A Review of 10 Years of Research of Offshore Wind Farms in Germany: The State of Knowledge of Ecological Impacts.

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Abstract: This paper presents a synopsis of the effects of offshore wind farms (OWFs) on benthos, fish, resting birds, migratory birds, and marine mammals based on published data collected in Germany during the past 10 years. German data was obtained from the StUKplus project at the Alpha Ventus wind farm and the first 13 OWFs in Germany. These data were validated against international data via a literature search. The results indicate the following effects of OWFs: (1) no negative effects on benthos or fish could be confirmed; (2) some species of birds avoid OWFs, whereas others ignore them or are attracted to them, and significant effects on migratory birds could not be proven; and (3) harbor porpoises were shown to be impacted during construction, although no long-term impacts to porpoises from the operation of OWFs have been proven.

Key-Words: Offshore Wind Energy, StUK, Ecological Impacts

1. Introduction

Offshore wind energy will play an important role in Germany's future energy supply. There are plans for 15.000 MW of offshore wind energy by 2030. Therefore, 33 offshore wind farms (OWFs) have been permitted in the German Exclusive Economic Zone (EEZ) and more than 2.300 MW of offshore wind energy is already installed.

Few years ago, little was known about the possible impacts of offshore wind energy on the marine environment. However, in the last 10 years, the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety has made efforts to understand such impacts. The ministry invested more than €50 million to establish the first offshore test field (Alpha Ventus) and launch the research initiative at Alpha Ventus (RAVE). The ministry's current highest priority is to minimize the impact of OWFs on the natural environment by developing mitigation measures against noise emissions.

2. Methods

The first aim of this study was to prepare a synopsis of the effects of OWFs on benthos, fish, resting birds, migratory birds, and marine mammals. The synopsis is based on published data and research. The first source was published data that were collected in Germany during the past 10 years in connection with Alpha Ventus and the first 13 OWFs in Germany. The second source was international published data.

2.1 Data from German Wind Farms

In Germany, wind farm developers have to extensively investigate and predict the impact of a proposed wind farm on the marine environment. The standards for environmental impact assessments (StUK) address monitoring those impacts on benthos, fish, resting birds, migratory birds, marine mammals, bats, and the landscape. Moreover, StUK specifies the methodology for investigating and monitoring impacts on the species of conservation interest. The study design framework for the

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environment impact statement (EIS) is a before–after, control–impact (BACI) design. Data sampling is conducted three years before, during, and three years after construction. Monitoring is performed in the affected area as well as in a reference area [1]. Use of the StUK methodology ensures that the quality of an EIS can be proven and that EISs are comparable.

At Alpha Ventus and the first OWFs in Germany, the StUK-mandated ecological monitoring and mitigation measures were supplemented by a large-scale ecological research program, called StUKplus (2008–2014). It covered a larger area at a higher intensity than StUK and incorporated new investigation methods. Furthermore, long-term studies were performed during the OWF operations. In aggregate, RAVE included more than 30 projects conducted by over 50 universities, research organizations, and private companies. It is the world's largest and most comprehensive OWF-measurement program and has delivered unprecedented, industrial-scale in situ data. Approximately 500 scientific papers, posters, and talks have resulted from RAVE data.

2.2 International Data

To validate the StUK plus results from Germany, the most important international studies were examined, including the results of the metastudy by Schuster et al. [2]. Sources were located using Google Scholar and ScienceDirect. The search terms *offshore wind*, *energy*, *ecology*, and *impact* were combined with the text searches of keywords for marine and animal life of interest (e.g., (increase) *benthos*, (increase) *fish*, *migrating/resting bird*, and *harbor porpoise*). International results were compared with the most relevant German results to validate or invalidate the German findings.

3. Results and Discussion

3.1 Impacts of OWFs on Benthos and Mobile Megafauna

Benthos-related research at Alpha Ventus surveyed the benthic fauna in the wind farm and a reference area for three years using a beam trawl and a Van Veen bottom grab sampler. Scientific divers sampled the assemblages of fouling organisms, such as mussels and sea anemones that were colonizing the turbine foundations, and of mobile demersal megafauna. Mobile demersal megafauna were also visually surveyed using belt transects that ranged on the seafloor away from the turbine foundations [1]. The survey showed an increase in endobenthos after construction. The mean species richness did not vary in the reference area but increased in impact locations. These results suggest significant temporal and spatial variation in the benthic community and sediment parameters five years after construction [3].

The OWF created new habitats for hard-bottom-associated mobile demersal megafauna and increased the population. Artificial hard substrata in the marine environment have substantial influence on nearby sediment and inhabiting benthic communities. After construction of the turbine foundations, species richness and biomass of the fouling assemblage increased steadily, reaching a biomass of over 20 kg/m^2 in the shallow subtidal mussel accumulation. Two years after construction, 100 times more hard-bottom species were present at the foundations than at former soft sediments. The foundation structures were densely and exclusively colonized by young brown crabs, in excess of 2300 individuals inside the OWF in comparison to 29 individuals in the reference areas. Evidently, the foundation structures served as nursery grounds [4]. Extrapolations of the observed densities of the mobile demersal megafauna predict an increase in population size of several hundred percent for some species [5,6].

Divers observed a large number of shells that were not present before the establishment of wind turbines. Moreover, atypically elevated populations for several species were recorded in areas of soft ground without reefs. Three years after the completion of construction, the growth was pronounced; mussels, fleas, crabs, and sea anemone settled in the wind farm. Massive mussel cover was observed around the foundations. Changes in the soil led to changes in species composition, and

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increased vegetation attracted larger animals that found new food sources around the foundations.

At Alpha Ventus, it was not possible to clearly distinguish between the impacts of turbine foundations (e.g., import of biomass into the sediment) and processes associated with operation (e.g., recovery of benthic communities after cessation of bottom trawling).

