Ecological impacts of a wave energy converter in Hammarudda, Åland Islands – a preliminary assessment after one year of operation

INTRODUCTION

Background

Wave Energy for a Sustainable Archipelago (WESA) is a joint project among Uppsala University, Ålands Teknikkluster and the University of Turku. The aim of the project is to study the potential for wave energy converters in the northern Baltic Sea. Preliminary studies are carried out with a prototype converter located outside of Hammarudda, in the south-western part of the Åland Islands in the northern Baltic Sea. In addition to issues directly related to energy conversion, the pilot project concerns also societal and environmental aspects associated with wave energy. The project WESA ordered in July 2012 a field study on and an assessment based on literature information of environmental impacts of the wave energy converter in the Hammarudda area, Åland, from Husö biological station, Åbo Akademi University. In this report, we present a preliminary assessment of environmental impacts observed at the prototype converter. This assessment is based on a small field study conducted by two divers (Matias Scheinin and Erik Holgersson). PhD Matias Scheinin has also analyzed the samples and results. Further, the obtained knowledge is extrapolated to predict future changes associated with the prototype converter and the potential impacts of expanding number of the converter units. The report is compiled by PhD Matias Scheinin and ass.prof. Johanna Mattila.

Site and schedule

The wave energy converter was mounted 700 meters southwest from the shore in Hammarudda (60°06′328″N and 19°43′763″E) in January 2012. The location is highly exposed to wind and waves from about a 180° angle between South and North. The energy converter is planned to be kept in operation at least until the end of 2013. The period may be extended by some months to cover the whole winter season.

The converter unit consists of a disk-shaped concrete foundation (Ø = 6.0 m, h = 0.7 m), and a steel cylinder (Ø = 1.5 m, h = 4.9 m) with a steel cone (Ø = 0.5-1.5 m, h = 4.7 m) on top for protecting the conversion apparatus (Figure 1). The concrete disk is encircled by rectangular cavities with the purpose of increasing the diversity of habitat types for the biota. Further, the steel cone has three oval-shaped openings for maintenance purposes. The converter unit is connected to a surface buoy by a cable which transfers the movement of the buoy mechanically to the converter. The buoy had been detached from the converter since May 2012 and was reattached only one day prior to the ecological examination of the converter unit.

The concrete foundation of the converter unit is at the depth of 25 meters, whilst the top of the unit is at 14 meters. Within the radius of about hundred meters, the depth varies between 20 and 30 meters.

The bottom in the whole area is topographically and compositionally very homogeneous. Sand with intermediate grain size is the only substrate. It is covered by very small quantities of sediment or any other material such as drifting algal mats.

Potential impacts of wave energy converters

The environmental impacts of a wave energy converter or any other corresponding device can be divided into three phases. Different types of disturbance will occur during the three phases, that is during the 1) construction, 2) routine operation and 3) decommissioning of the device (Table 1) (Gill 2005). This report is focused mainly on the two first phases, and in particular the second one.

During construction and decommissioning, the seabed is disturbed by work on the foundations for the energy conversion devices and the underwater power cables connecting the converter to the shore. Sediment removal and replacement lead to direct loss of habitats, and water turbidity increases locally. Resuspended sediments are transported by prevailing water movements during construction, influencing the distribution of any contaminants mobilized from within the sediments. By the same token, resuspension of organically rich sediments can temporarily reduce oxygen availability in the vicinity of the construction site (Gill 2005).

The physical and chemical disturbances associated with the operation of offshore energy converters, in general, can alter local community composition and its dynamics beyond natural variation (Blyth et al. 2004). The magnitude of the effects on the benthic community and the length of time that they are apparent depend on the duration and intensity of the disturbance (van Dalfsen et al. 2000) as well as the resilience and resistance of the local biota (Drabsch et al. 2001).

