Rapid increase of benthic structural and functional diversity at the *alpha ventus* offshore test site

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9.1 Introduction

The benthos of the German North Sea – consisting of both invertebrates and fishes associated with the seafloor – is characterised by notable biodiversity. Hundreds of species from almost every taxonomic invertebrate group exist in complex interactions with their biotic and abiotic environment, thereby providing important ecosystem goods and services. Specifically, in the sandy sediment of the *alpha ventus* windfarm, about 200 benthos species form the typical *Tellina fabula* association named after one of its dominant bivalve species (Salzwedel et al. 1985). Many of these organisms are representatives of basal levels of the marine food web. Accordingly, they form an essential link between marine primary production by planktonic microalgae and consumers from higher trophic levels such as birds, mammals and commercially valuable fishes (Gili & Coma 1998).

Because of the eminent ecological importance of benthic organisms, national nature conservation authorities have emphasised the need for careful research into the potential effects of offshore windfarms on the marine benthos (Merck & von Nordheim 2000). The Standard for Environmental Impact Assessment (StUK), compiled by the Federal Maritime and Hydrographic Agency (BSH), prescribes extensive studies on the potential effects of offshore windfarms on the in- and epifauna of the seafloor as well as the fouling assemblage on the foundation structures of the turbines (see Chap. 5). This chapter presents the results from research projects in which selected aspects of the StUK3 investigation programme were temporally intensified. Additional sampling campaigns were added to close temporal gaps in the seasonal sampling programme. Special emphasis was given to the investigation of the mobile demersal megafauna on and around the underwater structures of the turbines. This component of the benthos was studied by scientific SCUBA diving – a method which is very challenging under the rough offshore conditions of the North Sea, but provides unique results that cannot be obtained with any other method (► Information box: *Scientific offshore diving*). In interpreting the data from our benthos survey we drew upon a unique extensive dataset on the distribution of benthic species in the German Bight. This allowed an evaluation of the specific development of the benthic community in the *alpha ventus* windfarm area against the ambient large-scale variability of the benthic ecosystem caused by natural environmental fluctuations in combination with anthropogenic stressors such as bottom fisheries. In sum, common methods were applied in the investigation of the marine benthic in- and epifauna, standardised national strategies for environmental impact assessment modified, and new additional methods were included to provide a comprehensive understanding of the effects of offshore windfarms on the marine benthos.

9.2 Methods

The study objects, the sampling designs and the survey methods were mainly based on the StUK3 procedures (BSH 2007; ■ Fig. 9.1). Additional new methods were adopted to sample the mobile demersal megafauna, including large crabs and demersal fish that occur around the underwater structures of the wind turbines and on the adjacent seafloor.

9.2.1 Study design

One of the most widely used designs was applied to sample the benthic in- and epifauna: A modification of Green's (1979) Before-After-Control-Impact (BACI) design. This involves sampling the benthic fauna in an area that is planned to be affected by some disturbance and also in a single reference (control) area not affected by the development. Each area is sampled once prior to and several times after the potential disturbance.

Accordingly, the benthic fauna was surveyed within the *alpha ventus* area and also in a reference area outside the windfarm (■ Fig. 9.2). The reference area was similar to the windfarm area in terms of abiotic parameters such as water depth, type of sediment and biotic features (e.g. species inventory of the benthic community). Thus, the reference area served as a control to identify possible effects of the construction and operation of the windfarm on the temporal development of the benthic fauna.

