of as many activities as possible within a given space. Aquaculture in OWFs areas is better than fishing, shipping or marine aggregate extractions which are non-static activities and would thereby disturb the safe operation of the OWF.	This will put off any new investor. Investors would require real time successful examples of aquaculture in OWFs before they can finance such projects.

Table 4**Potential environmental effects of OWFs.**

Research area	Potential effects
Benthic ecology	
Habitat disturbance:	<ul style="list-style-type: none"> • Smothering of benthic organisms as suspended sediments resettle, particularly benthic invertebrates • Initial re-colonization of the site by benthic invertebrates takes place rapidly, sometimes within a couple of months; may take years in deeper waters not subject to disturbance • Local loss of sedentary bottom fauna; mobile bottom dwellers expected to be displaced from the area • Effects to benthic community were minimal when monopiles were used; limited to area immediately surrounding turbine (Horns Rev and Nysted, Denmark) • Studies conducted at wind farms in the North Sea did not find significant changes in the benthic community structure that could be related to changes in the hydrodynamics as a result of the placement of in-water wind turbine structures
Reef effects:	<ul style="list-style-type: none"> • Major changes in community structure of the offshore ecosystem from one based on infauna to that of a hard bottom marine community and a commensurate increase in biomass by 50 to 150 times greater (Horns Rev and Nysted, Denmark) • Wind turbines in the Baltic Sea built on monopiles are almost entirely encrusted with a monoculture of blue mussels (<i>Mytilus edulis</i>) • Estimated 60-fold increase in the availability of food for fish and other organisms in the area compared with the original benthic community (Horns Rev, Denmark)
Changes in community composition:	<ul style="list-style-type: none"> • An increase in bivalves and worms inside the park was attributed to a decline in predation from scoters who were avoiding the wind turbines (Horns Rev, Denmark) • Densities of sand eels were found to increase by 300% between 2002 and 2004, attributable to either a decrease in sand eel predation, or a decrease in fishing mortality (Nysted, Denmark)
Fisheries resources and habitat	
Noise:	<ul style="list-style-type: none"> • Potential effects of sound on fish may include: temporary or permanent hearing damage or other physical injury or mortality; behavioural responses; masking acoustic signals • One study of pile driving found fish of several different species were killed within at least 50 m of the pile driving activity • Another study found that the noise levels produced by pile driving during wind tower construction and cable-laying could damage the hearing of species within 100 m of the source • A study based on measurements of wind turbines in the German Bight and Sweden found that sound levels created during pile driving for construction of wind turbines were loud enough to be heard at distances of up to 80 km for some fish species • Noise created in construction and decommissioning may cause some animals to leave the area; the effect on fish populations would be greater if they are dispersed during the times of year when they would be naturally congregating for spawning or other purposes • Some studies have found that fish displaced from an area by noise during construction processes are likely to return following construction activity • One study found the operational noise created by a 1.5 MW turbine was merged with ambient noise within 1 km from the source
Electric magnetic field:	<ul style="list-style-type: none"> • The electromagnetic fields produced from the cables are within the range of electrical transmissions detectable by sharks and rays • Exposure to certain magnetic fields was found to delay the development of embryos in fish and sea urchins • One study found that European eels significantly decrease their swimming speed when passing over an alternating current cable • A study of cables at Danish wind farms found both attraction and avoidance behavioural effects of fish from the presence of the cables, but could not be correlated with the strength of the electric magnetic fields
Habitat disturbance:	<ul style="list-style-type: none"> • The placement of wind turbines may affect flow regimes by altering tidal current patterns around the structures, which may affect the distribution of eggs and larvae • Individual fish are likely to move out of the area during construction because of the disturbance and loss of food
Reef effects:	<ul style="list-style-type: none"> • Wind turbines may increase habitat for benthic species, increasing local food availability, which may bring some migrant species into the area • Predators moving into the area may result in prey depletion • While colonization of the new structures will begin shortly after construction, it will usually take several years for the colonization to be completed • Oil and gas platforms have been found to harbour large numbers of larval and juvenile fish, and wind turbine support structure can be expected to have a similar effect • In oil and gas platforms, fish that remain within the jacketed structures may be less vulnerable to fishing pressure than others • Increase in biomass of 50 to 150 times at Horns Rev in Denmark serves as food for fish and seabirds

chelonians and crustaceans) and any effect may be transient as the organism moves through the area. Alternatively, magnetosensitive species may be attracted to or may actively avoid the area^[21].

