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5 manufactured holes – a field experiment  
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## Abstract

Several Western European countries are planning for a significant development of offshore renewable energy along the European Atlantic Ocean coast, including many thousands of wave energy devices and wind turbines. There is an increasing interest in articulating the added values of the creation of artificial hard bottom habitats through the construction of offshore renewable energy devices, for the benefit of fisheries management and conservation. The *Lysekil Project* is a test park for wave power located about 100 km north of Gothenburg at the Swedish west coast. A wave energy device consists of a linear wave power generator attached to a foundation on the seabed, and connected by a wire to a buoy at the surface. Our field experiment examined the function of wave energy foundations as artificial reefs. In addition, potentials for enhancing the abundance of associated fish and crustaceans through manufactured holes of the foundations were also investigated. Assemblages of mobile organisms were examined by visual censuses in July and August 2007, 3 months after deployment of the foundations. Results generally show low densities of mobile organisms, but a significantly higher abundance of fish and crabs on the foundations compared to surrounding soft bottoms. Further, while fish numbers were not influenced by increased habitat complexity (holes), it had a significantly positive effect on quantities of edible crab (*Cancer pagurus*), on average leading to an almost five-fold increase in densities of this species. Densities of spiny starfish (*Marthasterias glacialis*) were negatively affected by the presence of holes, potentially due to increased predator abundance (e.g. *C. pagurus*). These results suggest a species-specific response to enhanced habitat complexity.

Key words: artificial reefs, coastal zone management, disturbance, fisheries, habitat complexity, habitat enhancement, wave power.