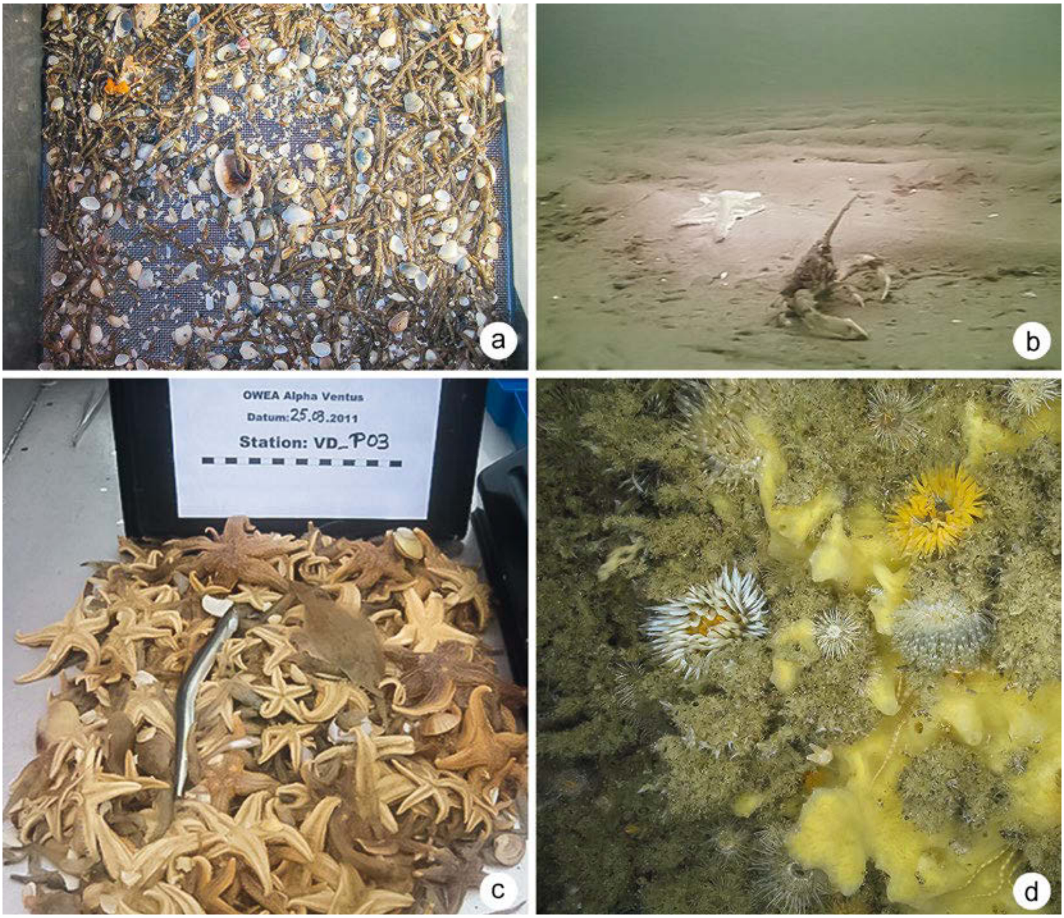


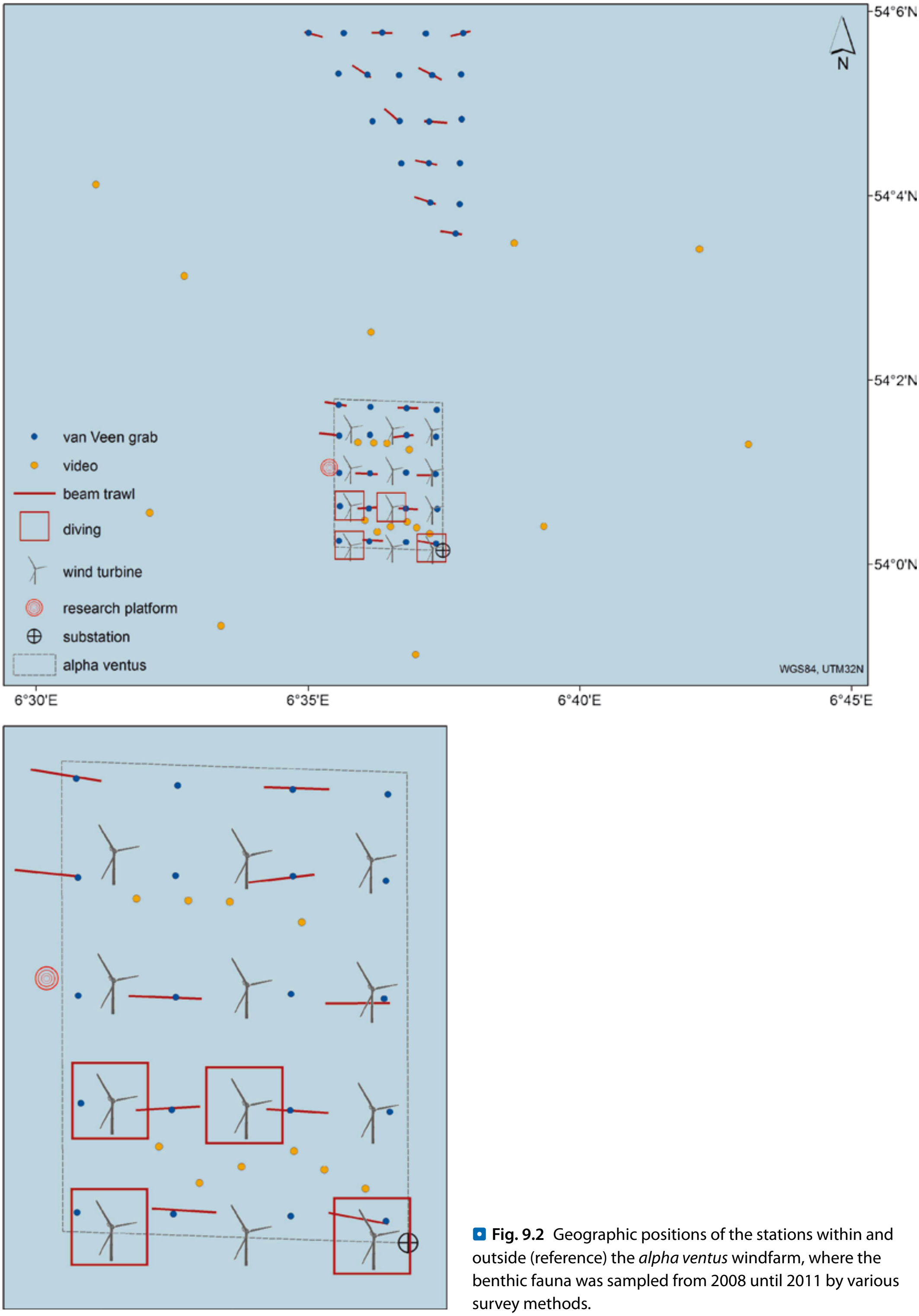
Fig. 9.1 Typical catches taken with the various survey methods used to study the benthic fauna. (a) Sieve residue of the van Veen bottom grab characterised by bivalves and tubeworms. (b) Video recording of sedimentary seafloor with the masked crab *Corystes cassivelaunus* and a starfish. (c) Typical beam trawl catch with numerous starfish *Asterias rubens*. (d) Characteristic fouling community on the foundation structure of research platform FINO1 which is located close to the *alpha ventus* windfarm (photo: (a-c) IfAÖ GmbH, (d) AWI).

After the baseline survey in spring 2008, which was conducted prior to construction of the offshore wind turbines in *alpha ventus*, the soft-bottom fauna was sampled biannually from 2009 until 2011, with sampling campaigns in spring and autumn. The assemblages of fouling organisms, such as mussels and sea anemones (Fig. 9.1d) that colonised the turbine foundations, were sampled for the first time after construction of the wind turbines in 2009. Repeated samplings followed in spring and autumn 2010 and 2011. The mobile demersal megafauna was sampled in spring and autumn 2011, i. e. two years after construction of the windfarm.

9.2.2 Data collection

Soft-bottom communities

The soft-bottom epifauna, i. e. often mobile invertebrate organisms that live on the seafloor, such as crabs, shrimps and starfish (Fig. 9.1b), was sampled with a beam trawl with an opening width of 200 × 60 cm and a mesh size of 1 cm (Fig. 9.3). Sampling was always done during daytime. For each epifauna sample, the beam trawl was towed on the ground for five minutes at a trawling speed of 1 to 3 kn. For each campaign, ten beam-trawl samples were taken within *alpha ventus* and in the reference area (Fig. 9.2), resulting in a total of 140 hauls be-



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■ **Fig. 9.2** Geographic positions of the stations within and outside (reference) the *alpha ventus* windfarm, where the benthic fauna was sampled from 2008 until 2011 by various survey methods.

