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Chapter 12

COLONIZATION OF BLUE MUSSELS (*MYTILUS EDULIS*) ON OFFSHORE WAVE POWER INSTALLATIONS

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ABSTRACT

The use of offshore energy conversion is predicted to expand significantly throughout estuarine and marine environments, with a global potential comparable to that of wind and hydro power. Therefore, it is important to study the interactions of offshore wave power devices with the marine environment. The *Lysekil Project* is a test park for wave power located about 100 km north of Gothenburg at the Swedish west coast. The concept is based on a linear wave power generator placed on the seabed, and connected via a wire to a buoy acting as a point absorber on the surface. Biofouling on offshore wave energy devices is an issue of concern for the operation or survival of the components. On the other side, these structures may provide habitats for marine organisms and thus increase biodiversity and form artificial reefs. In this chapter, size distribution and biomass of blue mussels on sheltered and exposed marking buoys are examined. Further, these results are used for calculating a worst case scenario of mussel growth on the lifting force of a specially designed toroidal buoy. The results show that more wave-exposed buoys were particularly favourable for blue mussel colonization, but that the hydrodynamic forces of the toroidal buoy were not affected by mussel growth. Thus, biofouling is not necessarily negative for the wave energy absorbance of the wave power buoys.

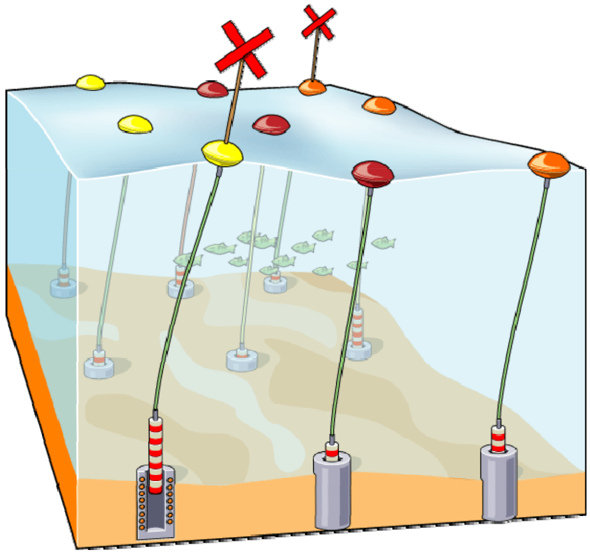
INTRODUCTION

Wave energy may contribute substantially to our energy supply; indeed the European coastline has been appraised to provide energy from wave power that is sufficient for Western Europe (Falnes and Løvseth, 1991). Little is known about ecological impacts of fouling on offshore devices, although studies have been carried out on other offshore structures such as wind power piles and offshore oil rigs (Whomersley and Picken, 2003; Wilhelmsson and Malm, 2006). Investigations of marine fouling communities on artificial structures in Kattegat and Skagerrak are rare (Berntsson and Jonsson, 2003; Langhamer and Wilhelmsson, 2007). To date there are only a few studies on this subject available that relate to wave power offshore devices (Langhamer and Wilhelmsson, 2007; Langhamer et al., 2009).

