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Abstract
Marine renewable energy conversion typically takes place at locations characterized by harsh physical parameters that challenge monitoring of the marine environment. These challenges are caused both by the lack of experience on what to expect in terms of impact, but also by a general lack of methods proven suitable for the monitoring of high-energy subtidal marine habitats. Here, the first offshore windfarm to be built in Norwegian waters, a project called Havsul I, is used as a model to provide (i) an overview contrasting the known effects and monitoring methods used at more sheltered offshore windfarms with those expected at a rocky, high energy site; (ii) a description and short assessment of the physical environment (bathymetry, current, wave and wind data) and marine assemblages at the site, (iii) an assessment of five methods used during the baseline study at Havsul I, including sediment grabs, sampling of assemblages from kelp stipes, video mosaics for rocky bottom benthic assemblages, traditional fishing gear for fish community evaluation, and C-PODs for harbour porpoise presence.

Keywords
Kelp - Marine renewable energy - Monitoring - Rocky seabed - Video mosaic
Assessing the Impact of Windfarms in Subtidal, Exposed Marine Areas

Thomas G. Dahlgren, Marie-Lise Schläppy, Aleksej Šaškov, Mathias Andersson, Yuri Rzhanov and Ilker Fer

Abstract

Marine renewable energy conversion typically takes place at locations characterized by harsh physical parameters that challenge monitoring of the marine environment. These challenges are caused both by the lack of experience on what to expect in terms of impact, but also by a general lack of methods proven suitable for the monitoring of high-energy subtidal marine habitats. Here, the first offshore windfarm to be built in Norwegian waters, a project called Havsul I, is used as a model to provide (i) an overview contrasting the known effects and monitoring methods used at more sheltered offshore windfarms with those expected at a rocky, high energy site; (ii) a description and short assessment of the physical environment (bathymetry, current, wave and wind data) and marine assemblages at the site, (iii) an assessment of five methods used during the baseline study at Havsul I, including sediment grabs, sampling of assemblages from kelp stipes, video mosaics for rocky bottom benthic assemblages, traditional fishing gear for fish community evaluation, and C-PODs for harbour porpoise presence.

Keywords

Kelp · Marine renewable energy · Monitoring · Rocky seabed · Video mosaic

Introduction

Siting of offshore renewable energy devices has tended to move from nearshore, shallow waters (in the late 1990s), to offshore, deeper water (EWEA 2012). One of the drivers of this development is the lack of space on land and conflict with property owners claiming visual disturbance from onshore and nearshore windfarms (Esteban et al. 2011). Other potential conflicts are with shipping routes or alternative uses of the seabed, such as fishing or pipelines and cables (Burkhard et al. 2011). One could also add the increase in the quality of the wind and wave resource farther from shore. All these incentives apply to areas that are highly exposed to oceanic wind and wave energies, such as the steep and energetic seaboards off the coasts of Portugal, Ireland, Scotland and Norway in Europe, and in areas elsewhere such as Chile and California (Dvorak et al. 2010).

With few exceptions, offshore windfarms have to date been placed in relatively shallow seas on flat seaboards in the...
southern Baltic and North Sea. The main environmental concerns about impacts on marine life in these areas relate to noise and sedimentation during the construction phase, and habitat change and noise during operation (Gill 2005; Wilhelmsson et al. 2010). The few studies of effects from the operation phase of a windfarm that have been published in peer-reviewed journals suggest that monitoring programmes have not detected any significant changes (e.g. Wilhelmsson et al. 2006; Lindeboom et al. 2011; Scheidat et al. 2011). A large volume of recently published reports from government agencies, research programmes and developers also indicate an absence of significant changes in community structure, species abundance and diversity after a few years of windfarm operation (Degrær et al. 2011; Stenberg et al. 2011; Bergström et al. 2012a, b). However, physical and biological conditions are dramatically different in more energetic coastal areas such as the Norwegian Sea (Shields et al. 2009).