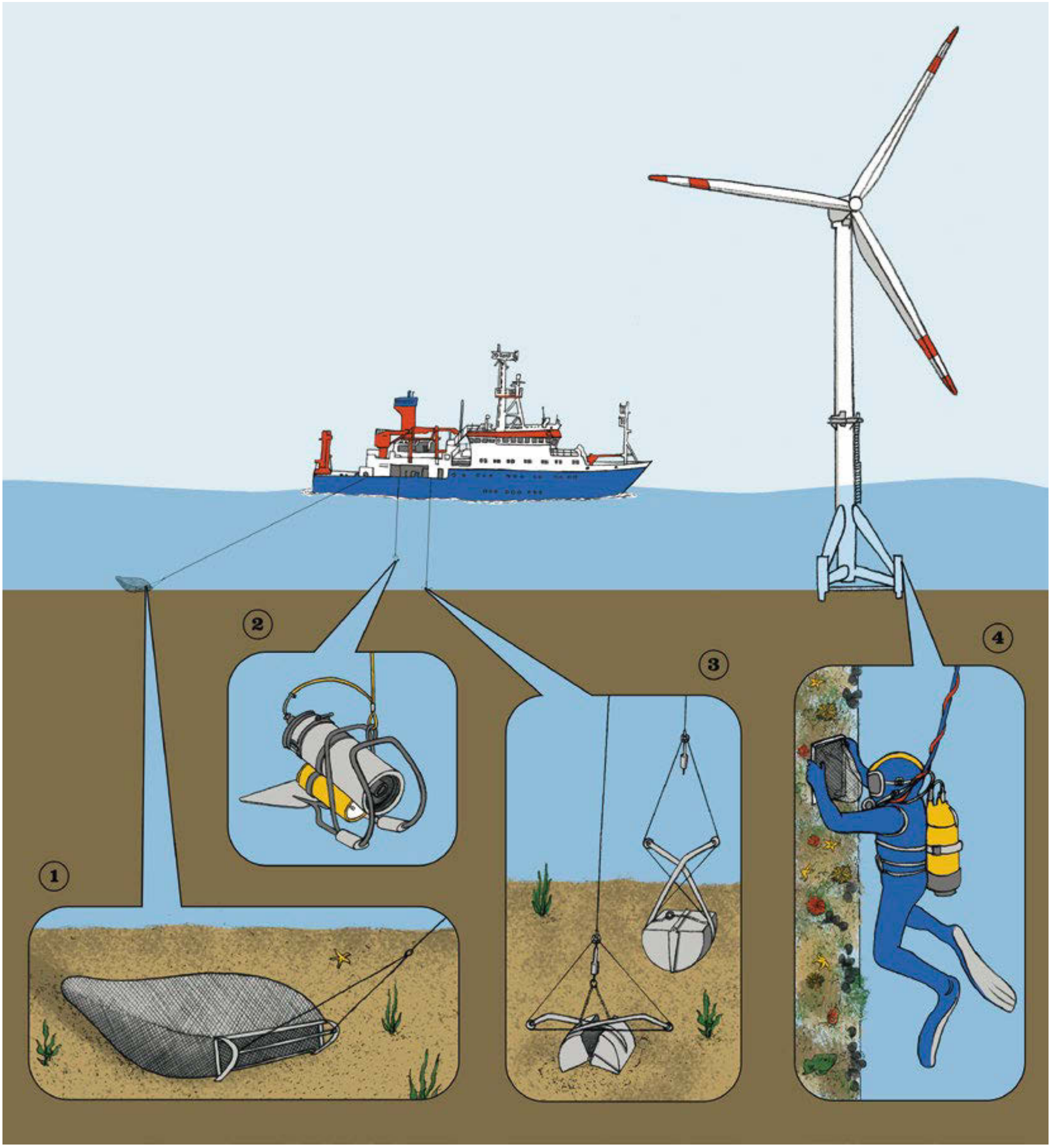

Fig. 9.3 Schematic depiction of the survey methods applied to achieve a thorough quantitative assessment of the benthic fauna at *alpha ventus*: (1) Epifaunal inhabitants of the sediment were collected by bottom trawling. (2) Video recording was carried out to obtain an overview of the mobile demersal megafauna on the sedimentary seafloor. (3) The infauna was sampled by using the van Veen bottom grab. (4) Scientific diving is an excellent method for sampling the fauna associated with the artificial hard substratum of the wind turbine foundations.

tween 2008 and 2011. On board the research vessel, the catch was sorted, counted and weighed (wet weight) by taxa.

The soft-bottom infauna, i. e. the animals that live inside the sediment, such as clams, tubeworms and burrowing crabs (Fig. 9.1a), was sampled with a van Veen bottom grab with a sampling area of 0.1 m^2 and a weight of 75 kg (Fig. 9.3). On each sampling campaign, 20 evenly distributed stations were sampled in the *alpha ventus* area and in the reference area (Fig. 9.2). Two replicate grabs were taken at each station, resulting in a total of 560 samples between 2008 and 2011. After the van Veen grab had been lifted from the seafloor, it was flushed out immediately with seawater and the sediment was sieved through a 1 mm mesh. The retained animals were preserved with 4 % borax-buffered formalin in seawater. The preserved infaunal organisms were then identified, counted and weighed (wet weight) by taxa in the laboratory.

Hard-bottom associated fauna

The hard-bottom fauna on the turbine foundations was sampled by scientific divers (Fig. 9.3). The scientific diving operation is described below, ► Information box: *Scientific offshore diving*.

During each sampling campaign, the fouling organisms were sampled on two wind turbine foundations (Fig. 9.2). A total of 126 samples were taken between 2008 and 2011. On each turbine foundation, three replicate scrape samples were taken randomly at water depths of 1, 5 and 10 m, respectively. The fouling organisms were scraped off with a spatula from a 20 × 20 cm area and captured in a mesh bag (mesh size: 1 mm). The organisms were fixed with 4 % borax-buffered formalin. The preserved individuals were then identified and weighed (wet weight) in the laboratory.