## 1. Introduction

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4 A number of countries are planning for a significant development of offshore renewable  
5 energy along for example the European Atlantic Ocean coast, including many thousands of  
6 wave energy devices and wind turbines forming energy farms that will require areas of  
7 several square kilometres each (Oxley, 2006; Callaway, 2007, Cruz, 2008, IEA, 2008).  
8 Nature conservation concerns with respect to offshore energy development commonly centre  
9 around adverse effects of habitat and hydrodynamic alterations, noise, and electromagnetic  
10 fields on the marine environment (e.g. Gill, 2005; Wahlberg and Westerberg, 2005; Petersen  
11 and Malm, 2006; Broström, 2008; Tyack, 2008). At the same time, there is an increasing  
12 interest in articulating the potentially positive aspects of creating artificial hard bottom  
13 habitats through the construction of offshore renewable energy devices (Wilhelmsson et al.  
14 2006a; Langhamer et al., 2009; Wilson and Elliot, 2009). The foundations of the energy  
15 devices will exclude trawling activities from the claimed area, and will also constitute  
16 “secondary artificial reefs” (Pickering et al., 1998) for fish and invertebrates and may also  
17 function as fish aggregating devices (FADs) (Wilhelmsson et al., 2006a; Fayram and de Risi,  
18 2007; Wilhelmsson and Malm, 2008; Langhamer et al., 2009). These aspects of local impacts  
19 of offshore renewable energy development may, in theory, be beneficial for fisheries  
20 management and species conservation.  
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36 Availability of shelter from predation may be a demographic bottleneck for several species,  
37 such as European lobster *H. gammarus*, and to some extent edible crab *C. pagurus* (e.g.  
38 Jensen et al., 1994; Pickering and Whitmarsh, 1997; Ackefors, 2005). Deployment of wave  
39 and wind power foundations could thus be hypothesised not only to aggregate marine biota  
40 and decrease fishing mortality, but also to significantly enhance biomass production of these  
41 shellfishes at local scale. By considering certain habitat preferences of marine organisms in  
42 the design of the structures, given acceptable costs, abundance and diversity of associated  
43 species could be enhanced. Commercially important or threatened species could be specially  
44 catered for where desired (e.g. Nakamura, 1985; Bortone et al., 1994; Kawasaki et al., 2002).  
45 For instance, the structural complexity of the foundations could be increased at relevant  
46 scales, to enhance the abundance, diversity and biological productivity of motile macrofauna.  
47 This would primarily be coupled to enhanced shelter properties, the creation of physical  
48 barriers and compartments of the habitat, and various behavioural responses (Risk, 1972;  
49 Luckhurst and Luckhurst, 1978; Hixon and Beets, 1989; Chabanet et al., 1997; Friedlander  
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1 and Parrish, 1997; Bortone et al. 1994; Potts and Hulbert, 1994; Spieler et al., 2001). For  
2 standardized examinations of the influence of structural complexity at various scales and on  
3 different species on both natural and artificial reefs, manufactured or already existing holes of  
4 different numbers, densities, sizes, and combinations have commonly been considered (e.g.  
5 Hixon and Beets, 1989; Friedlander and Parrish, 1998; Sherman et al., 2002).  
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10 There is, however, a great variability in taxon- and age specific responses of fishes to the  
11 deployment of differently designed artificial reefs, and regional ecological and environmental  
12 factors strongly influence the function of an artificial reef (Hueckel et al., 1989; Bohnsack et  
13 al., 1991; Baine, 2001). The information base for optimising artificial reef design to provide  
14 the specific habitat requirements of desired species and age groups, or enhancement of fish  
15 biomass production is generally weak (Seaman and Sprague, 1991; Baine, 2001; but see  
16 Nakamura's (1985) review on research in Japan). Invertebrates, fish, and algae may also be  
17 negatively affected by the presence of an artificial reef, through increased predation pressure  
18 in its vicinity (Davis et al., 1982; Kurz, 1995; Jordan et al., 2005).  
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29 Since 2005, the Lysekil wave energy research site, located near the city of Lysekil on the  
30 Swedish west coast, is being developed. Both technical and environmental studies are carried  
31 out within the project, in order to evaluate the wave energy converter concept for further  
32 commercialisation. One wave power unit consists of a steel buoy on the surface that drives a  
33 translator in a direct-driven linear generator moored to a concrete foundation on the seabed  
34 (Fig.1). This type of device functions at water depths ranging from 20 m to 100 m. The  
35 Lysekil research site covers about 40 000 m<sup>2</sup> and currently comprises 29 wave power devices;  
36 3 with generators and 26 without generators for initial ecological studies (Leijon et al., 2009).  
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45 Predictions of the influence of the wave power foundations on the distribution of  
46 macrobenthos are uncertain. There are only a few examples of artificial reef studies in cold  
47 temperate waters (Baine, 2001), and even fewer have included experiments with different  
48 structural factors or, additionally, been conducted at the depths below 15 m, at higher latitudes  
49 (but see Wilhelmsson et al., 2006b; Langhamer et al., 2009). A pilot study by Langhamer and  
50 colleagues (2009), conducted in the Lysekil wave energy park, indicated a sparse colonisation  
51 by fish while edible crabs seemed more affected by the hard substrata deployed. However, the  
52 number of foundations quantitatively surveyed was low (n=3), providing weak evidence for  
53 the conclusions.  
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1 The purpose of this study was to examine to what extent added protruding, but non-complex,  
2 hard substrate, through the deployment of wave power foundations on bare sandy bottoms,  
3 affect local distribution patterns of fish and motile invertebrates. Effects of low cost  
4 enhancements of shelter availability and compartment through holes in the foundations were  
5 also investigated. We hypothesised that wave energy foundation would aggregate fish and  
6 crustaceans, and that holes in the foundations would further enhance their abundance.  
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## 16 **2. Methods**