Bathymetry along the Norwegian coastal zone is typically steep, allowing little room for offshore wind developments (Fig. 4.1). These types of Norwegian offshore “banks” usually consist of pre-Cambrian crystalline rock with a rugged shape caused by glacial erosion. The resulting bathymetry is complex, giving such banks a mosaic of different benthic habitats. In the top 10–15 m, dense populations of kelp dominated by the species *Laminaria hyperborea* form a productive, diverse community (Mann 1972; Moore 1973), but below ~25 m, light intensities are too low to sustain the growth of brown algae and the wave action is too powerful to allow accumulation of sediment. With significant wave heights occasionally but annually in excess of 15 m, a highly eroded seabed extends down to around 70 m deep, forming a diverse habitat dominated by crust-forming algae and sessile invertebrates such as hydrozoans (Paine 1966). Fine sediment accumulates in deeper trenches (>100 m deep), where hydrodynamic forces are less, and because of the highly productive kelp community in the vicinity, the deeper trenches are organically rich and sustain an abundant and often diverse infaunal assemblage.

Some of the largest of these areas in Norway are found off the coasts of Møre and Romsdal county and have been subject to applications for offshore windfarm consents (Havsul I–IV). One project (Havsul I) was granted consent in 2009 and extended investigations were undertaken of bathymetry, geology, oceanography, wind resources and biology. The consent was given for a set of installations capable of producing 350 MW, covering an area of 49 km² centred on 62°49’37”N 06°18’29”E and situated 8 km from the closest inhabited island, Harøya (Fig. 4.1). The type of foundations or the size of turbines used had not been decided at the time of writing this chapter but will, because of the domination of rocky seabed, exclude monopiles. As the noise generated from pile-driving of monopiles has been the most important source of environmental concern during the construction phase of a windfarm (Wilhelmsson et al. 2010), disturbance effects during the construction phase will not be addressed further here, but we do discuss the challenges associated with planning and conducting environmental baseline studies and monitoring programmes suitable for marine renewable energy conversion projects in areas of high hydrodynamic forces. Calculated annual wave energy off the Møre coast is among the highest in the world, with an average of 438 MW m⁻¹ year⁻¹ (Golmen 2007). So-called extreme events are common there, with an average annual maximum significant wave height of 10.5 m for the period 1980–2006 (Golmen 2007), and with two events in excess of 12 m significant wave height during the last three months of 2011 (Fig. 4.2).

The environment there is, therefore, extremely harsh on any type of instrumentation left in situ to collect data over a period of time. This applies to instruments collecting physical data, such as current speed, temperature and salinity, and also to those collecting biological data, such as cetacean noise. Since the start of the project at Havsul I, no fewer than ten oceanographic, meteorological and biological instruments have been damaged or lost. The opportunities of calm weather available for fieldwork are also limited because of the high average wind speeds and exposure to oceanic swell breaking over shallow sites. The average mean wind speed at Ona Lighthouse (Fig. 4.1) between 15 August 2011 and 14 August 2012 was 8.8 m s⁻¹ (data from www.yr.no). Navigation in the area by larger, less-weather-sensitive research vessels that would allow for more productive fieldwork from a stable and safe platform is also limited because of the narrow channels and shallow water.

Deeper offshore marine habitats in the Norwegian and North Sea have been subject, for some 30 years, to intense environmental monitoring warranted by petroleum extraction activities (e.g. Kingston 1992), but monitoring at exposed offshore rocky banks is not routinely conducted and standard methods are lacking (Shields et al. 2009). In fact, the limiting factors for researchers to work in such areas render them as *de facto* remote, and not very different from polar regions. For monitoring programmes, this means that systematically collected baseline data are not available and our understanding of the ecological responses to new stressors is limited (Shields et al. 2009, 2011). The poor knowledge of these habitats is also reflected by the absence of comprehensive species lists and a relatively large number of species newly discovered in recent years.