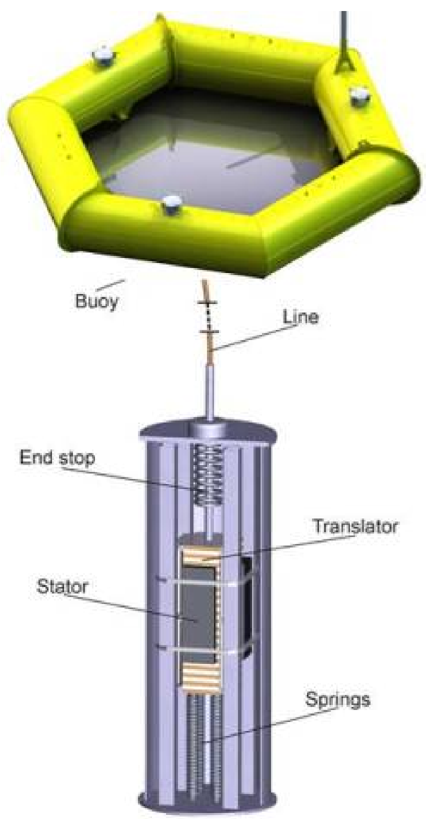
Artificial hard substrate provides an ideal basis for sedentary and sessile marine organisms to settle and grow, but assemblage structures of fouling communities on artificial substrates never resemble those on natural reefs (Connell, 2001; Svane and Petersen, 2001; Knott et al., 2004; Petersen and Malm, 2006). The formation of fouling communities depends on biotic and abiotic factors, such as predation, competition, geographic location, light levels, depth, temperature, salinity and local hydrodynamic regime, ice, bottom topography and substrate morphology (e.g. Dayton, 1971; Mook, 1981; Roughgaarden et al., 1988; McCook and Chapman, 1991; Pineda, 1991; Denny et al., 1992; Miron, 1995; Malm et al., 1999; Guichard, 2001). Although it was reported that about 4000 species has been identified on offshore structures, still, this is likely a very small proportion of the known marine species (Crisp, 1984). Fouling organisms must have the ability to adhere hard enough to resist strong forces and to avoid being washed off. Marine fouling can have a negative effect on both the structure itself and the operation associated with it. In the case of wave energy devices, the constructions have many moving parts and are particularly vulnerable compared to firm structures. For the wave energy industry, removal of fouling communities is expensive but may improve equipment performance and life span. The process should furthermore not present any harm to the surrounding area, such as toxins leaking from of anti-fouling paints. Thus, constructions ideally ought to be formed in a way that fouling has negligible impact on performance. From a technical point, fouling communities will have an impact on material, weight and shape and can further interfere with the buoys` hydrodynamics forces (Langhamer et al., 2009).

Exposure to wave action is an important factor in determining the community structure of marine organisms (Lewis, 1978) and comparisons have been made between sheltered end exposed shores (McLachlan et al., 1981). Water motion has been shown to affect all aspects of the life history of a marine organism, such as the rate of fertilization of gametes, settlement of larvae onto hard substrata (Bertness et al., 1992), growth (Koehl and Alberte, 1988), and mortality (Denny et al., 1985).

The blue mussel, *Mytilus edulis*, has been shown to dominate shallow hard bottom fauna communities including those on artificial constructions (Berntsson and Jonsson, 2003; Qvarfordt et al., 2006; Greene and Grizzle, 2007; Wilhelmsson and Malm, 2008; Langhamer et al., 2009). However, the development and distribution of *M. edulis* has not yet been investigated in combination with offshore wave power devices. Blue mussels are strong competitors for space due to massive recruitment and rapid growth (Okamura, 1986; Dürr and Wahl, 2004), and can distribute themselves widely by currents during their planktonic phase



a.



b.

Figure 1. Illustration of a section of a wave power park with a) several smaller units of wave energy devices and b) a technical description of a single unit.

(de Vooys, 1999). On offshore installations large *M. edulis* assemblages have been found due to low densities of predators (e.g. *Asterias rubens*) and due to the mussels` ability to withstand wave exposure (Whomersley and Picken, 2003). Furthermore, they may be able to outcompete other, older colonizers by inhibiting their growth by overgrowing them and preventing them from feeding successfully.

Within the *Lysekil Project*, both technical and environmental studies are carried out to evaluate the wave energy converter concept for further commercialisation (Figure 1a). A wave power buoy on the surface drives a translator in a linear generator via a wire (Figure 1b) (Leijon et al., 2009). The generator is moored to a concrete foundation placed on the seabed and the tension in the wire is retained by springs that are connected underneath the translator. The seabed generally consists of soft sediment, so the wave power park adds a hard substrate to the area (Cato and Kjellin, 2008). Fully built the Lysekil research site will consist of 40 units, 10 with generators and an additional 30 for environmental studies, and cover about 40 000 m^2 (Sundberg and Langhamer, 2005).

The aim of this chapter is to describe the colonization of *M. edulis* on offshore artificial hard substrate. The following questions were asked: does size and biomass of *M. edulis* assemblages differ between wave-exposed and wave-sheltered buoys? And do *M. edulis* assemblages on buoys have an impact on the hydrodynamic forces of a specially designed toroidal wave power buoys?