The mobile demersal megafauna was surveyed visually on belt transects extending on the seafloor away from three to four turbine foundations (Fig. 9.2). Additionally, the megafauna was recorded on the three-dimensional underwater structure itself. All individuals were identified *in situ* and counted by the diver. Each record was reported to a co-worker on the surface via underwater telephone. The megafauna abundance from the surveyed area of the underwater structure was extrapolated to the entire subtidal area of the foundation. The megafauna abundance from the belt transect was extrapolated to the projection area of the foundation on the seafloor, plus the surrounding 15 m transect belt resulting in what is referred to as the 'footprint area' of the turbine foundation measuring 2,400 m^2. Adding up the abundances of the mobile demersal megafauna from both the footprint area and from the turbine foundation allowed an estimate to be made of the overall amount of megafaunal individuals that accumulate above the footprint area of a wind turbine foundation.

As a reference for mobile demersal megafauna at the turbine foundations, the megafauna was surveyed on the sedimentary seafloor inside and outside the windfarm area using a ship-based underwater video camera system (CMOS video TV resolution; 9 W high power LED light; Fig. 9.3). The camera was towed above the seafloor at a drift speed of 0.2–0.5 knots. In total, 20 video transects of 500 m length each were generated (Fig. 9.2). The camera was equipped with parallel lasers which allowed for counting the animals on strips of defined width and length. Sections of the strips were randomly selected from each video to obtain transects of the same projection area as a dive transect, resulting in a total of 110 seafloor transects of 15 m^2 each. The comparability of dive and video transects was confirmed by Krone et al. (2013a).

Scientific offshore diving

Personnel demands

When diving for scientific purposes using self-contained underwater breathing apparatus (SCUBA), German researchers must follow the national hazard prevention regulation. This regulation entails safety requirements with regard to equipment and personnel. It requires that the diver takes an exam and qualifies in scientific diving, and prescribes that a scientific diving crew consists of at least an instructor, a diver and a safety diver.

Challenges offshore

Research at offshore windfarms in the North Sea involving scientific diving requires additional effort. Given the water depth, often poor underwater visibility, and the possibility that divers may become entangled in submerged structures, the diving operation should be conducted 'surface supplied' (umbilical with air and telephone; Fig. 9.4). Furthermore, windfarm operators have their own specific demands for diving operations, and the use of offshore occupational diving equipment is recommended. Divers must be educated and trained at regular intervals in surface-supported diving at larger depths and also in seamanship. In tidal seas such as the North Sea, diving is most secure during the short slack water periods. Thus, in most instances, only two dives are possible during daylight in the North Sea. A sea-worthy expedition ship and temporally flexible expedition planning are essential as the success of a dive mission depends on suitable sea conditions. The personnel and material efforts of scientific offshore diving therefore have only little in common with snorkelling or diving for recreational purposes in shallow coastal waters.

Opportunities

If the challenges of scientific diving are mastered and expeditions are run as scheduled, unique new observations from 'exotic' sites such as wind turbine foundations are possible. Unlike in studies of cultured organisms in aquaria, the behaviour of almost undisturbed animals can be studied in situ. Diving allows for non-destructive quantification of the fauna in habitats where the use of remotely operated devices is difficult. This enables us to create a more comprehensive picture of North Sea artificial reef ecology by capturing species that would otherwise remain hidden and by estimating their abundance and distribution. Moreover, in situ observation by means of diving allows for more than just numerical information on habitats und their inhabitants. The diver is the most multi-functional tool in the sea, and a diving marine researcher experiences personally how aquatic organisms might live in a three dimensional space with reduced gravity and elevated pressure.

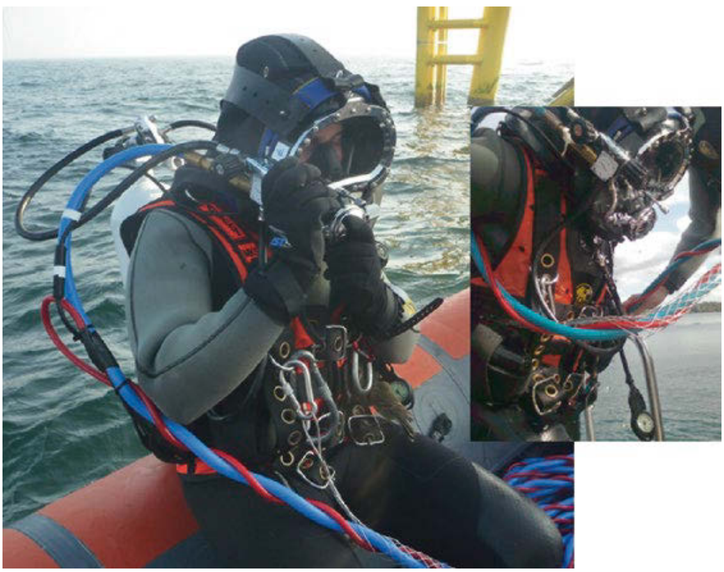

Fig. 9.4 Surface supplied equipment used for scientific diving operations to survey the fauna associated with the turbine foundations of the *alpha ventus* windfarm.

9.2.3 Data analysis

To evaluate potential windfarm effects on the marine benthic fauna, the data were analysed using common statistical methods (see e. g. Legendre & Legendre 1998). Univariate analyses, such as repeated measurements analysis of variance (rm-ANOVA), were carried out by means of the STATISTICA v7.1 software package (Hill & Lewicki 2007).