It should be noted, however, that our current knowledge with regard to the effects of electronic magnetic fields and noise is quite limited^[20].

Potential environmental effects of OWFs are summarised in Table 4 and it should be noted that any potential effects will vary greatly depending on the location, scale, technology, and other factors of a particular project^[25].

8. Impacts of OWFs on benthic organisms

The benthic organisms that live upon or within the

substrate at the sea bottom can be categorized according to their habitat, by taxonomic composition, and size of the organisms defined. Infauna are organisms that live within the sediments, whereas epifauna are animals that live on or in close association with the bottom, either attached to a hard substrate or moving on the surface of the sediment. Similarly, macrobenthos are organisms retained on a 1 mm mesh size sieve. They include most invertebrates, like worms, crustaceans and molluscs and bottom dwelling vertebrates that prey upon them.

Impacts directly associated with OWF construction can be assigned to five categories, namely, noise and vibration, temperature, electromagnetic field, contaminant, and disturbance. In addition to direct impacts during OWF construction and operation, the potential long term effects on the benthic environment must also be considered. Concerns

are focussing mainly on whether and how the benthic habitats in the vicinity of the OWFs are affected by changes in the hydrodynamic regime, and whether the effects of the installations, which act as artificial settling substrates for sessile organisms, are properly assessed. The ecological effects of OWFs include increased habitat structure and heterogeneity, changes in hydrodynamic conditions and modified sediment transport patterns. The ecological response of the benthos could involve long-term changes in organism abundance, biomass, species diversity, community structure and functional properties such as nutrient cycling or bioturbation^[26].

Therefore, it is impossible to make accurate predictions about the effects of OWF construction on benthic assemblages. This emphasises the need for continued assessment and monitoring at any particular OWF site. During OWF construction, practices such as dredging and blasting may adversely affect the local benthic populations and, therefore, have an indirect effect on other populations that feed on them. These effects, however, are likely to be short-lived.

In the research^[26] no detrimental effects have been observed at all OWFs. Differences in the biodiversity between sites is explained by natural variation. However, it is also note that the limits of what constitutes natural variability are better defined where such conclusions are drawn^[26].

9. Impacts of OWFs on fish

The potential impacts of OWFs on fish communities can be as follows^[1,5,7,8,27]:

- Disruption of orientation, especially for migratory species;
- Impediment of foraging activities;
- Habitat loss—not just from the actual wind turbines, fish may move out of areas due to increased stress levels;
- Damage to fish eggs;
- Alteration of fish species availability and abundance;
- Alteration of fish community composition and abundance.
- Disturbance and redistribution of sediments;
- Scouring of sediments around the base of turbines;
- Re-suspension of pollutants within the sediment;
- Accidental release of chemicals and hydrocarbons during installation;
- Physical presence of the structures;
- Pile hammering associated with the construction of the foundation for offshore wind turbines may result in damage to fish and fish larvae or changes in fish behaviour due to high levels of underwater noise associated with this;
- Underwater noise produced during the operational phase of offshore wind farms may change fish behaviour;
- The presence of offshore wind farms may cause changes in seabed characteristics which can influence the distribution of demersal fish species;
- Absence of fisheries within the offshore wind farm, because fishing is not allowed, may change the characteristics of both the fish community because detrimental impacts from fisheries will be absent;
- The presence of the offshore wind farm and wind turbines

may lead to the introduction of a new habitat for fish.

There are many studies related to the effects of OWFs on fish species. Thomsen *et al.* found that Atlantic cod (*Gadus morhua*) and Atlantic herring (*Clupea harengus*) would be able to perceive piling noise up to 80 km from the sound source^[28]. Similarly, dab (*Limanda limanda*) and salmon (*Salmo salar*) might detect pile-driving pulses at considerable distances from the source. However, these species are predominantly sensitive for particle motion and not pressure; the detection radius cannot be defined yet. Behavioural effects are also possible due to piling noise and physical effects, like internal or external injuries or deafness leading even to cases of mortality, in the close vicinity to pile driving^[28]. These authors pointed out that operational noise of wind turbines will be detectable up to a distance of 4 km for cod and herring and up to 1 km for dab and salmon. Behavioural and/or physiological effects are possible due to operational wind farm noise.