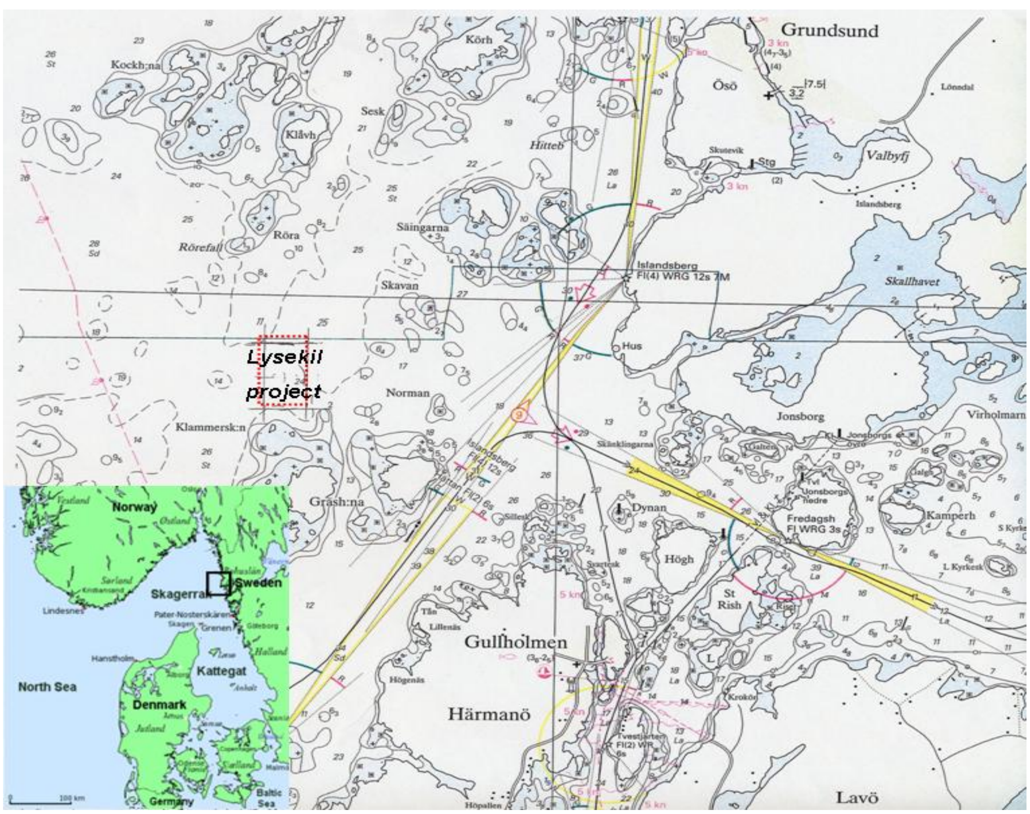


Figure 2. Location of the Lysekil research area outside the Swedish west coast. The test park is marked with a dashed rectangle.

THE LYSEKIL RESEARCH SITE

The Lysekil research site is situated near the town of Lysekil at the Swedish west coast in an archipelago about 100 km north of Gothenburg (Figure 2). The test park is situated between a northern (58°11'850"N, 11°22'460"E) and a southern navigational marker (58°11'630"N, 11°22'460"E) about 2 km offshore (Henfridsson et al., 2007). The area is exposed to westerly winds and waves. The first experimental setup was launched in March 2005. It consisted of five ecological buoys (without a generator). The purpose of the ecological buoys was to study environmental impacts and interactions with marine organisms, ranging from small bottom dwelling organisms living in the seabed, organisms involved in biofouling (and therefore of interest to mechanical wear and maintenance) to vertebrates, including fish, seabirds and marine mammals (Sundberg and Langhamer, 2005; Henfridsson et al., 2007). In spring 2005, the first wave energy converter has been deployed in the research area. The purpose of the wave energy converter was to measure the maximum line force from a cylindrical buoy with a diameter of 3 m and a weight of 1 t, simulating a wave generator that is disconnected from a grid (Leijon et al., 2008). A new kind of wave power buoy, in the shape of a toroid (Figure 1b) that has different measures and dynamics compared to the cylindrical buoys used earlier (Leijon et al., 2008), has now been installed to test its dynamics and ability to extract energy from ocean waves. The toroidal buoy connected to a generator was deployed in May 2008 in the research site. The buoy had a weight of 2.2 t and is a hexagonal ring with six sections, each 2.57 m along the centre-line and a diameter of 711 mm. All the devices were placed with a distance of between 100 m and 300 m from each other, all on a soft bottom 25 m deep.