9.3 Results and discussion

To describe the response of the marine benthos comprehensively, various components of the macrozoobenthos were studied, which were expected to react to both the construction and operation of the wind turbines at *alpha ventus*: The in- and epifauna of the sedimentary seafloor, the fouling assemblage on the underwater construction of the turbines, and the mobile demersal megafauna, which aggregated at the artificial structures. The applied BACI design is a common tool for the study of human impacts on natural communities (Green 1979). Proper statistical analysis of the collected data allows for (1) identification of an overall difference between the windfarm area and the reference area with regard to a selected variable such as species richness, total abundance or biomass of a species community. The analysis also tests for (2) any overall temporal variation in each variable in the entire area of investigation without distinguishing between the windfarm and the reference area. Finally, the analysis looks for (3) any interaction between the two factors 'area' (the comparison between the windfarm and the reference area) and 'time' (detection of temporal variation). An interaction between the two factors occurs if the temporal development of the variable is different in the two areas and is, thus, indicative of altered environmental conditions in the impact area given that the two areas are well comparable, i. e. the areas exhibit similar environmental conditions except for the focal disturbance. The reliability of this procedure rises with the degree of spatial and temporal replication in the sampling. Hence, optimal sampling would include several sampling campaigns before and after the impact, as well as several reference (and impact) areas to representatively portray the temporal and spatial variability of the community parameters (Underwood 1991, 1993). The sampling campaign prior to construction of *alpha ventus* in spring 2008 revealed minor differences between the prospective windfarm area and the reference area with regard to the sedimentary conditions and the structure of the local benthic communities. Nonetheless, the two areas were considered well comparable because the sediments were generally of the same type (i. e. homogeneous fine sand with low organic content).

The BACI approach allowed the identification of differential temporal variations in benthic communities in the *alpha ventus* area and in the reference area. However, the procedure is not able to clearly distinguish between direct impacts of turbine foundations (e.g. import of biomass into the sediment) and other processes associated with operation of the windfarm such as recovery of the benthic community after the cessation of bottom trawling in the windfarm area. The term 'windfarm effect' is therefore used here to refer to the gross effect arising from various interactive processes that occur within the windfarm area but not in the reference area.

9.3.1 Epifauna

Species richness of the epifauna on the sedimentary seafloor was generally higher in the reference area than in the *alpha ventus* area (Fig. 9.5a). The temporal variation of overall species richness during the investigation period was remarkable in both areas. The average number of species per haul was lowest in spring 2009 (4.9 ± 0.8 and 5.5 ± 0.8 in the *alpha ventus* and the reference area, respectively) and highest in the following spring 2010 (8.8 ± 1.1 and 10.5 ± 1.4 in the *alpha ventus* and the reference area, respectively). However, the temporal fluctuations in the number of species were largely synchronous in both areas, indicating that neither construction of the turbines nor the subsequent two-year operation period affected the development of species richness in the windfarm area. The total abundance of the epifauna increased slightly in both areas between 2008 and 2011 (Fig. 9.5b), with the starfish *Asterias rubens* being the dominant epifaunal species in both areas. The temporal variation of total abundance was different between the two areas indicating windfarm effects on the development of the epifaunal abundance. Especially by the end of the investigation period, from spring to autumn 2011, total epifaunal abundance in the two areas progressively diverged, indicating a persistent difference in the communities. In fact, a recent sampling in spring and autumn 2012 confirmed that the abundance of epifauna increased further in the reference area whereas in the windfarm area abundance remained relatively stable (A. Schmidt pers. obs., data not shown here). Future sampling campaigns will reveal whether the numbers of individuals will diverge further or whether this was just a transient development. Total biomass of the epifauna also fluctuated heavily throughout the study period (Fig. 9.5c). As for total abundance, fluctuations differed in the two areas, again indicating windfarm effects on the benthic epifaunal community structure.

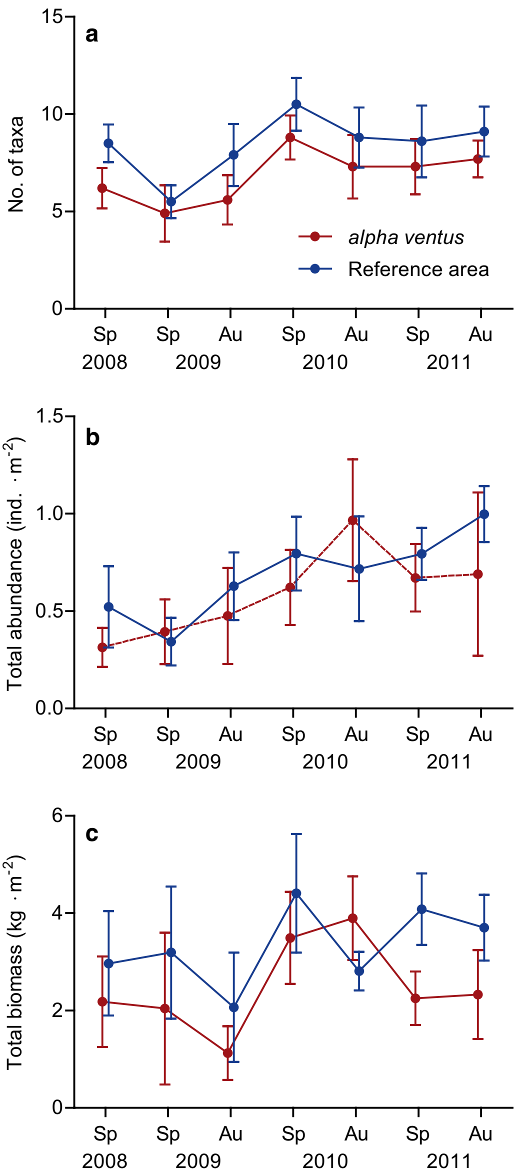

Fig. 9.5 Average (± standard deviation) (a) number of taxa, (b) total abundance and (c) total biomass of the benthic epifauna of the sedimentary seafloor inside *alpha ventus* and in a reference area outside the windfarm. In 2008, a single sampling campaign was conducted in spring (Sp). From 2009 to 2011, samples were taken semi-annually in spring (Sp) and autumn (Au).