### 17 *2.1. Study site and experimental design*

18 The Lysekil research site is situated on the Swedish west coast, about 100 km north of  
19 Gothenburg, near Lysekil (Fig. 2). The site is located 2 km offshore between a northern  
20 (58°11'850''N, 11 ° 22'460''E) and a southern (58°11'630''N, 11°22'460''E) marker. The  
21 shoreline of the area is characterised by rocky slopes covered by algae, with sandy and muddy  
22 bottoms below the rocky outcrops (Cato and Kjellin, 2008). The site is a flat sandy bottom at  
23 25 m depth, with little relief. The area is exposed to predominantly westerly winds and waves  
24 and the tidal range is about 0.3 m (Johannesson, 1989). The temperature of the surface water  
25 is in the range of 15-20 °C in the summer and 0-2 °C in the winter. Average salinity is 25 ‰,  
26 and covering ice occurs on average every fourth year (Åberg, 1992).  
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40 In May 2005, the first experimental set-up, including five wave power devices (without  
41 generators), was launched in the Lysekil research site on otherwise featureless soft bottom.  
42 The scope of the deployment of these devices was to conduct pilot-studies on environmental  
43 impacts and colonisation patterns of marine organisms on both wave power buoys and  
44 foundations (Langhamer et al., 2009). In spring 2006, the first wave energy converter (WEC)  
45 was deployed in the research site.  
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In April 2007, another 21 wave power devices were launched, and these were used in the present experiment. The foundations measured 3 m in diameter, were 1 m high, and weighed 10 t each. The distance between modules was 15-20 m, allowing access by research vessels and for waves to gain a certain fetch approaching the next wave power buoy. Eleven of the foundations were each perforated with 26 rectangular holes, 12 cm x 15 cm x 30 cm (width x height x depth). Thirteen of the holes were made in the lower edge of the structure, so that the seabed constituted the floor of the holes, while 13 holes were drilled on the vertical side of the foundation, 50 cm above the seabed (Fig. 3). On the 10 remaining foundations no holes were made. The foundations were positioned so that, generally, every second had holes (Fig. 2).

Eight meters from each foundation (in haphazard directions), bottoms of the same total area as on and around the foundations (12 m<sup>2</sup>) were examined for comparison to the newly added hard bottom habitats. These control areas comprised flat bare sandy bottoms.

## 2.2 Survey methods

The 21 wave power foundations added in 2007 were sampled once during July – August 2007 by SCUBA-diving, 2-3 months after deployment. Fish and crustaceans associated with the modules and in controls were recorded through visual censuses on the structures, including the holes where present, and on the surrounding bottom within 1 m distance (i.e. 5 m<sup>2</sup> sand bottom). On the foundations, the top of the structure was surveyed first. After that, the sides, the holes, and the adjacent bottom were surveyed by slowly moving clockwise around the foundation. The controls were censused in same way as the foundations, although these were predominantly two-dimensional (flat sandy bottom). One census, of either a foundation or a control took approximately 8 minutes

Two species of *Pomatoschistus* spp. are common on the Swedish west coast; sand goby (*P. minutus*) and common goby (*P. microps*). It is difficult to distinguish between them during *in situ* surveys. At the depths surveyed here, 25 m, most of the *Pomatoschistus* spp. are likely to be *P. minutus* (Jansson et al., 1985; Thorman and Wiederholm, 1986). Consequently, only the name *P. minutus* was used although our data could include some *P. microps*. Flatfishes were recorded as Pleuronectidae, and the two sculpins, sea scorpion (*Taurulus bubalis*) and bullrout (*Myoxocephalus scorpius*), were referred to as cottids.



### 2.3. Data analyses

1 Comparisons of numbers of fish, shellfish, and other invertebrates were made where  
2 frequencies of occurrence and abundances of species or taxa were sufficiently large.  
3 Comparisons between reef modules and controls were made using Wilcoxon's Matched Pairs  
4 Test. Shoals of juvenile fish were excluded in the data analyses to avoid skewness of data.  
5 Wilcoxon's was also used to compare the occupancy of the holes 50 cm above the bottom  
6 with that of the holes along the bottom. For comparisons of abundance data between non-  
7 complex foundations and foundations with holes, Mann-Whitney U-tests were performed.  
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### 3. Results