Lange *et al.* found that the fish abundance from the pelagic surveys showed a significant increase after the construction of the OWFs^[29]. Mainly responsible for this increase was the sand eel with very high abundances in all investigated areas. Similar results were obtained from demersal surveys. The fish abundance was the highest after the construction of the New South Wales and reference areas. No effects were found for the diversity of the pelagic and demersal fish species.

Offshore constructions have the characteristic to attract fish species. This is known as an artificial reef effect. Several man-made structures can provide the functions of artificial reefs. This also holds for OWFs and oil rigs, as they are structurally similar to wind turbines^[7]. Normally, reefs are built to increase the carrying capacity of an environment, but in the case of wind power, they would be used to ameliorate some of the environmental consequences of the wind turbines^[30].

Parkinson pointed out that artificial reefs have become popular fisheries management tools at a world-wide scale and are built to serve a variety of purposes^[30]:

- To improve quality and quantity of fish catches;
- To provide spawning areas;
- To provide refuge for juvenile fish;
- To protect natural stocks of shellfish and finfish;
- To protect the shore and reduce rates of beach erosion;
- To reduce fishing areas by excluding fishermen.

Therefore, there is a potential for creating similar reefs at the bottom of the wind turbines. As the turbines will probably disrupt the fishing effort in the area, Hence, reefs should be designed and constructed to enhance the local fish populations^[30].

It is noted that OWFs seem attractive to several fish species because of food access (*e.g.* small fishes) and habitat (*e.g.* scour protection) in the direct surrounding of the piles, which has an impact on fishery^[29]. This depends on the legal framework, *e.g.* ban of fishery due to restrictions on access to OWF areas for shipping including fish trawlers (legal decision to ban fisheries leads in practice to fish protection within the OWF). As a result, this fish is not available for fisheries anymore, but it is mentioned that overfishing might have a much larger negative impact on fishery than a ban on