After the disturbance has ceased, recolonization takes from months to years (Harvey et al. 1998). Small opportunistic species, such as polychaetes and amphipods, are the fastest colonizers after physical disturbance, while the recovery of epifaunal communities is likely to take longer (Newell et al. 2004). Change may be rapid with soft substrates. On coarse and more stable substrates, changes are likely to be slower (Kaiser and Spencer 1996).

Table 1. Potential environmental effects and ecological consequences associated with the three different phases of activity in utilizing wave energy converters (Gill 2005).

Activity phase	Potential environmental effects	Potential ecological consequences
CONSTRUCTION	Physical alterations, e.g. - habitat availability - light climate Chemical alterations, e.g. - nutrient availability - oxygen levels Turbidity Contaminant remobilization Construction noise Construction vibrations	Sedentary species - reduced diversity - increase in opportunist abundance Mobile species - temporary displacement - long-term displacement Short-term changes to: - trophic resource availability - species diversity and abundance - production and biomass - community composition and size structure - connectivity
OPERATION	Operation noise Operation vibrations Electromagnetic fields Physical heterogeneity, e.g. - habitat diversity - altered migration routes - sediment transport - water movements	Acoustically orienting species: - individual disturbance - population disturbance Species sensitive to electromagnetic fields: - individual attraction/avoidance - population attraction/avoidance →altered migration patterns → injury/fatality of individuals Long-term changes to: - trophic resource availability - species diversity and abundance - production and biomass - community composition and size structure - connectivity
DECOMMISSION	Physical alterations, e.g. - habitat availability - light climate Chemical alterations, e.g. - nutrient availability - oxygen levels Turbidity Contaminant remobilization Decommission noise Decommission vibrations	Sedentary species - reduced diversity - increase in opportunist abundance Mobile species - temporary displacement - long-term displacement Short-term changes to: - trophic resource availability - species diversity and abundance - production and biomass - community composition and size structure - connectivity

To assess the ecological consequences of wave energy converters, it is important to understand the susceptibility of organisms and their resilience to the effects of the constructing, operating and decommissioning of the converters, and the processes determining community recovery after the disturbance. Implicit in this understanding is knowledge of the stability of the substrate on which the converter is constructed.

Materials and methods

Since no environmental assessments had been carried out at the site for the wave energy converter prior to its construction, a corresponding site just outside the immediate sphere of influence of the converter (ca 50-100 meters aside) was examined for reference purposes. The examination was broad and superficial, with the focus on the substrate type and immediate, visual observations of the biota. One examination dive by two divers was carried out on September 19th 2012, a week before a corresponding dive was done at the wave energy converter.

Biota and other conditions at the wave energy converter were mapped during a single dive by two divers on September 26th 2012. As during the previous dive, two Metalsub XL 13.2 LED torches were used to enable visual observations in the otherwise dark conditions. In addition to the on-site observations, five samples were taken with a “Kautsky scraper” (Kautsky 1992) to study the biota attached (biofouling/epiphytes and epibenthos) to different parts of the wave energy converter (Figure 1).