MATERIAL AND METHODS

To quantify the potential colonisation of blue mussels (*Mytilus edulis*) on the toroidal buoy, marking buoys were surveyed since we had no wave power buoys in water for a long enough time (i.e. more than a few months). Field sampling of blue mussels was carried out the 18th and 19th of July 2005 and between the 30th of June and the 5th of July 2006. 5 wave exposed and 5 sheltered iron buoys from Swedish Maritime Administration, used to mark the inlet of Brofjorden north of Lysekil, a few km from the wave power test site were investigated by snorkelling. Exposed buoys were outside the fjord whereas sheltered buoys were situated inside the fjord (Figure 3). Just like our toroidal buoy, the marking buoys are coated with anti-corrosion paint, and some of them are exposed to westerly wind and waves, which make the marking buoys comparable to wave power buoys. Their height is, however, between 7 m and 10 m, an explicit difference from the wave power buoys. Every second or third year the marking buoys are cleaned from all fouling organisms and painted. All samples were taken by scraping all blue mussels of an A4-sized area about half a meter below the sea surface with a scraper into a 1 mm mesh net. The location of the sampling area was randomly determined and three samples were taken per buoy. The collected material was taken directly to the lab. All *M. edulis* > 0.5 cm were counted, their wet weight was taken and their shell-length measured and divided into 3 size classes; 0.5 – 2.5 cm, 2.5 – 5.5 cm and > 5.5 cm.

Subsamples were taken to estimate number and weight of *M. edulis* < 0.5 cm that appeared in high quantities (> 500 individuals per scraping area).

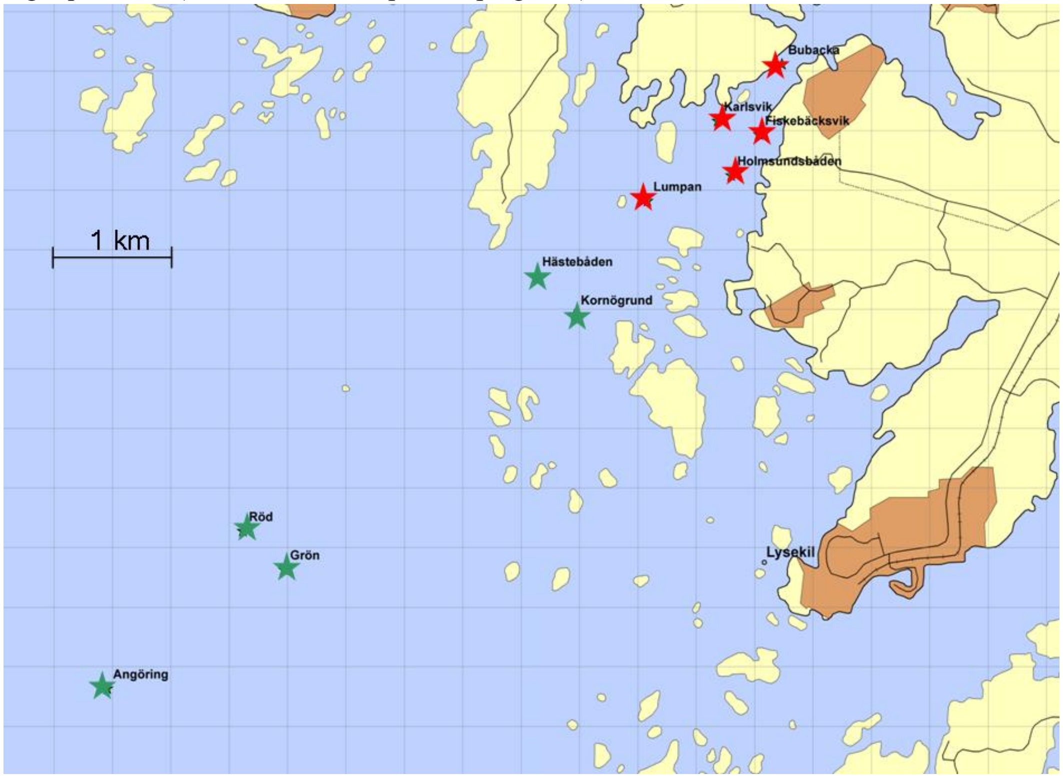


Figure 3. Gateway to Brofjorden with the town of Lysekil and the placement of the 5 exposed (green) and the 5 sheltered (red) marking buoys.