These results from German studies were mirrored in the international research, which showed OWFs, including both the wind turbines and associated activities (e.g., fishery cessation), impacted the population dynamics of benthic species. Another notable result from other European wind farms was a lack of short-term effects on marine soft-bottom benthos and an increase in benthos in the long term [7]. In the Thorntonbank wind farm in Belgium, structural changes in benthic communities were evident six years after construction [8].

In summary, StUKplus researchers concluded that OWFs increase the abundances of benthos inside OWFs [3,5,6]. This hypothesis was supported by international research reviewed in the present study [2, 7–22].

3.2 Impacts of OWFs on Fish

In StUKplus, fish were investigated before and during construction, and during operation of the OWF (inside and outside the wind farm area). All investigations were combined into a multiday, ship-based hydroacoustic survey conducted in an area of 200 km², with Alpha Ventus at its center. The survey was conducted along transects or with a stationary echosounder, and measurements were supplemented by a stationary long-term hydroacoustic measurement system. Net catches with a pelagic trawl showed species composition and size distribution. A statistical model was used to validate the comparison of composition and distribution inside and outside Alpha Ventus. The stomach contents of mackerel were investigated to understand the influence of the wind farm on the feeding behavior of pelagic fish [1].

Pile driving and other construction activities caused construction scaring effects on fish. A relative decline in the abundance of pelagic fish (primarily mackerel, horse mackerel, herring, and sprat) was observed inside Alpha Ventus during construction. Before construction, the hydroacoustic survey showed equal distribution of pelagic fish inside and outside the Alpha Ventus area. During construction, a 40–50% decrease in abundance of pelagic fish was observed in the Alpha Ventus area, compared with the surrounding area. The change was ascribed by Krägefsky [23] to the known sensitive hearing of these species. After construction, abundances of fish and crab were higher at wind turbine foundations than in open areas. Overall, there was an increase in the number and weight of fish after construction. The catches in 2011 were more than twice as productive as those in 2010, and larger fish were caught [24].

After construction, the artificial reef community included fish such as mackerel, striped dragonets, French cod or flatfish, and predatory fish that are rare on pure sand surfaces. Most experts evaluate this artificial effect as positive, as it increases biodiversity. However, some fear the impacts of a change in the benthic and fish communities on a habitat with predominantly sandy soil.

The true impact of an OWF on marine life can only be assessed after several years of operation. The recovery of fish stocks and benthic communities has been recognized so far. This is because of two reasons—the new artificial reef and trawling is prohibited inside OWFs.

As in the case of benthos, StUKplus researchers concluded that OWFs increase abundances of fish inside OWFs [23], and this conclusion was supported by the international research comparison in the present study [15, 21, 22, 25–30].

3.3 Impacts of OWFs on Resting Birds

The North Sea is an area of worldwide importance for seabirds breeding along coasts and for birds that are migrating and wintering. Seabirds can be affected by OWFs in different ways, such as collision, barrier effects, habitat loss, and attraction [31].

Comprehensive studies on resting birds were conducted by Garthe et al. [32]. The methods used were multiple-day, ship-based surveys and aerial surveys in Alpha Ventus and a reference area. Data were collected on seabird distribution, habitat, behavior, and flight heights for species that were abundant or of particular interest. Data from EIA studies of other OWFs were integrated. Flight heights were measured by a rangefinder using a laser, and behavior was observed by boat. Digital aerial surveys used high-definition technology [1]. Red-throated and black-throated divers were selected as species of interest. The most numerous species (lesser black-backed gulls and common guillemots) were also investigated before and after construction to show impacts on abundance.

The results indicated that seabird distribution changed substantially as a result of OWFs. A decline in the overall abundances of most seabird species was noted, but bird behaviors varied.

Several species completely (e.g., red-throated and black-throated divers) or partly (e.g., long-tailed ducks) avoided the wind farm and its direct vicinity. These birds may have lost part of their habitat to the OWF. However, there was no evidence indicating whether lost habitat affected population numbers [33]. The two most numerous species occurred in lower numbers after construction, as did the black-legged kittiwake and northern gannet.

Other seabirds were attracted to the OWF. Little gulls were numerous after construction, and some species did not hesitate to fly into wind farms to forage (particularly gull and tern species) or even to use the structures for resting (cormorant) [31]. For foraging, areas inside and outside the OWF both appeared suitable. For example, the proportion of black-backed gulls searching for food was relatively similar inside and outside the OWF. Actively feeding birds were observed proportionally more often in the OWF area. Half of the lesser black-backed gulls fed within Alpha Ventus. This might be a result of the new hard substrate or small-scale turbulence around the wind turbines providing an increased food supply. In the reference area, only a few actively feeding gulls were observed. Overall, foraging appeared to be more common inside than outside the wind farm [32].

Flight height measurements suggest some overlap between flight heights of seabirds and the operational height of Alpha Ventus. Large gulls were exposed to high collision risks [33]. Avoidances were observed among guillemots, razorbills, and loons. Such information may become relevant for collision risk models [33].

In recent years, guillemots and razorbills were sighted only sporadically in the wind farm; thus, the area of the wind farm is no longer considered a habitat of these species. The shy loons avoid Alpha Ventus; therefore, the resting ground has slightly decreased [32]. Dwarf and herring gulls are numerous inside Alpha Ventus. Data showed that approximately 80% of the seabirds in the wind farm are herring gulls [33]. The occurence of the birds is surely correlated with the increase of the benthic structural diversity (and of fish as prey) as shown by Gutow et al [34].

Data from OWFs in the Netherlands and Denmark confirmed data from Germany in showing habitat loss for some seabirds. In the Dutch wind farm Egmond aan Zee, eiders and cormorants used OWF areas and offshore platforms for hunting fish [8]. Furthermore, monitoring showed that some seabirds were attracted to OWFs and others ignored their presence [35]. Petersen [36] observed attraction to OWFs by gull species and avoidance reactions by divers and, to some extent, guillemots. The avoidance behavior seemed to be dependent on wind farm design elements, such as size and configuration of turbines.