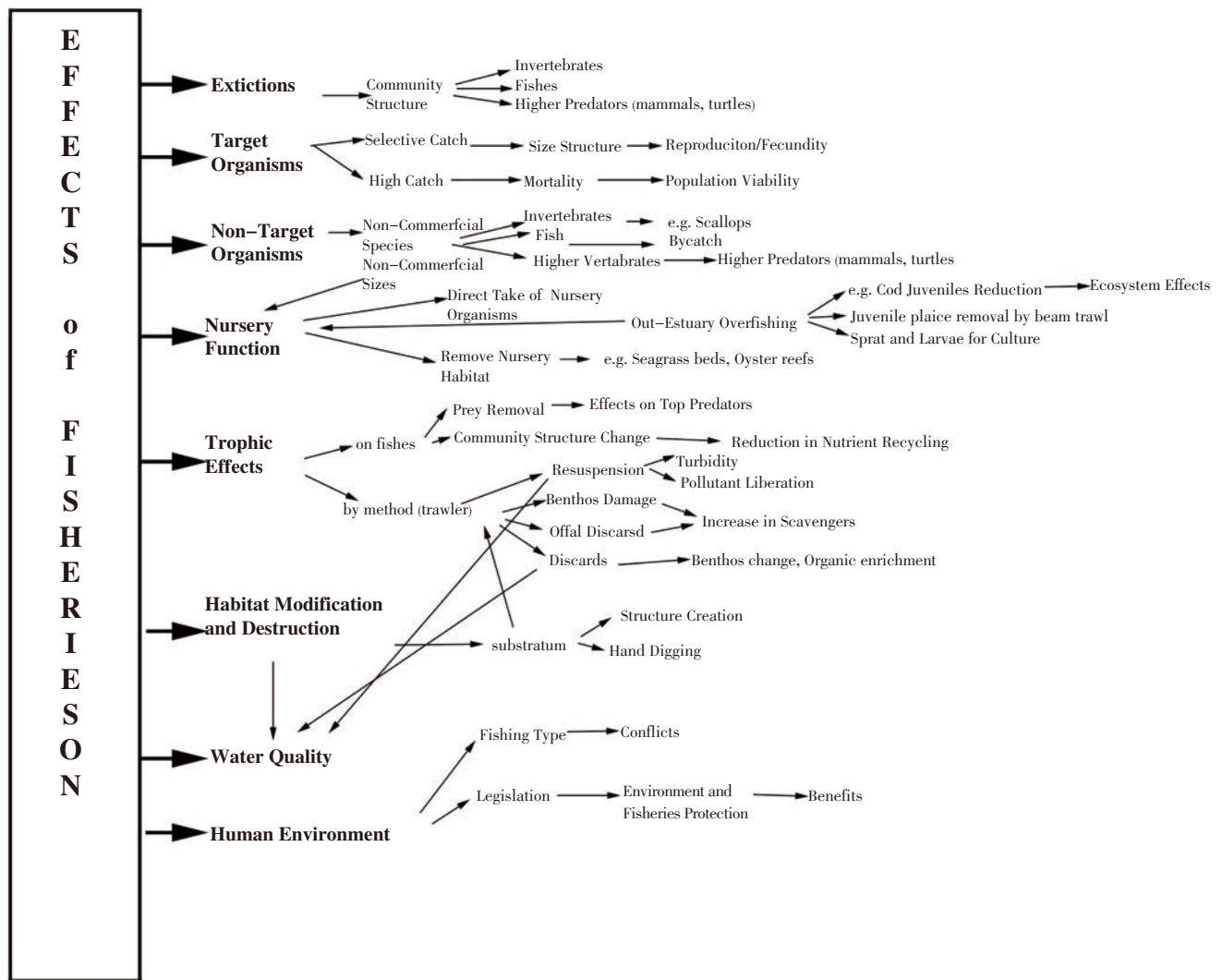


Figure 3. Ecosystem impacts of fisheries[31].

fishing in OWF areas[29]. The area around the turbines may serve as a closed area and allow fish populations to grow and this increases the fishermen's catches. Hard surfaces will increase sessile faunal populations and this in turn may increase food organisms available for the fish[30].

Elliott illustrated the ecosystem impacts of fisheries and trawl fishing (Figures 3 and 4)[31].

However, several studies have demonstrated that there was no or only temporal effects of OWFs on fish[32,33].

Most of the potential impacts (suspended sediment, temporary disturbance or longer term loss of seabed habitats, construction noise and electromagnetic fields) are expected to have no significance, typically being temporary in nature and affecting only small areas. Impacts from construction noise could disturb fish over a considerable distance from a piling operation, giving rise to short term changes in the distribution of fish. Such effects could also affect the spawning of some species for a short period and over a limited area but with no anticipated significant longer term effects. The buried cables will emit electromagnetic fields which can affect certain fish such as sharks and rays. However, such fields are only detectable

by these fish over very short distances. So no large scale effects on these fishes is expected[32].

Another report showed that no general or clear regional effects from the presence of OWFs were shown when comparing impact and reference areas[33]. To the contrary, there was an indication that the distribution of fish was generally influenced by other biotic and abiotic factors like sediment characteristics. No local statistically significant differences were found in the temporal and spatial distribution of fish communities inside the wind farm due to the presence of turbines[33].

An overview of possible impacts from the pre-construction activities on the fish communities is illustrated in Figure 5[8].

The impact of turbines on fishing depends on the importance of the area as a fishing ground. Before construction, local fisheries should, therefore, be identified and their importance be determined. A fishery intensity study should be carried out in association with the local authorities. If the area is used intensively for fishing then the turbines will be a physical obstruction for fishermen. This may demand to bring the nets back on board as