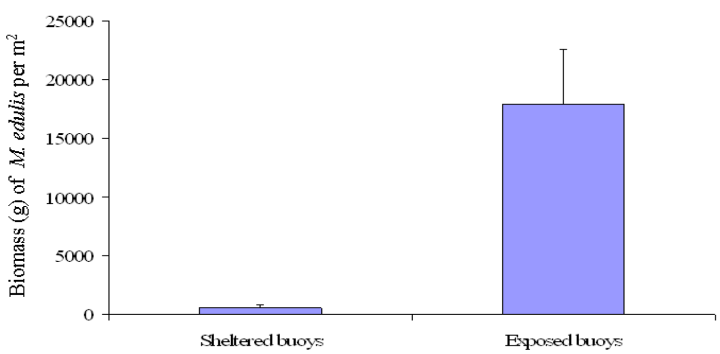


Figure 4. Biomass (mean ± SE) of *M. edulis* per m^2 found on sheltered and exposed marking buoys in Brofjorden.during summer 2005 and 2006.

STATISTICAL ANALYSES AND CALCULATIONS

Biomass of *Mytilus edulis* on exposed and sheltered Brofjorden marking-buoys was analysed with a one-way analysis of similarity (ANOVA). For comparison of the 3 different size classes of *M. edulis* on sheltered and exposed marking buoys a two-way ANOVA was used. One buoy was regarded as an outlier: heavy exposure to the Baltic current caused a very low biomass on it, and thus it was excluded from the results.

Surface under water of toroidal buoy and *M. edulis* biomass on the buoy were calculated. For hydrodynamic forces acting on the toroidal buoy it was assumed the same theoretical model was valid as we have used earlier for the cylindrical buoy (Langhamer et al., 2009). Further, the natural heave period of the toroidal buoy and how it changes due to added mass of blue mussels was calculated:

$$z = 2\pi \sqrt{\frac{(\rho\Delta + m_a)}{\rho g A_B}}$$

where z is the heave or vertical normal period of a floating object, ρ is the water density, Δ is the displacement of the buoy, m_a is the added mass which is the weight added to a system due to the fact that a body in motion moves some volume of surrounding water. The added mass m_a is dependent on the shape of the buoy. Further, g is acceleration due to force of gravity and A_B is the area of the toroidal buoy in the water surface (Eriksson et al., 2005). The calculated model is an approximation due to the circular buoy-surface and is adapted to small buoy heave movements.

RESULTS

The number of individuals of *M. edulis* found on marking buoys in Brofjorden was 3792 ± 611 individuals/m^2 (Mean ± SE). Mean biomass of *M. edulis* on the marking buoys was 11.3 ± 3.2 kg/m^2 and significantly higher on exposed buoys than on sheltered ones (ANOVA, $F_{1,25}$=6.4 ; p= 0.003, Figure 4). Maximum shell length of the mussels was 8.5 cm, and size-class distribution differed significantly between sheltered and exposed marking buoys (Table 1). In general, mussels were smaller on sheltered than on exposed buoys with no mussels in size-class 3 (5.5-8.5 cm) on sheltered marking buoys (Figure 5).

The total volume of the toroidal buoy is 6.12 m^3 and it lies 508 mm under water. Thus, the surface under water is 22 m^2. If all of that surface would be covered by *M. edulis*, it would carry an extra weight of 408.4 kg ± 56.2 kg. The calculated heave period of the unaffected toroidal buoy is 1.77 s, and with the added biofouling it increases to 1.82 s. At the Lysekil research site the measured average energy period is 5.1 s (Leijon et al., 2008). The energy absorption is at its peak when the system's resonance frequency (buoy's natural heave period together with the mechanical spring stiffness) is close to the wave period and thus have a resonance in the system (Falnes, 2002). The added biomass of around 400 kg may increase the buoy's natural heave period and thus its dynamics to a few percentages only which is a small amount, compared to the buoy's total mass of 4.8 t. With a damping from the generator of 60 kNs/m, the changed natural heave period due to mussel growth affected toroidal buoy is not of any relevance.