The issue of potential habituation of resting birds cannot yet be answered. At the Horns Rev 1 wind farm in Denmark, no habituation was observed in divers after five or six years. The birds still avoid the area [37]. The effects of ship and helicopter traffic must also be studied more intensively, as these cause disturbances and temporary habitat loss [38]. Species such as divers and sea ducks respond negatively to ship traffic.

StUKplus researchers concluded that OWFs can be positive, neutral, or negative for the abundance of seabirds, depending on the species [33].This conclusion was supported by the comparison with international research undertaken in this study. International data indicated that some species avoided OWFs, some were attracted, and some were unaffected [39–47].

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3.4 Impacts of OWFs on Migratory Birds

Millions of migratory birds pass through the Alpha Ventus area in autumn and spring. Studies investigated how the birds are affected during the day and at night (the OWF is lit). Automated techniques such as radar, camera systems, and recording of species-specific flight calls were used. Some studies used video and heat imaging, as well as various radar systems, to monitor birds that encountered the rotor-swept zone and to record evasive bird movements. The sensors could monitor birds from a fair distance [1].

Migration occurs mainly over the sea at night and partly at rotor height. Coppack et al. [48] attempted to quantify the collision risk within the rotor-swept zone in relation to overall migration rates. Some birds were measured in the lowest 200 m, suggesting that a part of migration over the sea occurred at an altitude that would bring birds within reach of the wind turbines [49]. In unfavorable weather conditions (e.g., fog), there is a possibility of collision.

The animals showed different behaviors, from resting inside the OWF to flying through it. They were often observed searching for food inside Alpha Ventus. In most cases, their flight altitude was so low that the birds could not collide with the rotor blades. Only a few of the birds flew partly in the height range of the rotors [33]. No collisions were observed in Alpha Ventus; however, this does not mean that none occurred. It was not possible to count the number of collisions; collision probabilities had to be inferred from the frequency of birds recorded in close proximity to wind turbines. The animals seemed to notice and avoid the rotating rotors during the day and night. The recorded results suggest that Alpha Ventus is not a barrier to large-scale bird migration [33].

Radar and night-vision cameras proved that the illuminated OWF attracted migrating birds, leading to a greater risk of collision for nocturnal migrants. However, such attraction effects might be offset by micro-avoidance in response to rotor movements at some OWFs [48].

Thus, species that migrate nocturnally might be slightly more affected by OWFs. Nocturnal migration is dominated by passerine species (e.g., thrushes). Circling flights were observed around illuminated OWFs by radar, thermal imaging, and video. No collisions could be detected. The total number of observed collisions at Germany's FINO1 platform (which is of a very different structure than a turbine) was approximately 1000 between 2003 and 2014, with four mass-collision events that caused between 88 and 199 casualties in total (mainly thrushes at night). The number of casualties caused by storms or being eaten by gulls is unknown.

Results from the international literature indicated that the construction of OWFs resulted in changes in the number and composition of species as well as migration volumes and flight altitudes [50]. Some studies found that OWFs are barriers in the daytime and that lethal collisions predominately occur at night or during bad weather, and some observed that collisions were more common when good migration weather changed to fog, drizzle, or tailwinds. At night and during bad weather, birds seem to be attracted by light sources on platforms or wind turbines [51].

Like Alpha Ventus data, international data indicated that different species generally have different reactions to OWFs. International studies showed ducks, geese, swans, waders, auks, fulmars, gannets, little gulls, and kittiwakes or sandwich terns with avoidance reactions. Large gulls of the genus *Larus*, black-headed gulls, and common gulls were shown to be unaffected by wind farms. Other species (passarine species) are attracted. Some research showed wind-farm-induced deviations in route under daylight conditions, and there was no evidence of attraction during daylight. The 50% reduction in the diversity of migrating birds at Alpha Ventus indicates the dominance of avoidance behavior across species [49].

International data do not allow quantification of the mortality rate of migrating birds that is associated with OWFs.

StUKplus researchers concluded that the fatality rate of migratory species offshore could be lower than expected, due to species-specific avoidance behavior [49]. The international comparison in the present study supports a theory of species-specific avoidance behavior [2, 42, 43, 46, 47, 52–63].

3.5 Impacts of OWFs on Harbor Porpoises and Other Marine Mammals

The current practice for constructing OWF foundations is impact pile driving, which produces strong impulse noise. Thus, given the sensitive hearing of this species, the harbor porpoise is at the center of research related to the ecological effects of OWFs. Limited data is available for impacts on other marine mammals around OWFs, and so the present study focuses on data related to porpoises.

At Alpha Ventus, aerial surveys, static acoustic monitoring, and shipboard line transect sampling were performed to study impacts of OWF construction on marine mammals [64]. The ship survey was accompanied by a towed hydrophone system capable of detecting porpoise echolocation clicks. Investigations were conducted during construction and operation in a sea area of thousands of square kilometers. A habitat modeling project was also conducted, which evaluated the distribution and abundance of harbor porpoises not only in the Alpha Ventus area but around other OWFs in Germany [1].

During construction, more porpoises were detected at distances greater than 10 km from Alpha Ventus than were detected near the OWF, which suggests that porpoises were displaced by construction in the zone within 8–10 km of the wind farm [64]. Wahl et al. [65] observed that harbor porpoises left the vicinity of the wind farm during pile driving, as porpoise acoustical activity was reduced by almost 100%. After construction, the acoustical activity stayed below normal levels for up to 20 h. The displacement time varied widely, from less than 1.5 h to more than 140 h; the average was approximately 17 h [64].