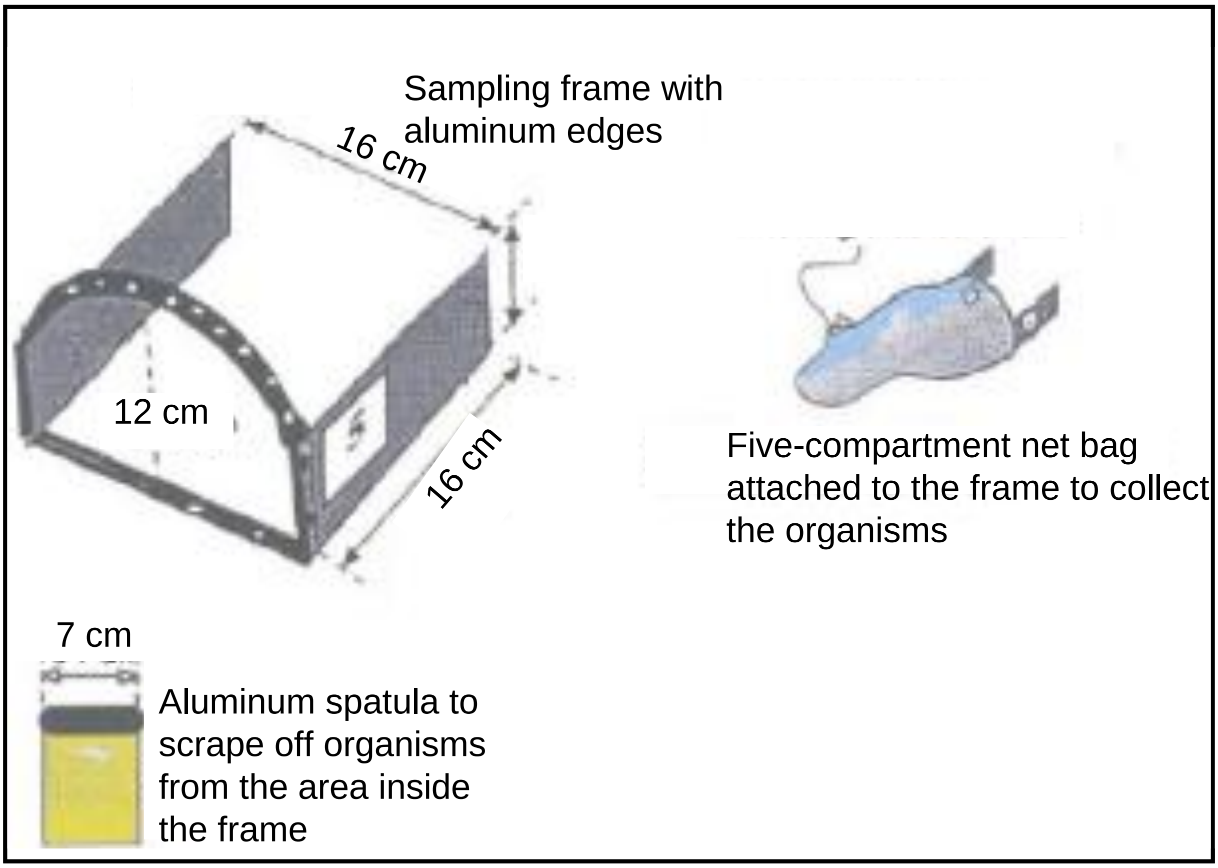

Figure 1. The Kautsky scraper used for taking samples of the biota on the wave energy converter (modified after Kautsky, 1992).

Three samples were taken on the concrete foundation. Two of them were taken on top of it, one close to the edge and the other near the converter. The third sample was taken from the wall of one of the cavities encircling the lower part of the edge of the foundation. Further, two samples were collected from the structures protecting the converter apparatus. One of them was taken in the middle of the cylindrical part and the other in the middle of the conical part (Figure 2). The buoy was not sampled at all, because it had been detached for several months and reinstalled only a day before the investigation.

The structures where the samples were taken from were also photographed. Some organisms, in practice the bryozoan *Electra crustulenta*, are not reliably collected with the Kautsky method. Their abundance was thus evaluated solely from the photographs.

The samples were preserved on ice immediately after the dive and in 70% ethanol two hours later. In the lab, the contents were sifted through a 7-stage sieve series (Pascal Engineering Co. Ltd Ins. M69) with mesh sizes ranging from 9.0 mm to 0.063 mm. The resulting fractions of the samples were examined separately using a preparation microscope. Every specimen was measured at a 0.1 mm resolution and identified with the highest possible taxonomic resolution.