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21 A total of 17 taxa of fish (8), crustaceans (6), and echinoderms (3), were recorded in the  
22 survey (Table 1). Eight species of fish were recorded on the foundations, while three species  
23 were noted in the controls (Table 1). Although generally low, fish abundance was  
24 significantly higher on the foundations than in the controls (Wilcoxon's,  $p = 0.02$ , Fig. 4).  
25 Only a few fish used the holes in the foundations, and no effect of holes on fish abundance  
26 was shown (Mann-Whitney,  $p = 0.95$ ). No fish was found in the holes situated 0.5 m above  
27 the bottom (Table 2). Species-specific affinity for holes was, however, preliminary indicated.  
28 Three species of fish occupied the holes, albeit only along the bottom; Atlantic cod *Gadus*  
29 *morhua* (two of five recorded adult specimens), bullrout (one of two specimens recorded), and  
30 rock gunnel *Pholis gunnellus* (one of three recordings). Both cod recorded on the complex  
31 foundations were inside the holes.  
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43 Abundance of edible crab (*Cancer pagurus*), on the other hand, was positively affected both  
44 by the foundations without holes (Wilcoxon's,  $p = 0.03$ , Fig. 5), and by the presence of holes  
45 when comparing the non-complex foundations with the perforated ones (Mann-Whitney,  $p <$   
46  $0.01$ , Fig. 5). *C. pagurus* used the holes situated 0.5 m above the bottom more frequently than  
47 it used the holes along the bottom (Wilcoxon's,  $p = 0.03$ , Fig. 5, Table 2). In addition, *C.*  
48 *pagurus* were often associated with steel bolts protruding from the top of the foundations. One  
49 European lobster (*Homarus gammarus*) and one Norwegian lobster (*Nephrops norvegicus*)  
50 were found in the survey. The lobsters resided in dug out cavities under the foundations.  
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The presence of the artificial hard substrate did not seem to influence numbers of hermit crab (*Pagurus bernhardus*), great spider crab (*Hyas araneus*), common starfish (*Asterias rubens*), and masked crab (*Corystes cassivalurus*), although, at least for the latter three species, only a few individuals were recorded as a whole. The foundations attracted the spiny seastar *Marthasterias glacialis*, however, with an average of 0.8 ( $1.2 \pm$  standard deviation) individuals on the foundations while the species was not represented at all in the controls (Table 1). The abundance of *M. glacialis* was significantly higher on the non-complex foundations compared to the ones with holes (Mann-Whitney,  $p = 0.03$ ). Densities of the sand dwelling echinoderm *Astropecten irregularis* (sand star) were, less surprisingly, negatively affected by the hard substrate added (Wilcoxon's,  $p < 0.01$ ).

#### 4. Discussion

Apart from the holes, the wave power foundations had low structural complexity. The reef modules, however, added relief to the seabed, and the steep walls of the foundations may offer a certain degree of shelter by eliminating angles of attack by predators and provide lee from currents. The foundations also serve as substrates for epibiota (Langhamer et al., 2009), as well as entrap detritus, and thereby enhance organic production (Wolfson et al., 1979). They may also be used as cues or reference points for spatial orientation for fish (e.g. Nakamura, 1985). A number of fish species, including codfishes, wrasses, and flatfishes have been shown to associate with high relief structures of comparably low complexity during parts or most of their life cycles (Gregory and Anderson, 1997; Light and Jones, 1997; Stanley et al., 2002; Johnson et al., 2003; Cote et al., 2004; Wilhelmsson et al., 2006b).

The present study demonstrated scale dependent as well as species-specific responses to habitat manipulations. Although fish abundance was low compared to other artificial reefs and natural rocky bottoms in the same region (e.g. Wilhelmsson et al., 2006b; Stål et al., 2007), it was positively affected by the enhanced habitat heterogeneity at the scale of meters, achieved by the deployment of protruding hard substrate on an otherwise featureless soft bottom. The finer scale complexity provided by the holes, on the other hand, did not seem, at least during day time, to be utilised by most fishes to any significant degree. No effects of the holes on fish abundance were shown, and our second hypothesis was thus not supported in terms of fish. Edible crab (*Cancer pagurus*), on the contrary, commonly used the holes for shelter, and

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their carapace width generally matched the size of the holes well. Thus, while the effect of foundations with no holes on crab abundance was relatively weak, structural complexity at the scale of the holes showed to have a strong influence. It is also worth noting that *C. pagurus* showed a strong affinity for the protruding steel bolts that probably offered a certain degree of shelter and points of reference.