During operation of Alpha Ventus, no effect on harbor porpoises has been proven. Noise effects were validated but did not prove an effect on harbor porpoise abundance around the OWF [64]. A study by von Radecke described the operational noise of the OWF as akin to “background noise” at a distance of 100 m from the site. No effect was observed on animals at that distance [66]. Furthermore, studies showed that the operation of OWFs does not appear to impact harbor porpoise density in the long term. Harbor porpoise density in the southern German Bight increased from 2004 (when the first OWF was constructed) onward from 3000 to 15000 in Germany [67–70]. Similar increases were observed in neighboring countries [71, 72]. The population of harbor porpoises in the entire North Sea is estimated to be higher than 200,000.

Findings of international research on the effects of construction noise on marine mammals are as follows. An aerial survey by Dähne et al. [73] showed ramming without mitigation had effects at up to 20 km. Diederichs [74] showed the effects of OWF construction on harbor porpoises in an area up to 8 km (with the use of technical mitigation measures). The effect gradually decreased with increasing distance. In the area between 5 and 8 km, nearly no effect was observed, and beyond 8 km no consistent pattern could be noted. Data from Horns Rev 2, in Denmark, showed spatial displacement effects up to 18 km from the construction site. Horns Rev 2 did not employ any noise mitigation [46]. This effect had a clear gradient, with more animals being affected with decreasing distance. One study showed the animals returning to the wind farm hours or days after pile driving ceased [3].

The impacts of OWF operation on marine mammals indicated by international research have varied. Increased porpoise detection rates were observed at the first OWF in the Netherlands, probably due to the artificial reef effect [75] and the absence of ship traffic and fisheries [73]. Some other studies showed that operational wind farms are regularly frequented by porpoises, presumably in search of the increased fish stocks at the structures [24]. However, data for another OWF in the Dutch North Sea did not indicate increased detection rates of porpoises after the wind farm was built [76].

StUKplus researchers concluded that harbor porpoises leave the area during pile driving (displacement effect) due to the noise, but that this displacement effect was temporary, and there were no long-term impacts on the numbers of porpoises around OWFs. The comparison with international data confirmed the displacement effect of pile driving [2, 70, 77–88] and confirmed that it is temporary [2, 75, 77, 84, 86, 88–90]. International data also showed the abundance of harbor porpoises to be similar or higher around operating OWFs than before their construction [73, 75, 83, 91, 93].

3.6 Summary of the Relevant Ecological Effects of OWF

As shown above, only parts of the ecological effects seem to be relevant negative impacts. The summary of the results found in the StUKplus research and confirmed by the international research are shown in Table 1.

Knowledge of the effects of OWFs on the marine environment has been considerably advanced by data gathered in Germany over the past decade. Sufficient data exists to assess some impacts, such as the change in habitats for benthic organisms and fish close to OWF foundations, the impact on birds caused by rotating and illuminated wind turbines, and the impact on the behavior of harbor porpoises. Although some unknowns exist, some findings are fairly clear.

Now, the tasks are to integrate these findings into future planning processes, licensing conditions, and construction processes and to share this knowledge internationally, as has been attempted by Lüdeke 2015 [94]. This review of the past 10 years of research into the impacts of OWFs in Germany and internationally provides strong evidence that sustainable development of offshore wind is possible.

References:

[1] Beiersdorf, A. Accompanying ecological research at alpha ventus: The StUKplus research project. In Federal Ministry and Hydrographic Agency/Federal Ministry of Environment, Naure Conservation and Nuclear Safety. Ecological Research at the Offshore Windfarm alpha ventus—Challenges, Results and Perspectives 2014, ISBN 978-3-658-02461-1.

[2] Schuster EV, Bulling L, Köppel J. Consolidating the State of Knowledge: A Synoptical Review of Wind Energy’s Wildlife Effects. Environmental Management 2015: 1-32.

[3] Schmidt A, Gutow L, Teschke K, Preuß S, Gusky M, Breyer S, Fürst R, Bönsch R. Development of a soft bottom community within an offshore wind farm, Presentation on StUKplus Conference, Berlin, 30–31 October 2013.

[4] Krone R, Krägefsky S. Untersuchung der Effekte von Windenergieanlagen auf Fische und vagile Megafauna im Testfeld "alpha ventus“ Arbeitspaket B: Untersuchungen der Auswirkungen auf demersale Fische und Megazoobenthos. BMU. 2012.

[5] Krone R, Gutow L, Brey T, Dannheim J, Schröder A. Mobile demersal megafauna at artificial structures in the German Bight–likely effects of offshore wind farm development. Estuarine, Coastal and Shelf Science 2013; 125: 1-9.

[6] Gutow L, Teschke K, Gusky M, Schmidt A, Krone R. The turbine focus: benthic fauna on and around offshore wind farm constructions, StUKplus Conference, Berlin, 30–31 October 2013.

[7] Lindeboom HJ, Kouwenhoven HJ, Bergman MJN, Bouma S, Brasseur S, Daan R, Fijn RC, de Haan D, Dirksen S, van Hal R, Lambers RHR, Ter Hofstede R, Krijgsveld KL, Leopold M, Scheidat M. Short-term ecological effects of an offshore wind farm in the Dutch coastal zone; a compilation. Environmental Research Letters 2011; 6: 035101.

[8] Coates D, Vanaverbeke J, Vincx M. Enrichment of the soft sediment macrobenthos around a gravity based foundation on the Thorntonbank. In: Degraer S, rabant R, Rumes B (eds.) Offshore windfarms in the Belgian part of the North Sea: heading for an understanding of environmental impacts. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, Marine Ecosystem Management Unit, Brussels, pp. 41-54; 2012.

[9] Coates D A, Deschutter Y, Vincx M, Vanaverbeke J. Enrichment and shifts in macrobenthic assemblages in an offshore wind farm area in the Belgian part of the North Sea.Original Research Article. Marine Environmental Research 2014; 95: 1-12.