9.3.2 Infauna

Similarly to the epifauna, the results for the infauna indicated windfarm effects on the benthic community structure. For all selected community descriptors (species richness, total abundance and total biomass), temporal development differed in the windfarm area and in the reference area. Species richness was higher in the reference area when the number of species was integrated over the entire investigation period (Fig. 9.6a). Contrastingly, total abundance was initially higher in the *alpha ventus* area. However, by the end of the study period in 2011, this relationship reversed so that total abundance was finally higher in the reference area (Fig. 9.6b). In both areas, the total abundance of the infauna was dominated by the highly abundant bristle worm *Spiophanes bombyx* so that the varying abundances were primarily the result of differential population dynamics in this single species. It is difficult to assign these differential dynamics solely to effects of the wind turbines in the *alpha ventus* area because the observed fluctuations were well within the range of natural population fluctuations for this species in the German Bight. Similarly, the temporal dynamics of the total infaunal biomass were dominated by the biomass of a single species, the sea urchin *Echinocardium cordatum*. Interestingly, the biomass of the urchin and, thus, the total infaunal biomass were substantially higher in the reference area than in the windfarm area only during the spring campaigns, whereas during the autumn campaigns the biomass was similar in both areas (Fig. 9.6c). This specific pattern might be the result of the specific mating behaviour of this urchin. These sea urchins are known to aggregate in spring and summer for mating (Buchanan 1966). Along with the preference of this species for sediments with elevated organic content (Wieking & Kröncke 2003), this behaviour might result in the observed spring aggregation of the urchins in the reference area where the organic content of the sediment was slightly higher than in the windfarm area.

In accordance with the principles of environmental impact assessment using BACI, the differential temporal variations of various community descriptors in the windfarm and in the reference area indicated differential environmental conditions in

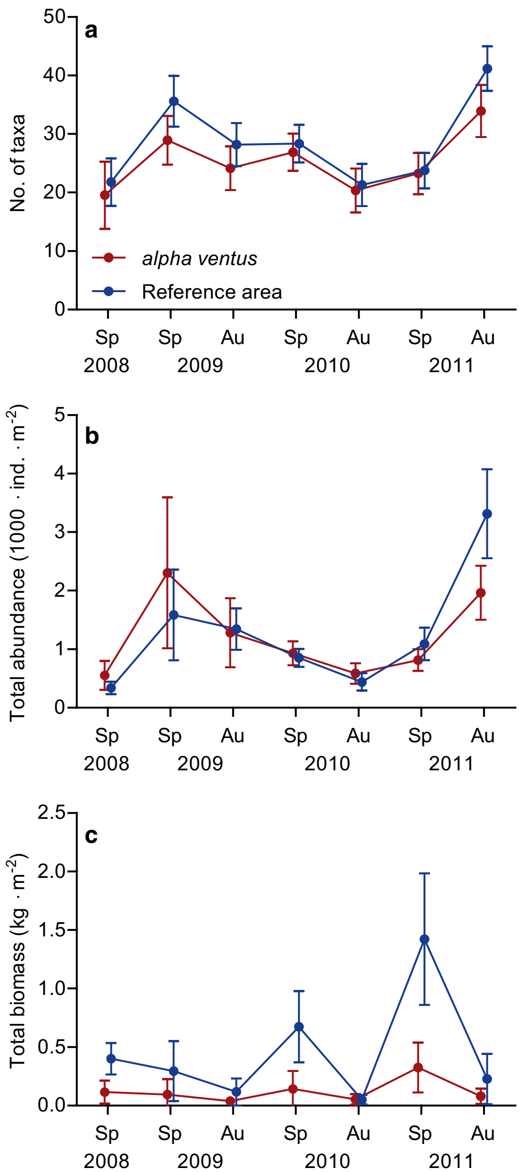

Fig. 9.6 Average (± standard deviation) (a) number of taxa, (b) total abundance and (c) total biomass of the benthic infauna of the sedimentary seafloor inside *alpha ventus* and in a reference area outside the windfarm. In 2008, a single sampling campaign was conducted in spring (Sp). From 2009 to 2011, samples were taken semi-annually in spring (Sp) and autumn (Au).

the two areas, which might have been the result of the construction and operation of the turbines in the *alpha ventus* area. However, the results have to be interpreted carefully. Although the sediments of the two areas as well as the inhabitant in- and epifaunal communities were similar, it cannot be entirely precluded that the differential community dynamics were the result of weak yet fundamental differences between the areas. In practise, it is impossible to find two entirely equal areas that would allow for straightforward identification of environmental impacts. Therefore, an optimised sampling would consider various suitable reference areas (Underwood 1993). The communities within these several areas are likely to display the entire range of ambient variation to which the variations observed in an impact area can be compared. An environmental impact could then be detected reliably when the temporal variation in the impact area exceeds the full range of ambient variation displayed by the communities of all reference areas. Additionally, an optimised sampling would include several sampling campaigns before the onset of an impact in order to obtain an estimate of the fundamental differences between impact and reference areas without the influence of the expected disturbance (Underwood 1992). To estimate the entire range of ambient fluctuations, a comprehensive data set was used on the abundance of the benthic fauna in the German Bight. As part of a project on the use of the benthos in marine spatial planning and permit procedures for offshore windfarms (funded by the BSH and the Federal Ministry of Transport, Building and Urban Development; grant no. 10016990), this dataset was used to estimate the variability of species richness and total biomass of the infauna on sediments which are comparable to the fine sand areas studied here (Fig. 9.7). The variations were expressed by the coefficient of variation (c_v) which was calculated as $c_v = \sigma/\mu$ with σ being the standard deviation and μ the mean of the respective variable. The coefficients of variation for the benthic infauna in the *alpha ventus* area were 0.2 and 1.2 for species richness and total biomass, respectively. For the infauna in the reference area, the coefficients were 0.3 and 1.1 for species richness and total biomass, respectively. A comparison shows that the variations in both the windfarm and the reference area were well within the range of the ambient variations of the infauna on fine sand sediments in the German Bight (Fig. 9.7). Hence, the infauna in the windfarm area did not show particularly strong