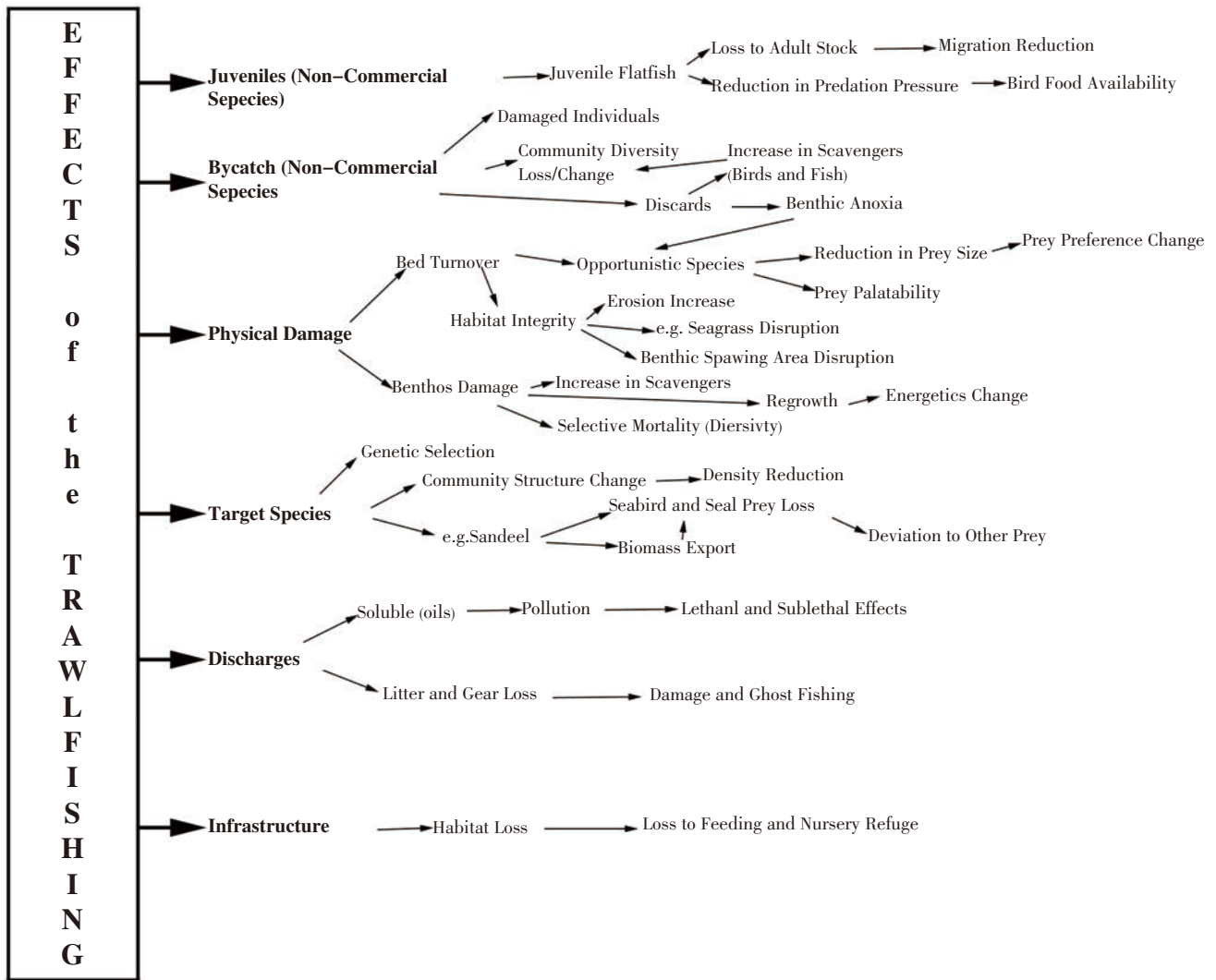


Figure 4. Ecosystem impacts of trawling[31].

fishing boats pass the turbines and then recast them. Since more manpower will be needed and the overall fishing effort will be reduced[30].

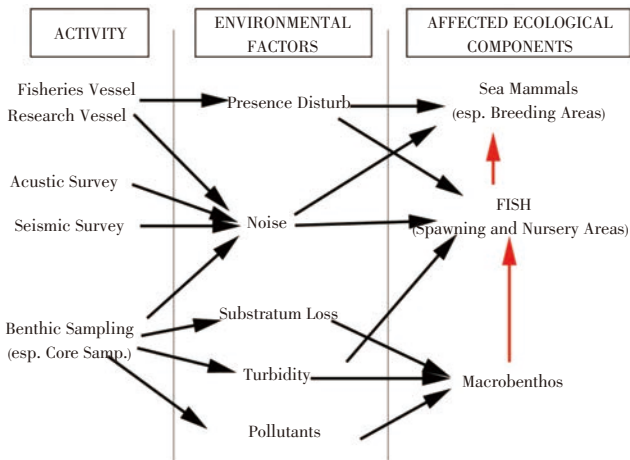


Figure 5. Sources of impacts and targets of effects in the pre-construction phase.

Red colour indicates changes in the biological interactions[8].