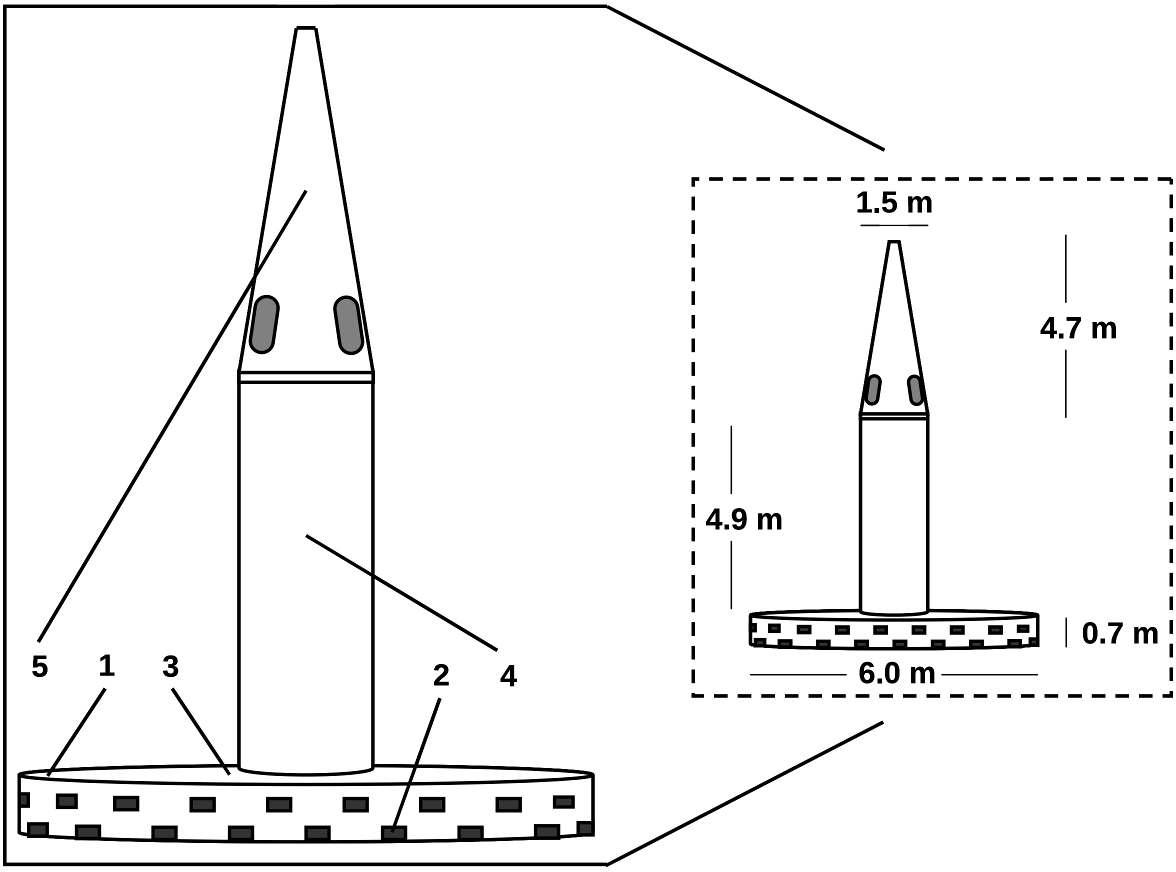

Figure 2. The plot of the wave energy converter on the right hand side illustrates the dimensions of the device. The enlargement on the left hand side shows where the samples for the biota (1-5) were taken.

Results

Epibenthic fauna in the reference area near the converter unit were comparably abundant. The clean sand bottoms were inhabited by high numbers of sand shrimps (*Crangon crangon*). Drifting forms of the red algae *Coccotylus truncatus* and *Sphacellaria arctica* were encountered occasionally. Blue mussels (*Mytilus edulis*) were often attached to the moving tufts, facilitating the distribution of the sessile, adult mussels. In addition to the shrimps, sand gobies (*Pomatoschistus minutus*) occurred abundantly in the area, whilst flounders (*Platichthys flesus*) and fourhorned sculpins (*Myoxocephalus quadricornis*) were encountered more sporadically. Observations in the immediate vicinity and on the converter unit were generally very similar to those made in the reference area.