A major challenge for programmes trying to quantify environmental change at energy conversion structures placed in high-energy sites such as Havsul I is that hypotheses on expected impact and the resulting effect on ecosystems are not well developed. In contrast to the relatively shallow, low energy, soft-sediment marine environments where offshore windfarms have been operating for up to as much as a decade already, little is known about what to expect for high-
Fig. 4.1 Map of coastal Møre and Romsdal area in western Norway showing a the position of the oceanographic mooring, b an outline of the consent area (Havsul I), and c the position of Ona Lighthouse, d Harøya, and e the reference area. The insert at the lower right is a multibeam bathymetric map of the consented area. The map was created using GeoMapApp. (http://www.GeoMapApp.org; Ryan et al. 2009)
Fig. 4.2 Havsul I offshore windfarm. Position 62°50’07”N 06°08’14”E. Time-series of a significant wave height ($H_s$), and b magnitude of the maximum hourly velocity ($U_{max}$ grey) and the depth-averaged 25-h low-pass velocity ($U_{ba}$ black) in the Havsul I area measured at approximately the 130 m isobath. The arrows in a mark storms Berit and Dagmar in late November and December 2011, respectively.

Energy seabeds. The highly energetic offshore areas of the Norwegian coast can be regarded as less affected by the most serious threats to European marine communities, so arguably also more vulnerable to low levels of disturbance. Compared with coastal sediment habitats, energetic hard seabed communities are more often regarded as less affected by accumulation of contaminants, less affected by habitat-degrading fishing activities such as bottom trawls, and less affected by eutrophication (e.g. Gray 1997, but see Piola and Johnston 2007). Following the beliefs of Foley et al. (2011), we should strive to reduce the environmental footprint from energy and food production by focusing on halting the expansion of the area used for such activities. A more efficient use of areas could be achieved in coastal and offshore regions by placing windfarms in already impacted areas and combining them with, for example, aquaculture (Buck et al. 2008).

Direct impacts from offshore windfarms, such as the addition of habitats with the introduction of hard substrata in areas otherwise devoid of them, habitat loss from excavation of sand or replacement of soft sediments with hard blocks for scour protection, are not easily discernible at high-energy sites. If turbine foundations are placed at more exposed sites, one may expect increased drag causing decelerations, wakes and a sheltering effect. This, in turn, can increase the number of available microhabitats for fauna such as crabs (Langhamer and Wilhelmsson 2009). Parts of the planned windfarm Havsul I overlap with an area where kelp is harvested for the alginate industry, harvesting that can be compared with the bottom trawl fisheries excluded from some windfarms in sedimentary seabeds. By removing kelp from part of the Havsul area on a regular five-year cycle, the practice has been shown to increase net kelp productivity but to decrease the diversity of associated fauna (Steneck et al. 2002; Lorentsen et al. 2010). Hence, cessation of kelp removal by banning harvesting within the windfarm would probably increase the diversity of associated fauna. An increased diversity of fish species was observed at Horns Rev windfarm in Denmark, probably in response to an increase in habitat heterogeneity (Stenberg et al. 2011). The end (or reduction) of kelp trawling at Havsul is expected to result in greater species richness because of a changed demography of the kelp population with increased longevity of kelp plants (Christie et al. 2003). The diversity of fauna and flora associated with kelp stipes and holdfasts increases with the age of the plants, and the recovery of the associated fauna from regular kelp removal by trawling depends on the dispersal capabilities and assemblage structure of the surrounding kelp forests (Christie et al. 1998).

Whereas sessile benthic fauna will be impacted directly by all phases of the Havsul I windfarm construction, operation and decommissioning, such mobile fauna as fish and mammals have the choice of entering or leaving the area. Laboratory simulations have suggested that harbour porpoises (Phocoena phocoena) and common seals (Phoca vitulina) can detect the noise generated by a 2 MW wind turbine at sea (Koschinski et al. 2003). The Harøy archipelago has a large population of common seals that frequently use the Havsul I area for foraging and haul-out (Bjørge et al. 2002). Harbour porpoises are found in fjord systems right along the Norwegian coast, but little is known about their abundance offshore outside the North Sea, although a regional census was undertaken in 1994 (Bjørge and Øien 1995; Hammond...
et al. 2002). Current understanding of the impact on seal and porpoise populations from operational offshore windfarms is limited, but suggests that if the area is important for foraging, the long-term abundance of seals and porpoises within the farm will not be altered significantly (Tougaard et al. 2003, 2006). One study suggests that the abundance of porpoises may actually increase, possibly as a consequence of lessened disturbance from fishing vessels and the greater patchiness in fish abundance increasing foraging success (Petersen and Malm 2006; Scheidat et al. 2011).