[10] Wilding, Thomas A. Effects of man-made structures on sedimentary oxygenation: Extent,

seasonality and implications for offshore renewables. Marine environmental research 2014; 97: 39-47.

[11] Dannheim J. et al. Trophic look at soft-bottom communities—Short-term effects of trawling cessation on benthos. Journal of Sea Research 2014; 85: 18-28.

[12] Bergman, Magda JN, et al. Effects of a 5-year trawling ban on the local benthic community in a wind farm in the Dutch coastal zone. ICES Journal of Marine Science: Journal du Conseil (2014): fsu193.

[13] Wilhelmsson D, Malm T, Thompson R, Tchou J, Sarantakos G, McCormick N, Luitjens S, Gullström M, Patterson Edwards JK, Amir O, Dubi A. Greening Blue Energy: Identifying and Managing the Biodiversity Risks and Opportunities of Off Shore Renewable Energy. Gland, Switzerland: IUCN; 2010: 102.

[14] Lindeboom HJ, Kouwenhoven HJ, Bergman MJN, Bouma S, Brasseur S, Daan R, Fijn RC, de Haan D, Dirksen S, van Hal R, Hille Ris Lambers R, de Hofstede R, Krijgsveld KL, Leopold M, Scheidat M. Short-term ecological effects of an offshore wind farm in the Dutch coastal zone: a compilation. Environmental Research Letters 2011; 6: 035101.

[15] Andersson MH, Berggren M, Wilhelmsson D, Öhman MC. Epibenthic colonization of concrete and steel pilings in a cold-temperate embayment: a field experiment. Helgoland Marine Research 2009; 63 (3): 249-260.

[16] Wilson JC, Elliott M. The habitat creation potential of offshore wind farms. Wind Energy 2009; 12 (2): 203-212.

[17] Vaissière, AC. et al. Biodiversity offsets for offshore wind farm projects: The current situation in Europe. Marine Policy 48 (2014): 172-183.

[18] van der Winden J, van Vliet F, Rein C, Lane B (2014). Renewable Energy Technologies and Migratory Species. (2014). UNEP/CMS/COP11/Inf.26. Agenda Item 23.4.3 of the 11th MEETING OF THE CONFERENCE OF THE PARTIES in Quito, Ecuador, 4-9 November 2014.

[19] Krone R, Gutow L, Joschko T J, Schröder A. Epifauna dynamics at an offshore foundation—Implications of future wind power farming in the North Sea. Original Research Article. Marine Environmental Research 2013; 85: 1-12.

[20] Hooper T, Austen M. The co-location of offshore windfarms and decapod fisheries in the UK: Constraints and opportunities Original Research Article Marine Policy 2014; 43: 295-300.

[21] Punt M J, Groeneveld R A, van Ierland E C, Stel J H. Spatial planning of offshore wind farms: A windfall to marine environmental protection. Original Research Article.Ecological Economics 2009; 69(1): 93-103.

[22] Ashley MC, Mangi SC, Rodwell LD. The potential of offshore windfarms to act as marine protected areas—A systematic review of current evidence Original Research Article Marine Policy 2014; 45: 301-309

[23] Krägefsky S. Effects of the alpha ventus offshore test site on pelagic fish. In StuK plus Buch in Federal Ministry and Hydrographic Agency/Federal Ministry of Environment, Nature Conservation and Nuclear Safety: Ecological Research at the Offshore Windfarm alpha ventus—Challenges, Results and Perspectives; 2014.

[24] Reichert K, Dannheim J, Gusky M, Krägefsky S, Krone R, Gutow L. Fish and benthos at alpha ventus. International Conference RAVE 2012, Bremerhaven, Germany, 8–10 May 2012.

[25] Reubens Jan T. et al. Diel variation in feeding and movement patterns of juvenile Atlantic cod at offshore wind farms. Journal of Sea Research 2014; 85: 214-221.

[26] Langhamer O., Wilhelmsson D., Engstrom J. Artificial reef effect and fouling impacts on offshore wave power foundations and buoys—a pilot study. Estuarine,Coastal and Shelf Science 2009; 82: 426-432.

[27] Leitao, F., Santos, M.N., Monteiro, C.C. Contribution of artificial reefs to the diet of the white sea bream (Diplodus sargus). ICES Journal of Marine Science 2007; 64: 473-478.

[28] Reubens, J., Degraer, S., Vincx, M. Aggregation and feeding behavior of pouting(Trisopterus luscus) at wind turbines in the Belgian part of the North Sea. FisheriesResearch 2011; 108: 223-227.

[29] Reubens J T, Braeckman U, Vanaverbeke J, Van Colen C, Degraer S, Vincx M (2013): Aggregation at windmill artificial reefs: CPUE of Atlantic cod (Gadus morhua) and pouting (Trisopterus luscus) at different habitats in the Belgian part of the North Sea.Original Research Article. Fisheries Research 2013; 139: 28-34.

[30] De Troch M, Reubens J T, Heirmann E, Degraer S, Vincx M. Energy profiling of demersal fish: A case-study in wind farm artificial reefs. Original Research Article Marine Environmental Research 2013, 92: 224-233.

[31] Dierschke V, Garthe S. Literature review of offshore wind farms with regards to seabirds. In: Zuccho C, Wende W, Merck T, Köchling I, Köppel J (eds). Ecological research on offshore wind farms: international exchange of experience. Part B: Literature review of ecological impacts 2006; 186: 131-198. BfN-Skripten.

[32] Garthe S, Mendel B, Kotzerka J, Sommerfeld J. Effects of alpha ventus on distribution patterns, behavior and flight heights of seabirds. Presentation on StUKplus Conference, Berlin, 30–31 October 2013.