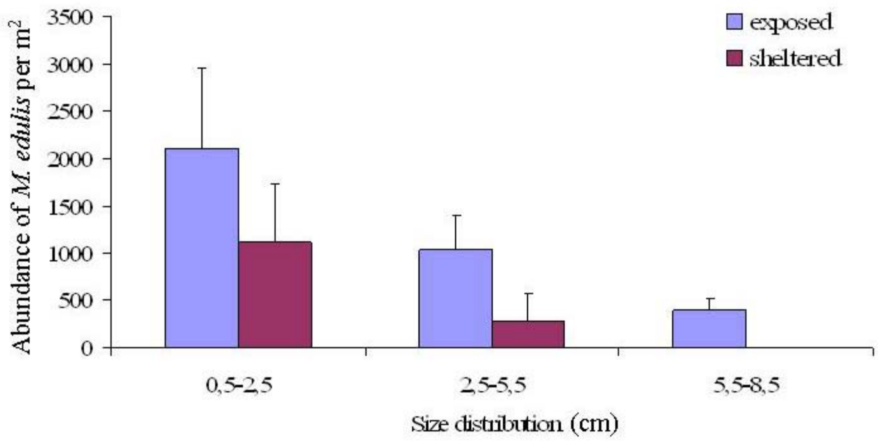


Figure 5. Abundance (mean ± SE) of different size classes (0.5-2.5cm; 2.5-5.5cm; 5.5-8.5cm) of *M. edulis* per m^2 on wave exposed (blue) and sheltered (purple) marking buoys at Brofjorden during summer 2005 and 2006.

Table 1. Comparison of different size classes in *M. edulis* on wave exposed and sheltered marking buoys using a two-way analysis of variance (ANOVA) with measure of abundance

	df	MS	F	p
Size class	2	34742	13.6	0.0002
Exposure	1	42203	16.6	0.0005
Size class*Eposure	2	6675	2.6	0.10
Error	21	2548		

Shell length was divided into 3 classes; >0.5 – 2.5 cm, >2.5 – 5.5 cm and > 5.5 cm.

CONCLUSION

The colonization of *M. edulis* on artificial substrates (here: marking buoys in Brofjorden) varies highly with wave exposure, and the significance of wave exposure on size and biomass of blue mussels is clearly shown. These results are consistent with earlier studies, indicating wave exposure as an important factor determining size and distribution of *M. edulis* (McQuaid et al., 2000; Westerbom and Jattu, 2006). Generally, mussel settlement and recruitment is depending on several biotic and abiotic factors and both local and larger geographic scale (Bayne, 1976; Seed, 1992; Lachance et al., 2008). *M. edulis* has a broad distribution (Gosling, 1992); the larval development takes about 4-6 weeks and thus allows a spread over wide geographical regions (Seed, 1992; Seed and Suchanek, 1992). The coastal current system is important for passive particle transport and it is an efficient conveyor of fouling organisms to offshore installations. Local hydrodynamics thus have an immense impact on the settlement of larvae (Shanks, 1995). Many different factors such as less competition for space and/or increased feeding resources during initial colonization may thus explain the higher success of mussels on the wave exposed buoys. Higher water turbulence which influences the flux of phytoplankton and thus the nutrients supply may be the biggest supporter for high growth rates of mussel assemblages, since turbulent areas generally host a higher amount of suspension feeders (Kautsky, 1982; Frandsen and Dolmer, 2002). Drain of food in depressions and cavities of a complex habitat might explain low growth rates of *Mytilus* (Frandsen and Dolmer, 2002).