No macroscopic plants or algae were found in the Kautsky samples taken in the different parts of the wave energy converter unit. By contrast, altogether ten species (or higher taxons) of attached animals were encountered. These were the bay barnacle (*Balanus improvisus*), the lagoon cockle (*Cerastoderma glaucum*), the bryozoan *Electra crustulenta*, hydrobids within the genus *Hydrobia* (*Hydrobia* spp.) the isopod *Jaera albifrons*, the Baltic clam (*Macoma balthica*), the mysids bloody-red mysid (*Hemimysis anomala*) and/or the opossum shrimp (*Neomysis integer*), the blue mussel (*Mytilus edulis*), roundworms i.e. nematodes (Nematoda sp.), and bristleworms i.e. polychaetes (Polychaeta sp.). As opposed to the other animals, the modularly growing *Electra crustulenta* and Polychaeta spp. are not included in the figure depicting the densities of the different size classes of the animals (Figure 3). Based on the photographs, *Electra crustulenta* covers 25% of the surfaces of the metal cylinder and the metal cone. Although corresponding quantitative assessments could not be made for the concrete foundation due to the roughness of the surface, the species is known to grow there. Several fragments of it were found in Sample 2. Since only one polychaete specimen (l = 4.0 mm) was encountered (Sample 2), the data are not included in the figure.