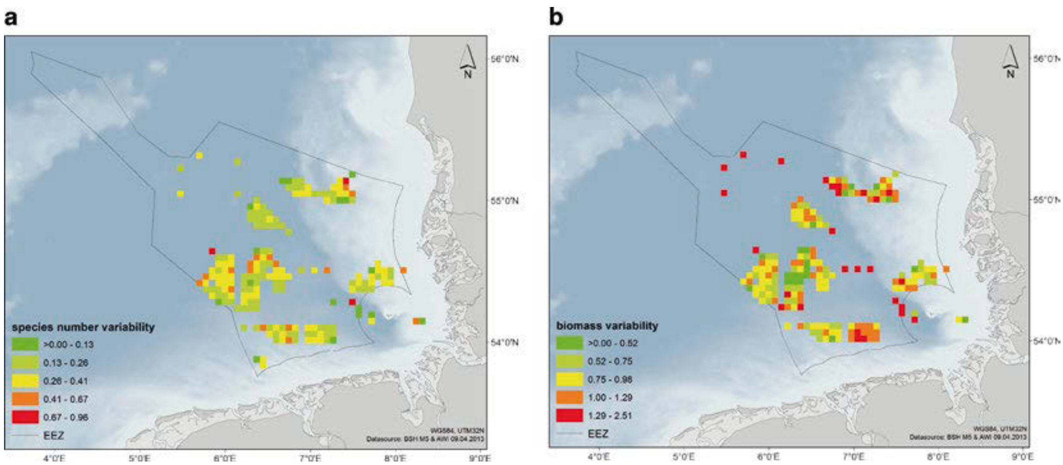

Fig. 9.7 Variability (calculated as coefficient of variation; for details see text Sect. 9.3.2) of (a) species number and (b) total biomass of the benthic infauna on sublittoral fine sands in the German Bight.

variation that would indicate exceptional temporal development of the community due to the presence of the wind turbines.

In sum, the results on the benthic in- and epifauna of the sedimentary seafloor indicate windfarm effects on benthic communities or single species thereof. However, continued seasonal sampling will be necessary to confirm the potential effects. Studies from other European windfarms confirm the lack of short-term effects of offshore windfarms on the marine soft-bottom benthos (Lindeboom et al. 2011). However, in Belgium's Thorntonbank windfarm, structural changes of the benthic communities were evident six years after construction of the turbines and the results indicate a slow but persistent spatial expansion of the effects (Coates et al. 2012). It remains to be seen whether the effects will expand over the entire area of the windfarm or remain restricted to the vicinity of the turbine foundations.

9.3.3 Biofouling on the foundation structures

The investigations on biofouling provide the first continuous description of the temporal development of fouling biomass on the underwater structure of offshore wind turbines from the time of construction onwards. The results show that artificial hard substrata in the North Sea become colonised by a rich fouling community that can reach a substantial biomass. After construction of the turbine foundations in 2009, the average species richness of the fouling assemblage on the underwater structures increased steadily in water depths of 1 to 10 m, from about five taxa per sampled area (i. e., 0.12 m^2) in autumn 2009 to about 15 taxa per sampled area by the end of the study period in autumn 2011 (Fig. 9.8a). Dominant taxa (in terms of biomass) of the fouling assemblage were the blue mussel *Mytilus edulis*, the amphipod crustacean *Jassa herdmani* that builds extensive tubes on the surface of the substratum, anemones, and the starfish *Asterias rubens*.

The biomass of the fouling assemblage was not evenly distributed relative to the water depth. At 5 and 10 m depths, the average biomass hardly exceeded 1 kg m^{-2} throughout the entire study period. In contrast, at the 1 m depth level the average biomass of the fouling assemblage increased rapidly from about 1 kg m^{-2} in spring 2010 to about 25 kg m^{-2} in autumn 2011 (Fig. 9.8b).

The massive increase in fouling biomass at 1 m depth was primarily due to colonisation of the turbine foundations by the blue mussel. A similar development of mussel biomass was observed on the underwater structure of the FINO1 research platform, which is located next to *alpha ventus* (Joschko et al. 2008). Two years after the construction of the platform, the mussel population had risen to about

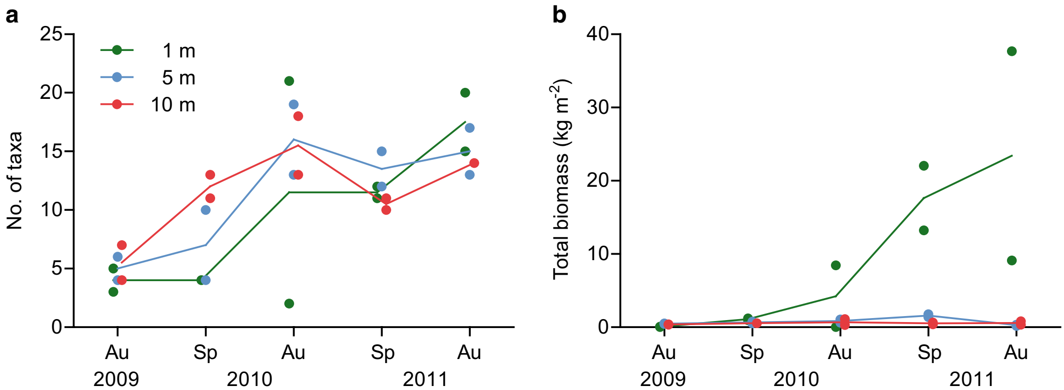

Fig. 9.8 (a) Number of taxa and (b) total biomass of the community of fouling organisms on the turbine foundations at *alpha ventus*. Samples were taken in 1, 5 and 10 m water depth. Solid lines connect the seasonal means of two replicate samples from the same depth level. Samples were taken semi-annually in spring (Sp) and autumn (Au).

35,000 individuals m^{-2} and a biomass of 40 kg m^{-2}. Accordingly, the mussel population on the turbine foundations in the *alpha ventus* windfarm area has likely continued to increase since the final sampling in autumn 2011. Contrastingly, at 5 and 10 m depths no substantial biomass increase is expected for the future. In these water depths, the fouling biomass on the FINO1 platform appeared to be largely stabilised at an average of about 1 to 4 kg m^{-2} four years after construction (Krone et al. 2013b).