An overview of possible impacts from the construction activities on the fish communities is illustrated in Figure 6 [8].

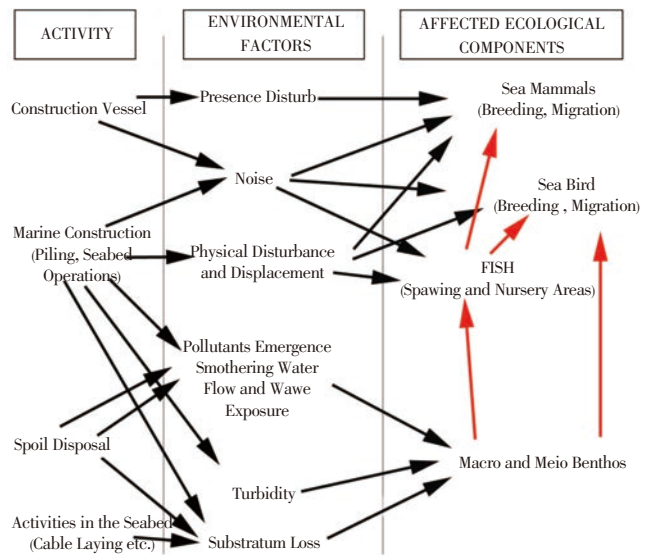


Figure 6. Sources of impacts and targets of effects in the construction phase. Red colour indicates changes in the biological interactions[8].

An overview of possible impacts on the fish communities during the operation phase is illustrated in Figure 7[8].

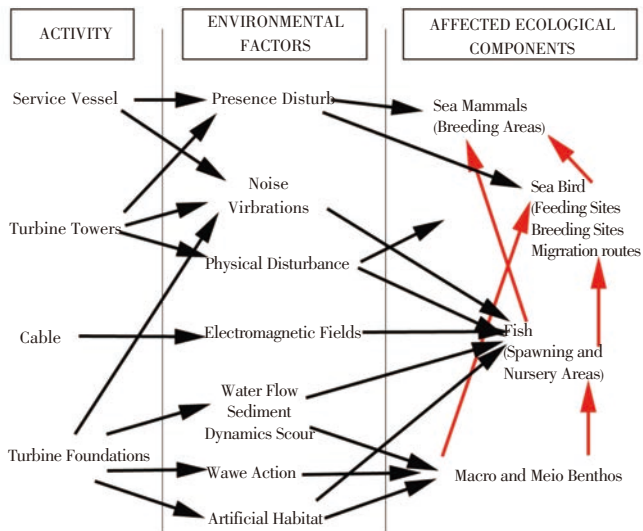


Figure 7. Effects and impacts in the operation phase.

Red colour indicates changes in the biological interactions[8].

Parkinson[30] listed in the mitigation measures proposed to minimise the impacts:

Construction of alternative roost sites of birds for the coastal turbines;

Removal of sediments during construction to reduce suspended sediment levels;

Careful timing to avoid affecting the flora and fauna;

Comprehensive monitoring to assess all impacts on the system;

Clear marking of turbines on admiralty charts;

Lights and foghorns on turbines to reduce chances of collisions;

Good engineering practice to minimise chances of contamination of the sediments.

An overview of possible impacts on the fish communities during the decommissioning phase is illustrated in Figure 8 [8].

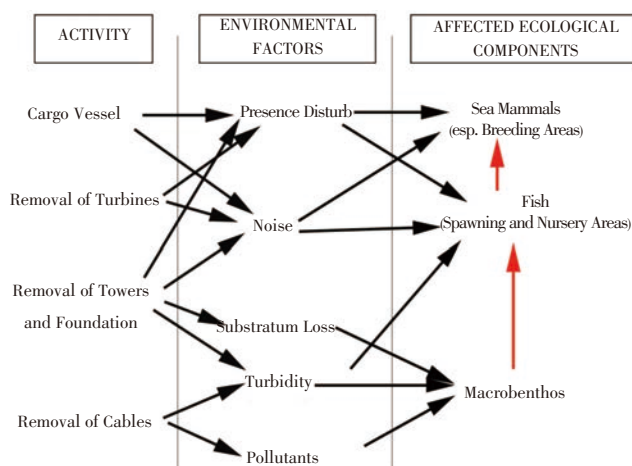


Figure 8. Effects and impacts in the decommissioning phase.