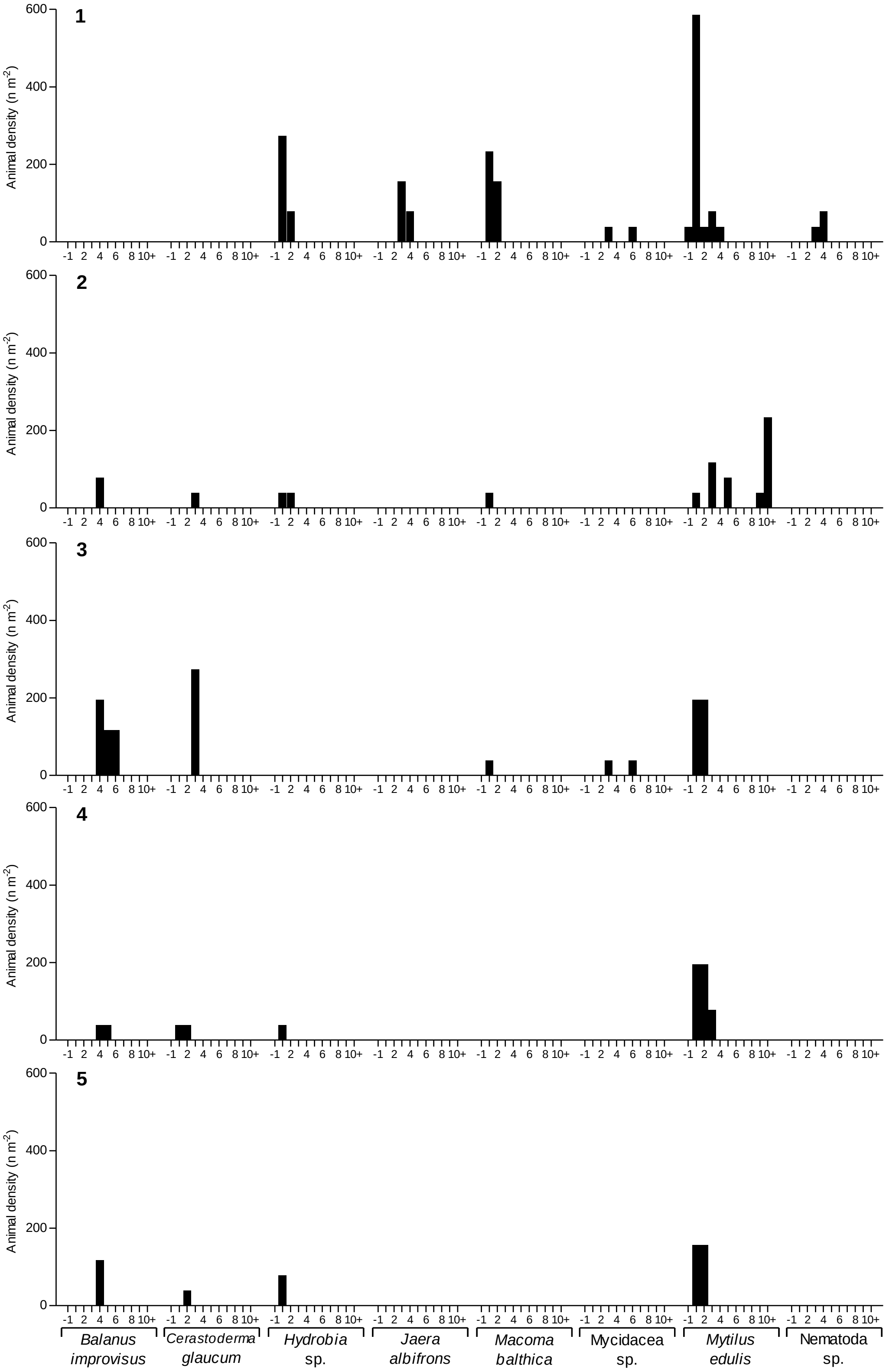

Figure 3. Animal densities (n m^{-2}) in the five samples (1-5) divided according to size classes. The classes cover 1.0 mm intervals between 0.0 mm and 10.0 mm ("-1" stands for organisms smaller than 1.0 mm). The larger specimens are lumped into a single category denoted as "10+".

The highest total densities of animals were found in the two samples taken on the horizontal surfaces of the concrete foundation. In sample 1, taken close to the edge of the foundation, the total density of animals was 1 953 n m^{-2}. In sample 3, covering an area close to the converter, the corresponding figure was 1 211 n m^{-2}. Total animal density was slightly higher (781 n m^{-2}) in sample 2, taken on the vertical surface of one of the cavities on the edge of the concrete foundation than in samples 4 (664 n m^{-2}) and 5 (547 n m^{-2}), taken on the metal cylinder and metal cone, respectively.

The concrete foundation was generally a more suitable substrate for animals to live on than the metal coverings of the converter. Ten species were encountered on the foundation, whilst only five were found on the metal surface. *Balanus improvisus*, *Cerastoderma glaucum*, *Electra crustulenta*, *Hydrobia* spp. and *Mytilus edulis* occurred on both surface materials. By contrast, *Jaera albifrons*, *Macoma balthica*, Mycidacea spp., *Mytilus edulis*, Nematoda spp. and Polychaeta spp. were found only on the concrete surface. Since neither the total number of species nor their identity seemed to depend on the orientation of the concrete surface, variation in the assemblage of the communities associated with the converter unit appear attributable mainly to the surface material and possibly to the distance to bottom and/or surface. However, when the relative densities of the animals and thus the general composition of the communities is taken into consideration, the most distinctive differences in the biota are found between the vertical and the horizontal surfaces, regardless of the material.

The size structure of the animals varied only a little among the different samples. Regardless of the species, almost 95% of the individual animals were shorter than 2.0 mm. This means that a clear majority of the fauna has settled on the converter unit as larvae during the past spring and summer and metamorphosed into sessile forms, still very small in size. The most notable differences in size structure among the samples concerned *Mytilus edulis*. Older and larger specimens of the species had drifted to the concrete foundation on algae and possibly other vectors and resettled at least on the surfaces where samples 1 and 2 were taken, close to the edges of the concrete foundation. This kind of non-larval or secondary settlement is an important contribution to the biomass associated with the converter unit especially during early succession/colonization.