Colonisation of artificial reefs by reef dwelling fish is commonly relatively rapid (i.e. a few days to months), as was also shown in an experiment in the same region as the present study site (Wilhelmsson et al., 2006b). However, on the reef units in this experiment, species often dominating rocky bottoms in the area, such as cottids and wrasses (Pihl and Wennhage, 2002; Stål et al., 2007), were rare or absent. On other wave power foundations in the same area, similarly low numbers of these species were consistently recorded over three summer seasons (2006-2008, Langhamer et al., 2009). This indicates that, although this survey was conducted before the major period for settlement of year-juveniles of for example *C. rupestris* (i.e. August-September, Hilledén, 1981), abundances and species numbers may not increase notably with time.

The nearest natural reef was situated 200 m away, and the reef units may have been too isolated for the sustenance of sufficient colonization rates of adult fish to maintain sizable assemblages. It is more likely, however, that the reefs are located too deep and are too devoid of refuge at relevant scale (e.g. smaller holes, macroalgae) both for aggregation of adult fish and direct recruitment and survival of juvenile fish of any quantities (Shulman, 1984; Hixon and Beets, 1989; Levin, 1993; Stål et al., 2007). Furthermore, some fishes have been shown to avoid holes with only one opening, due to the limited escape options and water exchange (Dean, 1983; Spieler et al., 2001). In addition, a portion of the holes was occupied by sizable *C. pagurus*. Many species, on the other hand, migrate to deeper waters in the autumn, when water temperature drops (Hilledén, 1981; Jansson et al., 1985; Pihl and Wennhage, 2002). It could, thus, be relevant to investigate fish assemblages on the reef units during winter months, although weather conditions make surveys more difficult and costly.

In this study, as well as in the pilot study by Langhamer with colleagues (2009), European lobsters (*Homarus gammarus*) were only present in cavities under the foundations. No lobster used holes for shelter. The scope for manipulations of the design of wave power foundations to enhance densities of associated lobsters will be matter of assessing the costs relative to

benefits. For potential application in wave power development, a number of suggestions and hypotheses regarding shelter preferences and habitat optimisation for different species of lobsters, particularly for *H. gammarus*, would be worthwhile to develop or verify, including for example size, shape and number of shelter entrances, optimal size distribution and density of shelters, and preferred substrate composition (e.g. Spanier, 1994; Hernkind et al., 1997; Jensen et al., 2000 and references therein; Spieler et al., 2001; Miller et al., 2006)

*C. pagurus* clearly favoured the holes on the side of the foundations, 50 cm above the seabed, over the holes along the bottom. The reasons for this preference are unclear as knowledge on behaviour of *C. pagurus* at microhabitat level is very limited. Speculations may include: less sediment build-up compared to the holes along the bottom and thus less maintenance work required, less disturbance from lobsters (Richards and Cobb, 1986), and enhanced protection from predators. The negative effect on abundance of sand stars (*Astropecten irregularis*) of the foundations is likely to be simply due to the loss of soft bottom area. Further, the suggested adverse influence of structural complexity on densities of the hard-bottom dwelling spiny starfish (*Marthasterias glacialis*) is potentially a result of the significantly increased predator abundance (i.e. *C. pagurus*) on the foundations with holes (Verling et al., 2003).

Once sufficient shelter has been provided, one limiting factor for numbers of associated fish and crustaceans could become food supply on and in the vicinity of the artificial structures. Blue mussels (*Mytilus edulis*) dislodged from the energy converter buoy at the surface could constitute an important source of prey for *C. pagurus* and *H. gammarus*. During subsequent diving on the foundations in 2008, many *C. pagurus* and hermit crabs (*Pagurus bernardus*) were observed preying upon blue mussels scattered in numerous lumps on and around the foundations. The buoys, 25 m above, are thus integral parts of these artificial reef systems.