Red colour indicates changes in the biological interactions[8].

10. Social impacts

OSPAR Commission[16] evaluated that OWFs can potentially have a major impact on the landscape and on local communities. OWFs will affect both the local communities

(if it is visible from the coast) and the people visiting the area. The impact on tourism and on local communities can be either negative or positive. A negative impact will occur if the tourists stay away from the area, the rental of holiday cottages is reduced and the general use of the area for recreational activities such as yachting, angling, diving *etc.* is reduced because of the presence of the OWF. A positive impact will occur if the OWFs become an attraction for tourists. The noise emitted from the wind turbines during operation can potentially be a nuisance to the people on land. According to the modelling of the noise emitted by an OWF, the wind turbines will be heard at a distance of 1 km at the most[16].

Results of study on public attitudes towards wind power are given below[34]:

Those in favour of wind energy tend to believe:

Renewable energy is an alternative to other energy sources;

The climate change argument must be taken seriously;

Wind energy is unlimited, unlike fossil fuels;

Wind energy is non-polluting;

Wind energy is safe.

Those against wind energy tend to believe:

Renewable energy cannot solve energy problems;

Wind turbines are unreliable and dependant on the wind;

Wind energy is expensive;

Wind turbines spoil the scenery;

Wind turbines are noisy.

11. Overall conclusions

The installation of an OWF has the potential to have positive and negative impacts on the ability of the ecosystem. SWOT analysis of OWFs are shown in Table 5.

SWOT analysis shows that the wind power generation industry has the potential to become very significant in the attempt to reduce greenhouse gas emissions. The large-scale wind resource makes it a more attractive source of power than hydropower or fossil fuels. Wind power is generated from a free energy source and generates zero emissions. During construction many jobs will also be created during the development, manufacture and assembly of the turbine components[30].

Studies have shown that any adverse environmental consequences that occur during the exploration and construction phases will be relatively short lived. Once the construction is complete the system should return to its original state. Local effects on fish communities can be reduced or mitigated by carrying out the construction at a carefully chosen time of the year. It would appear that the operation phase does not cause many significant problems [30].

The presence of an OWF site will also modify the behaviour of fishermen, whether this will be an exclusion of trawler activity within a site, or alternatively, a more intensive linear trawling pattern between turbines, is unknown, but may have additional impacts on benthic communities. An additional point is that fishing activity may be displaced to reference

sites, thus potentially masking any deleterious impacts within the OWF area as they are negated by such changes in fishing effort[26]. A good communication is needed so that fishermen know where they can still work once the turbines are in operation[30].

The environmental impacts of an OWF are listed below[2,4,6,7,8,18,19,20]:

The construction and operation of OWFs do have some environmental impacts, such as disruption of the seabed and noise pollution, but many of these impacts are to a lesser extent than originally predicted;

The effects of noise from the turbines on commercial fish species are not clearly established;

Despite the loss of the existing seabed habitat to make way for the installation of the turbines, this loss is relatively small when compared to the remaining undisturbed habitat surrounding the wind farm;

Through careful design of the required scour protection, new habitats can actually be created, which may be beneficial not only for the surrounding ecosystems and environment, but also potentially to local fishermen. These new habitats may act as artificial reefs;

A range of scour protection methods to be used within any individual OWF, including synthetic fronds, gravel and large boulders. This will mimic a broader range of natural habitats and increase habitat heterogeneity, which has been proven to aid increased biodiversity and abundance;

Ensuring that a large range of hydrodynamic niches are created for a wider range of species. These will allow both fast current and shelter preferring species to find habitats within the scour protection;

Maximisation of surface area to allow maximum levels of colonisation of benthic organisms will then allow the development of a food web, leading to a support of a diverse species community. The use of specially designed materials, such as reef balls, maximise habitats and abundance;

matching dominant scour protection methods to the existing local ecosystems and communities;

Good planning in terms of timing, to ensure that the turbine foundations are in place to capture plankton and allow the development of the earliest stages of desired food webs;

Aquaculture in OWFs will reduce the impact of OWFs on fisheries;

The lack of inshore sites for aquaculture has necessitated the move to offshore regions. The infrastructure available with OWF developments would become a site of choice without any disturbance to the main purpose;