Discussion and conclusions

The construction of wave and wind energy devices such as the one in question can produce noise up to 260 dB. Such high levels can cause damage to the acoustic systems of species within tens or hundreds of meters of the source, and should thus cause many mobile organisms to avoid the area (Nedwell et al. 2004). Breeding seabirds are disturbed by various sources of anthropogenic noise pollution (Beale and Monaghan 2004). By the same token, various fully aquatic species that interact acoustically e.g. cetaceans, pinnipeds, teleosts and crustaceans) can suffer, since sound is used for communication, finding prey, echolocation (particularly by the mammals), locating recruitment sites in fish, finding potential mates and avoiding predators (Gill 2005). In general, any effects of the noise will depend on the sensitivity of the species present, and will diminish when the level of noise has decreased following completion of the construction (or decommissioning) phase. The noise pollution associated with the wave energy converter unit is likely to have only transient negative effects.

Variation in food and habitat availability associated with the construction and operation of the wave energy converter unit could affect reproductive success. Potential failures may be disastrous particularly for species already under human pressure. Seabirds, marine mammals and other species that invest in parental care can suffer from reduced breeding success if their food quality and/or quantity are/is altered (Barrett and Krasnov 1996). By contrast, species with little post-reproduction parental investment, such as most fish, use specific spawning and nursery sites. During construction and decommission early life stages may be vulnerable to burial and removal. Introduced structures may also change water movements and thus have notable implications for species whose instars disperse passively over larger scales (Kinlan and Gaines 2003). Habitat degradation and loss is perhaps the single most effective way of slowing or preventing fish population recoveries (Dulvy et al. 2003). It is a particular concern when spawning grounds or nursery areas are limited in their availability or extent and the species that rely on them have small numbers of recruits, long maturation periods and are already being impacted by other human activities (Gill 2005).

The converter unit functions clearly as a so called artificial reef (Langhamer et al. 2010). It provides a hard substrate in an area otherwise covered only by sandy surfaces. In the specific surroundings near the headland of Hammarudda, the immediate effects of even several such artificial reefs are likely to be small. Although the structural complexity of the environment clearly increases at smaller spatial scales, the effects should be limited to local ones. Skerries, cliffs and other hard substrates are common within a couple of hundreds of meters from the wave energy converter unit. It is thus unlikely that even several converter units in the area would influence the dispersal dynamics of species that require a hard substrate.

Importantly, the clean sand bottoms that cover the area around the wave energy converter are getting increasingly rare. In the long term, several converter units may have a detrimental effect on the sandy biotope. The increased structural complexity is likely to increase species diversity in the area, thus violating its integrity or natural state. As opposed to the widely held misconception among non-experts, increasing biodiversity is not necessarily positive for the functioning of the system in question (Woodwell 2010). On the other hand, the newcomers should not outcompete the original biota at least in the first instance.

The most serious risks associated with the artificial extra structures in the sandy area are related to longer biogeochemical processes. Enormous quantities of sessile biota can attach to the surfaces of the structures (Langhamer et al. 2009). Since epifaunal growth on different parts of wave energy converter units result in increased sedimentation, the surrounding area is bound to be influenced. An increase in the sedimentation rate of the mineral fraction and of the organic fraction is expected from direct and indirect sedimentation of the epibiotic biomass. These sedimentological and ecological transformations can induce eutrophication of the benthic ecosystem and can alter community composition and function (Guiral et al. 1995). Thus, it is of primary importance to investigate the prevailing currents in areas planned for wave energy use, and to model how the water movements may be influenced by the additional structures. This is especially important in the investigated area due to its rare state. These studies should obviously be accompanied with at least annual mappings of the biota around the wave energy converter unit.

Turku, October 31st 2012

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