Blue mussel shell length of 85 mm on exposed buoys was reached within two years, concordant with the high growth rates reported (up to the double compared to onshore growth) of blue mussels further off the coast (Buck, 2007; Joschko et al., 2008). Yet, mussel settlement is likely to decrease again above a certain threshold of wave exposure due to dislodgement of larger mussel clumps in a case of too strong wave action and gravity, and inhibition of filtrating by hydrodynamic forces (Hunt and Scheibling, 2001; Steffani and Branch, 2003; Lachance et al., 2008). In previous studies it has been noted a severe loss of mussel clumps after heavy wave action and storms (Reusch and Chapman, 1995; Hunt and Scheibling, 2001). In this chapter, the exposed area actually may represent an intermediate area, offering favourable growth conditions for mussels colonizing those buoys. Thus, wave power parks built further than 10 km offshore, where the wave climate is severe, will carry smaller and fewer mussel assemblages. Future commercial wave power parks will be placed more offshore, with lower concentration of mussel larvae, due to dilution during offshore dispersal and intense predation on larvae. This, in concert with even stronger wave action, blue mussel growth will render fouling to the status of a minor problem.

The starfish, *Asterias rubens*, is one of the main predators of *M. edulis* and controls the distribution and abundance of subtidal mussel assemblages (Dare, 1982; Saier, 2001). An earlier study (Langhamer et al., 2009) showed that the occurrence of *A. rubens* on marking buoys in Brofjorden was in rather low quantities, i.e. 0.6% of the fouling community. This suggests that starfish may be sensitive to wave exposure and thus kept away from mussel assemblages. Another predator that might have an influence on blue mussel populations in sheltered locations is the common eider. Eider may contribute to a low frequency of medium (2.5 – 5.5 cm) and to an absence of larger sized (> 5.5 cm) blue mussels on the sheltered marking buoys.

Furthermore, another factor contributing to better colonization of blue mussels on exposed buoys may be parasite infestations. It has been observed that *M. edulis* in open ocean sites suffer fewer parasite infections due to both a higher dilution of parasites in offshore transport processes and the absence of intermediate hosts (Buck et al., 2005). If this enhances survival and growth of blue mussels is still unknown.

The lower coverage and smaller size of *M. edulis* on wave sheltered marking buoys can be related to ice that covers the inner-most part of the fjord during cold winters. Ice may scrape off benthic assemblages especially in the upper littoral and sublittoral and can lead to disturbance and mortality (Gutt, 2001). The local devastation and dislodgement of blue mussels by ice creates free spaces available for recolonisation, causing a patchy pattern on the sheltered marking buoys. *M. edulis* is quick and very successful in colonizing free space by crawling from nearby areas and thus the population structure is kept more or less stable (Qvarfordt et al., 2006).

Estimations of the fouling biomass that may develop on our wave power buoys state that 400 kg may be added on a toroidal buoy. The weight of a translator/buoy together with the added mass is over 10 t, so the increase of mass due to blue mussels is negligible. These results are consistent with an earlier study of Langhamer et al. (2009) on fouling organisms and buoy dynamics, where only a slight decrease in energy absorption was observed. Mussel growth will increase the buoys` surface and thus the resistance in the water mass around the buoy. An increased turbulence followed by increased friction drag and higher energy discharges might be less important in a heavily damped system (Kundu and Cohen, 2004). Consequently, the most cost-efficient strategy would be to leave biofouling organisms on the wave energy converters.

Serious impacts might occur from aggregations of blue mussels on hundreds of neighbouring wave power devices in commercial wave parks. *M. edulis* removes suspended particles from the water column and provides an input of sediment and organic matter in form of faeces and pseudofaeces (Kautsky and Evans, 1987). Biodeposition and increased sedimentation from mussel beds can result in enrichment with organic material and increased oxygen consumption in the sediments beneath which can lead to anoxic conditions (Kaspar et al., 1985). These processes have significant impacts on local benthic faunal composition and abundance which has been shown in several studies (Mattsson and Linden, 1983; Ragnarsson and Raffaelli, 1999; Hartstein and Rowden, 2004). In the Lysekil research site it has been observed a higher abundance of mobile organisms (e.g. edible crabs) that are feeding on blue mussels, and thus may be favoured by blue mussel aggregations on buoys (Langhamer et al., 2009).

Finally, current offshore research suggests a multiple use of offshore energy parks for both the generation of electricity and cultivation of aquatic organisms, especially blue mussels (Buck et al., 2004; Michler-Cieluch et al., 2009). The present chapter shows the potential of mussel colonization and growth on offshore structures. However, for commercial aquaculture deployment in wave power parks, further studies on larvae ecology are needed. If there is an economical pay-off in harvesting the blue mussel clumps growing on wave power buoys, it will be a possible secondary use of wave power installations, especially in developing countries.

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