With regard to species composition, biomass and functionality, the fouling assemblage on the turbine foundations differed substantially from the common benthic communities of the surrounding sedimentary seafloor. For example, many species of the fouling assemblage are suspension feeders which exploit other food resources compared with the numerous benthic deposit feeders in the sediments. In comparison with the findings from previous studies on the fauna on wrecks in the North Sea (e.g. Zintzen et al. 2006), it becomes evident that offshore wind turbines differ from wrecks. Turbine foundations extend through the entire water column, providing settling space in shallow waters for mussels which are largely absent from wrecks on the seafloor (Krone et al. 2013b). Given their enormous biomass volumes, mussel aggregations on the underwater structures of offshore facilities are expected to have substantial impact on the fluxes of energy and matter, at least on a local scale (Joschko et al. 2008).

9.3.4 Mobile demersal megafauna

The large turbine foundations and, above all, the associated fouling organisms, attract huge numbers of mobile demersal megafauna. This faunal group consists mainly of demersal fishes and large decapod crustaceans known to aggregate at solid structures in the marine environment, probably for feeding, mating and/or shelter (Page et al. 1999, Sadovy & Domeier 2005). The fouling community on the turbine foundations provides a valuable food resource for large predatory species. Additionally, dead fouling organisms fall off their substratum and end up on the seafloor where they are foraged upon by benthic scavengers. During the scientific diving operations, 16 species of mobile demersal megafauna associated with the turbine foundations were observed versus 18 species on the nearby sedimentary seafloor. However, the much higher sampling effort on the sedimentary seafloor increased the probability of encountering additional species. Accordingly, we expect the species richness of the mobile demersal megafauna on the turbine foundations to be at least as high as on surrounding sediments. Much more striking than the comparison of the species richness is the comparison of the megafaunal abundance between the sedimentary seafloor and the artificial structures. For some species that aggregated on the turbine foundations, such as the edible crab, *Cancer pagurus*, and the common hermit crab, *Pagurus bernhardus*, abundances were

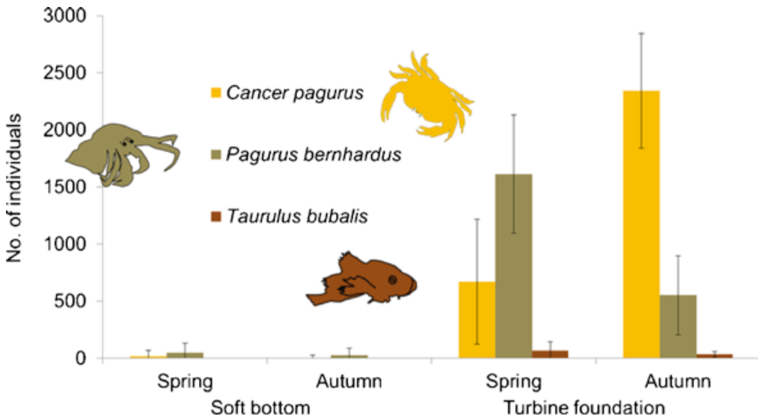

Fig. 9.9 Average (± standard deviation) abundance of selected species of the mobile demersal megafauna on the footprint area (2,400 m^2) of the tripod foundations at *alpha ventus* and on soft-bottom areas of the same size. Samples were taken in spring and autumn 2011.

several orders of magnitude higher than on the sediments (Fig. 9.9). Other species that were found on the turbine structures in the *alpha ventus* offshore windfarm, such as the longspined bullhead, *Taurulus bubalis*, are obligate hard-bottom dwellers and, thus, entirely absent from the sediments.

The seasonal dynamics of the assemblages of large and mobile species are largely unknown. The study showed clear seasonal variations in the abundances of common megafauna species, indicating intensive exchange of individuals between the localised artificial hard substratum and other habitats (Fig. 9.9). For example, edible crab is known to migrate tens of kilometres between suitable habitats, e.g. in search for mates or other, still vacant hard-bottom habitats (Bennet & Brown 1983). The observed densities of the mobile demersal megafauna allow for an extrapolation of the population sizes to the total amount of hard substrata that will become available in line with current planning for expansion of the offshore wind sector. These extrapolations predict an increase in population size for some species by several hundred percent (Krone et al. 2013a). The calculation assumes that the introduction of artificial habitats allows for production of additional individuals. As yet, however, it remains to be investigated to what extent the new structures allow for the production of new individuals. Individuals might also be attracted from other, perhaps less favourable habitats (i. e. production versus attraction dilemma; Pickering & Whitmarsh 1997).

9.4 Perspectives

The results show that offshore windfarms will have a substantial effect on the marine benthos. Independent structural variations of the benthic in- and epifauna of the sedimentary seafloor were observed both in the *alpha ventus* area and in a reference area, indicating an influence of the wind turbines and/or the associated activities (e.g. fishery cessation) on population dynamics of benthic species. Further continuous monitoring will reveal whether the communities of the two areas will further differ or if the observed difference was merely transient.

For decades, both the later windfarm area and the reference area were subject to intense bottom trawling. Since 2008, the windfarm area has been closed to any kind of ship traffic, including fishery vessels, while bottom trawling was still allowed in the reference area. There were no clear signs of recovery of the benthic communities from long-term bottom trawling in the windfarm area. This recovery process appears to take much longer and possibly requires larger untrawled areas to overcome possible edge effects. Depending on sedimentary conditions and the fishing gear used, recovery of benthic habitats after fishery cessation could take up to eight years (e. g. Kaiser et al. 2000) or even longer (Duineveld et al. 2007).

The other – and possibly the major – effect of the introduction of numerous wind turbine constructions into the marine environment is the aggregation and production of marine biota on the submersed structures, resulting in a substantial increase of the structural and functional biodiversity of the benthic system. Tens of tons of fouling organisms and thousands of large mobile demersal animals per windfarm will lead to a drastic shift in the distribution of biomass and thus, in the flow of energy and matter, at least on a local scale. The aggregated organisms interact intensively with each other and with the established fauna of the surrounding sandy seafloor. Accordingly, artificial hard substrata promote the development of complex trophic and competitive interactions within a modified benthic community consisting of both hard- and soft-bottom species. Currently, it is unknown whether these effects will remain locally restricted to single turbines or if they will expand to the entire windfarm area or even beyond resulting in large-scale ecosystem effects.

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