Artificial reefs have positive local effects on the species richness and the biodiversity in the OWF area;

A consequence of that extended influence may be that OWFs of the future, containing tens to hundreds of turbines, will have additional synergistic effects on the fish community structure, with biological interactions between the biota around the turbines;

If fishing effort is limited around the OWFs, they may act as marine protected areas, which are used to manage fishery resources worldwide;

In areas with little or no hard substrate, OWFs will provide not only new habitats, but also create a stepping stone for the spread of hard substrate organisms and thereby facilitate the spread of non–native and invasive species;

An OWF area with homogeneous sand sediment has a higher impact on the fish fauna compared to OWFs in areas with heterogenous sediment;

Despite the fact that OWFs will provide an intrusion in a natural system, it can be assumed that several benefits arise from the construction.

The combination of all these factors should ensure that the construction of OWF need not necessarily have a detrimental impact on their surrounding environments, and actually have the potential to contribute to the environment. Their application could also potentially make the development of future, larger OWFs easier to gain consent, as their environmental argument would be strengthened[7]. Thus, regarding fish the installation of the OWF is not believed to impose any significant negative effects on the fish fauna[8].

Elliott[9] said that “Scientists will be increasingly required to consider the whole marine system, to continue to derive conceptual models and to attempt quantitative, numerical predictive models and decision support systems. However, they will have to educate managers and politicians to the view that the marine system is so complex that it is unlikely that we will ever be able to fully and quantitatively predict all natural and anthropogenic changes and so best (expert) judgement will have to be relied on for decision making.”

Table 5
SWOT analysis for OWFs[19].

Strengths	Weaknesses
Free and inexhaustible energy source.	Conflict with fishing, shipping, marine aggregate extraction, communication cables, sailing, marine archaeology, radar, oil and gas, tourism.
Emission free helps to reduce greenhouse gases.	Impact on organisms (fish, marine mammals, benthos, birds <i>etc.</i>) especially from noise, construction debris. Re–piling can destroy the benthic habitat multiple times during the lease of an OWF.
Technology is available, OWFs already up and running.	Intermittency in wind and wind speed changes.
Improvements in wind turbine technology promises to produce more electricity at a cheaper rate.	
Opportunity	Threat
Most suited for islands which do not have many other sources of energy due to logistics problems.	Decrease in costs is envisaged not guaranteed.
Reduction in cost of construction due to improvements in technology and scale could result in more OWFs.	Rough seas, cyclonic conditions can damage the infrastructure.
Decrease in fossil fuels creates a need for alternative energy.	Intermittency in wind creates gaps in supply to the grid.
Climate change scenarios create a need for clean energy.	Navigational accidents can damage the infrastructure.
Employment for people trained in offshore and marine sciences.	Energy policy in the UK is being reviewed at present to compensate for the energy gap with a shift towards nuclear energy.
	Repayment of debt may not reduce production costs over time.

Conflict of interest statement

We declare that we have no conflict of interest.

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Comments

Background

Wind energy is renewable energy source for electricity generation that becomes a key objective of most European and other countries. Number of currently OWFs is constantly increasing which raise concerns about their impact on the marine environment during the preconstruction, construction and post-construction period with short and/or long term effects.

Research frontiers

Focus of this paper is to show possible impacts of OWF on the physical and biological environment, including disturbance effects from noise, emergence of shadows electromagnetic fields, changes in substrate structure, bottom living fish and invertebrates communities and texture and changed hydrological conditions, within the existing literatures.

Related reports

As this paper is based on a literature review of the impacts of OWF installations on fisheries a lot of related results are reported.

Innovations and breakthroughs

Focus of this review is to show possible impacts of OWFs on the physical and biological environment within the existing literatures, so this is a paper that summarize all the existing reports and results on this subject known to this date.

Applications

All environmental impacts of an OWF are listed within the paper and based on these reports it is concluded that the installation of the OWF is not believed to impose any significant negative effects on the fish fauna.

Peer review

The paper summarize a potential environmental impacts of OWFs, recognized from a literature review and gives an comprehensive overview of these impacts on the fish communities during the pre-construction, construction

and operation phase of OWFs. The most important benefit of this paper is conclusion that OWF, based on current results, is not believed to impose any significant negative effects on the fish fauna, which is of the utmost importance for a future application of OWFs and discussion on their impact on environment.

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