[33] Mendel B, Kotzerka J, Sommerfeld J, Schwemmer H, Sonntag N, Garthe S. Effects of the alpha ventus offshore test site on distribution patterns, behavior and flight heights of seabirds. In Federal Ministry and Hydrographic Agency/Federal Ministry of Environment, Nature Conservation and Nuclear Safety. Ecological Research at the Offshore Windfarm alpha ventus—Challenges, Results and Perspectives, 2014.

[34] Gutow L, Teschke K, Schmidt A, Dannheim J, Krone R, Gusky M. Rapid increase of benthic structural and functional diversity at the alpha ventus offshore test site. In Federal Ministry and Hydrographic Agency/Federal Ministry of Environment, Nature Conservation and Nuclear Safety. Ecological Research at the Offshore Windfarm alpha ventus—Challenges, Results and Perspectives, 2014.

[35] Leopold MF, van Bemmelen RSA and Zuur AF. Responses of local birds to the offshore wind farms PAWP and OWEZ off the Dutch mainland coast. Report C151/12,Imares, Wageningen, 2013.

[36] Petersen IK. Is the distribution and abundance of waterbirds altered in and around offshore windfarms. Presentation on StUKplus Conference, Berlin, 30–31 October 2013.

[37] Petersen IK, Fox AD, Kahlert J. Waterbird distribution in and around the Nysted offshore windfarm, 2007. NERI Report, commissioned by DONG Energy, DK, 2008.

[38] Schwemmer P, Mendel B, Sonntag N, Dierschke V, Garthe S. Effects of ship traffic on seabirds in offshore waters: implications for marine conservation and spatial planning. Ecological Applications 2011; 21: 1851-1860.

[39] King, J. G., and Sanger, G. A. Oil vulnerability index for marine oriented birds. In Bartonek and Nettleship 1979; 227-39.

[40] Williams J, Tasker M, Carter I, Webb A. A method of assessing seabird vulnerability to surface pollutants 1994;. Ibis 137: 147-152

[41] Furness, R.W. and M.L. Tasker. Seabird-fishery interactions: quantifying the sensitivity of seabirds to reductions in sandeel abundance and identification of key areas for sensitive seabirds in the North Sea. Marine Ecolology Progress Series 2000; 202: 253-264.

[42] Garthe S, and Hüppop O. Scaling possible adverse effects of marine wind farms on seabirds: developing and applying a vulnerability index. Journal of Applied Ecology 2004; 41.4: 724-734.

[43] Furness R W, Wade H M, Masden E A. Assessing vulnerability of marine bird populations to offshore wind farms. Journal of environmental management 2013; 119: 56-66.

[44] Bradbury, G., Trinder, M., Furness, B., Banks, A. N., Caldow, R. W., Hume, D. Mapping Seabird Sensitivity to Offshore Wind Farms. PloS one 2014; 9 (9): e106366.

[45] Mateos M. Muñoz Arroyo G, Alonso del Rosario JJ (2011) Modelling seabird collision risk with off-shore windfarms. In May R, Bevanger K (eds.) Proceedings. Conference on Wind energy and Wildlife impacts. NINA Report 693. Conference on Wind energy and Wildlife impacts, 2-5 May 2011. Norwegian Institute for Nature Research. Trondheim, Norway, p 39

[46] Petersen IK, Christensen TK, Kahlert J, Desholm M, Fox AD (2006) Final results of bird

studies at the offshore wind farms at Nysted and Horns Rev, Denmark: Report request. Commissioned by DONG Energy and Vattenfall A/S. National Environmental Research Institute, 2006.

[47] Plonczkier P, Simms IC. Radar monitoring of migrating pink-footed geese: behavioral responses to offshore wind farm development. Journal of Applied Ecology 2012, 49 (5): 1187-1194. doi: 10.1111/j.1365-2664.2012.02181.x

[48] Coppack T, Dittmann T, Schulz A. Avian migration over offshore wind farms: How many birds will get stuck plus the tools you need to find out. Presentation on StUKplus Conference, Berlin, 30–31 October 2013.

[49] Hill R, Aumüller R, Boos K, Freienstein S, Hill K. Results, conclusions and perspectives from 10 years of offshore bird migration research in the German Bight, in Federal Ministry and Hydrographic Agency/Federal Ministry of Environment, Nature Conservation and Nuclear Safety: Ecological Research at the Offshore Windfarm alpha ventus—Challenges, Results and Perspectives, 2014.

[50] Helmut W, Gottfried W, Dieter T. Comparing baseline and construction studies in the BARD Offshore 1 wind farm: aspects of bird migration, in Federal Ministry and Hydrographic Agency/Federal Ministry of Environment, Nature Conservation and Nuclear Safety: Ecological Research at the Offshore Windfarm alpha ventus— Challenges, Results and Perspectives, 2014.

[51] Hüppop O, Dierschke J, Exo KM, Fredrich E, Hill R. Bird migration studies and potential collision risk with offshore wind turbines. Ibis 2006; 148: 90–109.

[52] Cook ASCP, Johnston A, Wright LJ, Burton NHK (2012) A review of flight heights and avoidance rates of birds in relation to offshore windfarms. BTO Research Report No. 618.

[53] Desholm M, Kahlert J (2005) Avian collision risk at an offshore wind farm. Biology Letters 2005; 1 (3): 296-298. doi: 10.1098/rsbl.2005.0336

[54] Christensen TK, Hounisen JP, Clausager I, Petersen IK (2004) Visual and radar observations of birds in relation to collision risk at the Horns Rev offshore wind farm. Annual status report 2003.

[55] Kahlert JA, Laubek B, Aaen K, Waagner S,Groom G, Andersen PN (2011) Rødsand 2 Offshore Wind Farm—Post-construction Studies on Migrating Land Birds autumn 2010.

[56] Pettersson J. The Impact of Offshore Wind Farms on Bird Life in Southern Kalmar Sound, Sweden. A final report based on studies 1999-2003.