## 5. Conclusion

The present experiment, along with earlier studies, provides some initial indications of how wave power foundations, as well as added structural components, could both enhance abundances of associated fish and invertebrates and have adverse effects on local numbers of certain species. The value of habitat enhancement efforts through structural design of wave foundations would benefit from additional and more comprehensive experimental studies

1 targeting preferences of specific species or assemblages. In addition, the carrying capacity in  
2 terms of prey availability on and around these artificial habitats under different circumstances  
3 should be investigated, including effects of aggregations of predators on abundance and  
4 diversity of associated and surrounding biota.  
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3 **Figure legend:**  
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6 Fig. 1. Wave energy park and technical description of the wave power devices developed in  
7 the Lysekil Project. © Centre for Renewable Electric Energy Conversion and Seabased Ltd,  
8 respectively.  
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13 Fig. 2. Location of study area and configuration of the experimental wave power foundations  
14 (not to scale). H = foundations with holes.  
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19 Fig. 3. Deployment of an experimental unit (i.e. wave power foundation) that has been  
20 perforated with 26 holes. Wave absorbing buoys can be seen in the background.  
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24 Fig. 4. Average fish abundance ( $\pm$  SE) on foundations and controls. \* =  $p < 0.05$   
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27 Fig. 5. Average number of ( $\pm$  SE) edible crabs (*Cancer pagurus*) on foundations with and  
28 without holes, and in controls. \* =  $p < 0.05$   
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32 Fig. 6. Overview of microhabitat use by edible crabs (*Cancer pagurus*), illustrated by average  
33 ( $\pm$  SE) number of recorded specimens in different categories of holes as well as on and around  
34 the foundations (outside holes). \* =  $p < 0.05$   
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Table 1. Mean abundance of echinoderms, decapods, and fish recorded on wave power foundations without holes, with holes, on all foundations, and in the control areas.

Taxa		Foundations	Foundations	Foundations	Control
Common name	Latin name	without holes	with holes		
<i>Echinoderms</i>					
Spiny seastar	<i>Marthasterias glacialis</i>	1.4	0.18	0.76	-
Common starfish	<i>Asterias rubens</i>	0.1	0.09	0.10	0.10
Sand star	<i>Astropecten irregularis</i>	0.2	-	0.10	1.8
<i>Decapods</i>					
Norwegian lobster	<i>Nephrops norvegicus</i>	-	0.09	0.05	-
European lobster	<i>Homarus gammarus</i>	-	0.09	0.05	-
Hermit crab	<i>Pagurus bernardus</i>	0.9	0.82	0.86	1.52
Harbour crab	<i>Liocarcinus depurator</i>	0.9	0.82	0.86	0.95
Edible crab	<i>Cancer pagurus</i>	0.9	4.82	2.95	-
Great spider crab	<i>Hyas araneus</i>	0.2	0.09	0.14	0.10
<i>Fish</i>					
Cod	<i>Gadus morhua</i>	0.3	0.18	0.24	-
Juvenile codfish	<i>Gadidae</i>	0.3	0.09	0.19	-
Pipefish	<i>Nerophis</i> spp.	-	0.09	0.05	-
Bullrout	<i>Cottidae</i>	0.1	0.09	0.10	-
Goldsinny wrasse	<i>Ctenolabrus rupestris</i>	0.1	0.09	0.10	-
Rock gunnel	<i>Pholis gunnellus</i>	0.1	0.18	0.14	-
Sand goby	<i>Pomatoschistus minutus</i>	0.2	-	0.10	0.10
Dragonet	<i>Callionymus</i> spp.	0.1	0.18	0.14	0.38
Flatfish	<i>Pleuronectidae</i>	0.2	-	0.10	0.10

Table 2. Total abundance of echinoderms, decapods, and fish recorded on foundations with holes, in the upper holes, and in the bottom holes.

Taxa	Foundations with holes		
	On foundations	Side holes	Bottom holes
<i>Echinoderms</i>			
Spiny seastar	2	-	-
Common starfish	1	-	-
Sand star	-	-	-
<i>Decapods</i>			
Norwegian lobster	-	-	1
European lobster	-	-	1
Hermit crab	8	-	1
Harbour crab	6	-	3
Edible crab	3	33	17
Great spider crab	1	-	-
<i>Fish</i>			
Cod	-	-	2
Juvenile codfish	1	-	-
Pipefish	1	-	-
Bullrout	-	-	1
Goldsinny wrasse	1	-	-
Rock gunnel	1	-	1
Sand goby	-	-	-
Dragonet	2	-	-
Flatfish	-	-	-