To monitor environmental change in a mosaic of different habitats with limited access to evidence-based impact hypotheses, a diverse set of methods is required. Infaunal diversity and abundance of deeper areas with soft sediment can be monitored successfully using established grab methods, but other less proven methods are required for rocky seabeds and in kelp forests. Below, some of these methods are outlined and experiences from assessing them during a baseline study at the Havsul I windfarm site discussed.

### Monitoring at Havsul I Offshore Windfarm

Here, we limit ourselves to the methods being considered by the developing company and the responsible authorities for baseline studies at Havsul I and an associated reference area. In particular, we look at technical challenges, limitations and potential sensitivity specific to the extreme physical environment (chaotic bathymetry, currents, wind and wave action) experienced at this offshore high-energy site. The following methods have been adopted:

1. physical oceanography;
2. traditional van Veen grabs to sample the biota of sediments;
3. video mosaics to map rocky seabed habitats;
4. traditional kelp dredges to sample the diversity and demography of kelp forests;
5. traditional bottom-set longlines, gillnets, traps and fykenets to sample assemblages of benthic fish;
6. C-PODs.

### Physical Oceanography

On 25 October 2011, an oceanographic mooring consisting of instrumentation to measure the vertical distribution of ocean currents, temperature and salinity was deployed approximately 6 km offshore of the Havsul I area off the coast of Ålesund (Fig. 4.1). The water depth at the mooring site was ~130 m and the hourly averaged time-series for currents was obtained between 10 and 120 m, and for other parameters between 25 and 115 m. The mooring was recovered on 4 March 2012. An additional subsurface buoy (at ~10 m over the 130 m isobath) equipped with high-resolution pressure and motion sensors was deployed to infer surface wave parameters. The wave spectra and the corresponding wave parameters were obtained using 15-min segments of data, after applying the appropriate corrections for vertical acceleration and pitch of the platform and the transfer function for the attenuation of surface wave pressure signal with depth. Wave data were collected from 25 October 2011 to 10 January 2012. Current measurements were made by an RD-Instruments 300 kHz acoustic Doppler current profiler (ADCP) and a pair of Nortek Aquadopp current meters fixed at the bottom on the same mooring. Temperature and salinity measurements were made with Sea-Bird Electronics (SBE) loggers (6 Microcats and 2 SeaCat) distributed evenly in the vertical. The measurement period covered two storms with wind speeds in excess of 20 m s\(^{-1}\) and 30 m s\(^{-1}\) (storms Berit and Dagmar, respectively), as measured at the nearby Vigra Airport meteorological station on 25 November and 25 December 2011. The site is highly energetic (Fig. 4.2), and the significant wave height, \(H_s\), typical of the region varied between 1 and 5 m, increasing to >12 m during storms. Although the hourly maximum velocity in the water column typically varied between 0.2 and 1 m s\(^{-1}\), it did reach ~1.5 m s\(^{-1}\) during storms. When tidal variability is removed (using a 25-h low-pass filter), depth-averaged currents there vary between 0.1 and 0.5 m s\(^{-1}\), occasionally reaching values >0.6 m s\(^{-1}\).