[57] Reichenbach M, Grünkorn T (2011) A multimethod app roach to determine the impact of existing wind power plants on bird and bat migration on the island of Fehmarn, Germany. In: May R, Bevanger K (eds.) Proceedings. Conference on Wind energy and Wildlife impacts. NINA Report 693. Conference on Wind energy and Wildlife impacts, 2-5 May 2011. Norwegian Institute for Nature Research. Trondheim, Norway, p 118

[58] Aumüller R, Boos K, Freienstein S, Hill K, Hill R. Beschreibung eines Vogelschlagereignisses und seiner Ursachen an einer Forschungsplattform in der Deutschen Bucht. Vogelwarte 2011; (49): 9-16

[59] Hüppop O, Dierschke J, Wendeln H. Zugvögel und Offshore-Windkraftanlagen: Konflikte und Lösungen. Ber Vogelschutz 2004; 41: 127-218

[60] Hüppop O, Dierschke J, Exo K, Fredrich E, Hill R. Bird migration studies and potential collision risk with offshore wind turbines. Ibis 2006; 148: 90-109

[61] Grünkorn T, Diederichs A, Poszig D, Diederichs B, Nehls G. Wie viele Vögel kollidieren mit Windenergieanlagen? How many birds collide with wind turbines. Nat Landsch 2009; 84 (7): 309-314

[62] Masden EA, Haydon DT, Fox AD, Furness RW, Bullman R, Desholm M. Barriers to movement: impacts of wind farms on migrating birds. ICES J Mar Sci 2009; 66: 746-753. doi: 10.1093/icesjms/fsp031

[63] Hill R, Hill K, Aumüller R, Schulz A, Dittmann T, Kulemeyer C, Coppack T. Of birds, blades and barriers: Detecting and analyzing mass migration events at alpha ventus. In: Federal Maritime and Hydrographic Agency / Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (eds.) Ecological Research at the Offshore Windfarm alpha ventus, 2014, pp 111-131

[64] Gilles A, Dähne M, Peschko V, Adler S, Ronnenberg K, Siebert U. Harbor porpoises in the southern North Sea – analysis of potential influences of alpha ventus in the context of general distribution trends. In Federal Ministry and Hydrographic Agency/Federal Ministry of Environment, Nature Conservation and Nuclear Safety: Ecological Research at the Offshore Windfarm alpha ventus— Challenges, Results and Perspectives, 2014.

[65] Wahl V, Braasch A, Gauger M, Diederichs A, Rose A, Dahne M. Kalibrierung von C-PODs: Evaluierung von Kalibrierungsdaten und Einbindung in statistische Auswertungen.Forschungsvorhaben im Auftrag des Bundesministeriums fur Umwelt, Naturschutz und Reaktorsicherheit (FKZ: 0327689A). 79.

[66] van Radecke H, Benesch M. Operational underwater noise at alpha ventus, presentation on International ConferenceRAVE 2012, May 8-10, 2012 in Bremerhaven, Germany

[67] TSEG (Trilateral Seal Expert Group). Aerial surveys of Harbor Seals in the Wadden Sea in 2012. Trilateral Seal Expert Group, Wilhelmshaven 2012; 3. http://www.waddensea-secretariat.org/sites/default/files/downloads/trilateral_seal_counts_report_2012.pdf, accessed 04.09.2013.

[68] Gilles A, Scheidat M, Siebert U. Seasonal distribution of harbor porpoises and possible interference of offshore wind farms in the German North Sea. Marine Ecology Progress Series 2009; 383: 295-307. doi: 10.3354/meps08020.

[69] Gilles A, Adler S, Kaschner K, Scheidat M, Siebert U. Modelling harbor porpoise seasonal density as a function of the German Bight environment: implications for management. Endangered Species Research 2011; 14: 157-169. doi: 10.3354/esr00344.

[70] Dähne M, Gilles A, Lucke K, Peschko V, Adler S, Krügel K, Sundermeyer J, Siebert U. Effects of pile-driving on harbor porpoises (Phocoena phocoena) at the first offshore wind farm in Germany. Environmental Research Letters 2013; 8: 025002. doi: 10.1088/1748-9326/8/2/025002

[71] Scheidat M, Verdaat H, Aarts G. Using aerial surveys to estimate density and distribution of harbor porpoises in Dutch waters. Journal of Sea Research 2012; 69: 1-7. doi: 10.1016/j.seares.2011.12.004.

[72] Hammond PS, Macleod K, Berggren P, Borchers DL, Burt L, Cañadas A, Desportes G, Donovan GP, Gilles A, Gillespie D, Gordon J, Hiby L, Kuklik I, Leaper R, Lehnert K, Leopold M, Lovell P, Øien N, Paxton CGM, Ridoux V, Rogan E, Samarra F, Scheidat M, Sequeira M, Siebert U, Skov H, Swift R, Tasker ML, Teilmann J, Van Canneyt O, Vázquez JA. Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biological Conservation 2013; 164: 107-122. doi: 10.1016/j.biocon.2013.04.010.

[73] Dähne M, Peschko V, Gilles A, Lucke K, Adler S, Ronnenberg K, Siebert U. Marine mammals and windfarms: Effects of alpha ventus on harbor porpoises. In Federal Ministry and Hydrographic Agency/Federal Ministry of Environment, Nature Conservation and Nuclear Safety (2014): Ecological Research at the Offshore Windfarm alpha ventus— Challenges, Results and Perspectives, 2014.

[74] Diederichs A. Lesson learned—effects of pile driving for three offshore wind farms in the German Bight on harbor porpoises, presentation on StUKplus Conference, Berlin, 30-31 October 2013.

[75] Scheidat M, Tougaard J, Brasseur S, Carstensen J, van Polanen-Petel T, Teilmann J, Reijnders PJH. Harbor porpoises (Phocoena phocoena) and wind farms: a case study in the Dutch North Sea. Environment Research Letters 2011; 6 (2): 25102. doi: 10.1088/1748-9326/6/2/025102

[76] van Polanen Petel T, Geelhoed SCV, Meesters HWG. Harbor porpoise occurrence in relation to the Prinses Amaliawindpark. Report Number C177/10, Wageningen, Imares 2012; 34.

[77] Brandt MJ, Diederichs A, Nehls G. Harbor porpoise responses to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. Final Report to DONG Energy February 2009. BioConsult SH, Husum, Germany

[78] Brandt MJ, Diederichs A, Betke K, Nehls G. Responses of harbor porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. Marine Ecology Progress Series 421: 205-216. doi: 10.3354/meps08888

[79] Carstensen J, Henriksen OD, Teilmann J. Impacts of offshore wind farm construction on harbor porpoises: acoustic monitoring of echo-location activity using porpoise detectors (T-PODs). Marine Ecology Progress Series 2006; 321: 295-308. doi: doi:10.3354/meps321295

[80] Haelters J, van Roy W, Vigin L, Degraer S. The effect of pile driving on harbor porpoises in Belgian waters. In: Degraer S, Brabant R, Rumes B (eds.) Offshore wind farms in the Belgian part of the North Sea. Heading for an understanding of environmental impacts. Royal Belgian Institute of Natural Sciences. Brussels, Belgium, 2012; 127-143

[81] Kastelein RA, van Heerden D, Gransier R, Hoek L. Behavioral responses of a harbor porpoise (Phocoena phocoena) to playbacks of broadband pile driving sounds. Marine Environment Research 2013; 92: 206-214. doi: 10.1016/j.marenvres.2013.09.020

[82] Nedwell J, Howell D (2004) A review of offshore windfarm related underwater noise sources. Tech. Rep. 544R0308. Prep. By Subacoustech Ltd., Hampshire, UK, for COWRIE.

[83] Nedwell J, Parvin S, Edwards B, Workman R, Booker A, Kynoch JE (2007) Measurement and interpretation of underwater noise during construction and operation of offshore windfarms in UK waters. Subacoustech Report No. 544R0738 to COWRIE Ltd.

[84] Nehls G, Betke K (2011) Darstellung und Bewertung der Auswirkungen von Schallemissionen durch offshore-Rammarbeiten auf Meeressäugetiere. http://www.bioconsult-sh.de/pdf/Nehls%20&%20Bethke%202011%20Schallbericht%20OFW20111215.pdf.

[85] Tougaard J, Carstensen J, Ilsted Bech N, Teilmann J. Final report on the effect of Nysted Offshore Wind Farm on harbor porpoises. Technical report to Energi E2 A/S. Edited by Ministry of the Environment. National Environmental Research Institute (NERI). Roskilde, Denmark, 2006.

[86] Tougaard J, Carstensen J, Wisz M, Jespersen M, Teilmann J, Ilsted Bech N, Skov H (2006b) Harbor Porpoises on Horns Reef. Effects of the Horns Reef Wind Farm. Final Report to Vattenfall A/S. Roskilde, Denmark.

[87] Tougaard J, Carstensen J, Teilmann J, Skov H, Rasmussen P. Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (Phocoena phocoena (L.)). Journal of the Acoustical Society of America 2009; 126 (1): 11-14. doi: 10.1121/1.3132523

[88] Wahl V, Braasch A, Joost M, Ketzer C, Michalik A, Todeskino D (2013) Behavioral responses of harbor porpoises to pile driving on a temporal and spatial scale at the BARD Offshore 1 windfarm. Presentation at StuKplus—Five Years of Ecological Research at alpha ventus—Challenges, Results and Perspectives, Berlin 30 October 2013

[89] Danish Energy Agency (2013) Danish Offshore Wind. Key Environmental Issues - a Follow-up. 1st ed. Edited by The Environmental Group. The Danish Energy Agency; The Danish Nature Agency; DONG Energy; Vattenfall.

[90] Haelters J, Vanermen N. Top Predators at Presentation. WINMON.BE conference, Brussels, Belgium, 26-27 November 2013.

[91] Diederichs A, Hennig V, Nehls G. Investigations of the bird collision risk and the responses of harbor porpoises in the offshore windfarms Horns Rev, North Sea, and Nysted, Baltic Sea, in Denmark. Part II: Harbor porpoises. Final Report 2008. Universität Hamburg; BioConsult SH GmbH & Co. KG.

[92] McConnell B, Lonergan M, Dietz R (2012) Marine Estate Research Report: Interactions between seals and offshore wind farms.http://www.thecrownestate.co.uk/media/288846/interactions_between_seals_and_offshore_wind_farms.pdf

[93] Scheidat M (2012) Porpoises and offshore windfarms - conflict, co-existence or refuge? Presentation at OWEZ Congress, Amsterdam,Netherlands, 11-12 October 2012. http://www.noordzeewind.nl/wpcontent/uploads/2012/11/pdf/OWE%202012%20Imares%20Scheidat%20Harbor%20Porpoises.pdf.

[94] Lüdeke J (2015): Strategies for a Sustainable Development of Offshore Wind Energy: Suggestions for a better Planning, Assessment, Mitigation and Compensation of Impacts of OWF. Submitted to Renewable and Sustainabe Energy Reviews (unpublished).

Tab. 1 Summary on the main results of impacts by OWF

Impacts	**Fish**	**Benthos**	**Resting Birds**	**Migrating Birds**	**Harbor Porpoises (Ramming of OWF)**	**Harbor Porpoises (Operating OWF)**
positive ecological effects	x	x	x (species specific)			x
neutral			x (species specific)	x (day)		x
negative ecological effects			**x (species specific)**	**x (night, bad weather)**	**x**	

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