### Sediment Habitat

The deeper trenches in the area are filled with soft sediment. The hypothesis behind monitoring the soft-sediment community is that any change in productivity at shallower depths caused by the windfarm (Wilhelmsson and Malm 2008) would lead to changed flux of organic carbon to the surrounding sediments. Changes in hydrodynamics of the area, for instance, the presence of turbine foundations or wake gradients, could also lead to changes in organic carbon flux (Broström 2008). A common method of monitoring infaunal organisms uses a 0.1 m\(^2\) van Veen grab (Norsk Standard 2005). In addition, samples for sediment characteristics and organic content were also collected. Biological samples were collected on a sieve of 1-mm diameter holes, fixed in formaldehyde, then rinsed in seawater and preserved in ethanol. During the first year of baseline data collection, a number of the randomized sample stations were dominated by sediment and gravel too coarse for the van Veen grab to close properly, and new replacement positions had to be selected and new samples taken. The feasibility of the method in areas with chaotic bathymetry and large hydrodynamic forces is limited by the heterogeneity of the seabed characteristics. In such rough seas, large vessels are normally used to withstand the bad weather, allowing for a stable working platform, access...
Fig. 4.3 Example of the bottom video mosaic. Two preliminarily named biological features, “Lithothamnion” and black crust, are extracted from the initial mosaic using selected training colours (shown next to each layer). The coverage is calculated as a proportion of pixel count. 

a Initial mosaic. b Lithothamnion sp. c Crust-forming algae.

Rocky Seabed

Traditional benthic sampling techniques are not feasible on hard substrata. The use of a SCUBA-based monitoring method is also limited by cost and safety issues in this highly energetic offshore area (Sisson et al. 2002). Therefore, we used a camera-based approach, with data collected as video imagery (Sheehan et al. 2010). Three types of platform can be used to collect the data, autonomous, towed or remotely operated. The last of these allow for better compensatory manoeuvrability in high energy situations (Sheehan et al. 2010). A work-class remotely operated vehicle (ROV) was used to collect data at Havsul I, the system equipped with powerful xenon lights (total power 600 W), colour HD camera (resolution 1920 × 1020 pixels) and two laser-line pointers for image-scaling. Video data were collected in transects with an average length of ~200 m. To optimize the video footage for mosaic construction, the camera was orientated vertically, and ROV altitude was kept as constant as possible. This was done as well as possible although water movement in the area is very dynamic, and some variations in camera altitude and angle to the seafloor were unavoidable. The optimal ROV altitude is dictated by illumination of the seafloor; when the ROV is too close to the seabed, illumination is excessive and there is image brightness saturation, but when it is too far from the seabed, images are dark through insufficient lighting and there is strong distortion of colour attributable to wavelength-dependent light absorption.

Data acquired from a moving camera are difficult to use in combination with the use of various support facilities on shore.

To powerful winches, plenty of deck space and storage space, repair workshops, and well-ventilated areas and cabins. With narrow channels, limited depth and hence limited possibilities to manoeuvre large vessels, smaller, less optimal boats have to be used in combination with the use of various support facilities on shore.

For the computer-aided coverage estimation, we used a colour-based approach. For each feature, a set of training colours was selected, and features were assigned a value (a microhabitat) on the basis of this set (Fig. 4.3), allowing fast, reproducible extraction of features from mosaics. Once appropriate training sets had been selected, there was no need for an expert to do the balance of the analysis. The quality of the output at this stage is operator-independent, and after a small amount of training, any technician could process the data. The final results depend upon the training sets of colours and can vary. To evaluate possible errors, three mosaics were selected for testing, and for each feature in each, an expert picked seven different training colour sets. To compare the method with manual analysis, the same video segments were analysed manually using point-based feature selection (Carleton and Done 1995). Comparison of the results obtained with different training colours and between computer-aided and manual analyses revealed that deviations attributable to a different choice of training colour sets were minimal (<5 %, and for some features <2 %), so the
results were comparable with manual analysis performed by a trained marine benthic ecologist (Fig. 4.4).

**Kelp Ecosystem**

The area where Havsul I is planned overlaps with a key area for kelp harvesting along the Norwegian coast. Water 10–15 m deep is dominated by dense kelp, mainly *Laminaria hyperborea*, a species that is harvested regularly in some areas of Norway (Vea and Ask 2010). The presence of turbines and cable trenches will affect kelp harvesting inside a planned windfarm area, but mitigate any negative effects on the habitat caused by trawling. A baseline study is crucial to the quantification of any impacts, so to assess the impact on the kelp forest and the associated community of plants and animals, we collected samples of kelp stipes with a small commercial kelp trawl (Vea and Ask 2010). The associated species were removed from the kelp stipes, then fixed in formaldehyde, and sections of the stipes were made to estimate kelp age structure (Kain and Jones 1964). The diversity and abundance of associated animals can be enormous, with up to 80,000 individuals from up to 238 species on a single stipe (Christie et al. 2003). To render monitoring of this diversity and abundance feasible, a subsample of representative taxa is required. Following work by Kongsrud (2000), the diversity and abundance of crustaceans and annelids was sampled in a semi-quantitative design in which kelp stipes were cleared of all associated fauna. All samples from the baseline study were preserved and stored for future reference. One reason for potential later use would be the need to re-examine the baseline samples using broader taxonomic sampling, if changes in diversity are suggested from the more restricted sample.
Porpoise and Seal Abundance

We opted for annual estimation of harbour seal abundance by aerial survey in August at known haul-out sites within the area (Bjørge et al. 2002); in August, the seals are moulting and are more predictably out of water. The average ratios of seals at haul-out sites in relation to the total population size have been calculated for the moulting period at different areas along the Norwegian coast (Bjørge et al. 2007), so using a correction factor of 1.35 for More and Romsdal, the total population size can be estimated from the number of seals at the haul-out sites (Bjørge et al. 2007). Seals are counted from photographs taken from a light aircraft collecting, to reduce costs and environmental impact, material for baseline studies of seabird abundance.

Harbour porpoises are the most common cetacean in many north European waters and are frequently monitored when offshore windfarms are being built, so as to better understand and minimize the impact of offshore windfarms construction on their population size. Although there are no other data on their abundance in the Havsul area, data from bycatch and other studies in Norwegian waters indicate that they are common year-round, peaking in coastal areas between July and October (Bjørge et al. 2011). The aim was to monitor harbour porpoises acoustically using autonomous underwater echolocation click detectors, called C-PODs (Chelonia Limited; www.chelonia.co.uk), for abundance and habitat use at both the planned windfarm site and a control site. The hypothesis was that neither construction nor operation of the proposed windfarm site would have an impact (negative or positive) on porpoise abundance. The C-PODs were deployed from August to November 2011 and from July to September 2012, and deployments are planned for four more periods during the operational phase. The Havsul I region is a very challenging area to work in weather-wise and particularly in winter, so to take advantage of short windows of good weather during summer, a small rib boat was used to deploy and retrieve the sensors quickly.

For the first two periods of deployment of the sensors, the location was selected using available data on bottom substrata and oceanographic conditions. To allow the recorded data to be analysed separately, the sensors were positioned in positions of similar environmental conditions. The three deployment positions in each of the impact and reference areas were selected to be of similar depth, topography and, at the future construction site, 100 m from the planned wind turbine position. No data exist for porpoise habitat usage or behaviour for this area or any Norwegian offshore site, so only one type of habitat was chosen, a plateau 30 m deep at the edge of a much deeper (>50 m) area. The rigs were bottom-mounted and without a surface buoy, to reduce the risk of theft and impact from wave motion, advice being offered by scientific groups that had experience of the deployment of C-PODs in various types of water body. The rigs each contained a C-POD, an acoustic release (pop-up), ballast weights of jute bags containing 35 kg of gravel, and buoys for buoyancy (Fig. 4.5). The choice of size and weight of the ballast was also constrained in that it had to be managed by two people in a rib boat. Each bag was tied with ropes to a shackle and 2-mm stainless steel wire to the acoustic release. For buoyancy, two hard Nokalon trawling buoys were used, each with a lifting force of 4 kg. Both C-POD and acoustic release are durable and reliable in rough sea conditions.

During the first year of the baseline studies (2011), harbour porpoises were sighted on the surface during deployment, in both impact and reference areas. In early October 2011, before the planned C-POD retrieval, however, the Havsul I region was hit by several severe storms, resulting in delayed recovery and the breaking loose of several of the C-PODs, probably as a result of failure of the stainless steel wire and wire lock (Fig. 4.5). Local fishers up to 130 km north of the deployment site found some of the lost sensors, but two sensors were never found and the data therefore lost. Of the other four, two were originally deployed at the...
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