Effects from wave power generators on the distribution of two sea pen species on the Swedish west coast

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Abstract — **Global electricity demand doubled between 1990 and 2016 and several countries are planning for a significant increase in offshore renewable energies along the European coast. In 2015 renewable energy accounted for more than half of the new generating capacity installed in the power sector worldwide. These activities bring up an increased interest about possible environmental impacts or additional values of the new technologies. The Wave Energy Park "Sotenäs Project" is located on the west coast of Sweden, 120 km north of Gothenburg, and was the site for environmental impact studies from wave energy generators on two sea pen species, *Virgularia mirabilis* (Müller, 1776) and *Pennatula phosphorea* (Linnaeus, 1758). Sea pens and burrowing mega fauna communities are designated threatened or declining habitats or species by the OSPAR convention. Investigations of those taxa in relation to marine renewable energies are thereby both interesting and important. A ROV aided seabed survey in the wave power park and respective control areas were primarily conducted to assess *Nephrops norvegicus* (Linnaeus, 1758) abundance and video footages were used to compare the abundance of the two sea pen species within the same area. Preliminary results show a significant difference between the transects and years. However, a clear increased number of individuals inside the wave power park for the two sea pen species compared to the control transects were not identified. Long-term observations and complementary studies are necessary in order to draw firm conclusions.**

Keywords— **Environmental Studies, Marine Renewable Energy, Sea Pens, *Pennatula phosphorea*, *Virgularia mirabilis*, ROV Survey, Wave power**

I. Introduction

THE global electricity demand doubled between 1990 and 2016 [1]. European countries aim to partly fill this gap by a significant increase in offshore renewable energies along the European coast. To date, windpower is the dominant offshore technology. It represents the biggest part of renewable electricity production but other technologies such as wave and tidal power are increasing. Increased offshore activities also raise the pressure on the marine environment and thereby increase the interest in environmental impacts or additional values of the new technologies [2].

Offshore renewable energy technologies are often deployed on soft bottom habitats and thereby soft seabed habitat is lost. However, most of the offshore renewable energy sites are restricted for marine activities after the deployment phase, during the operational phase. The sites often reflect a so called “marine protected area” where fishing and other activities are restricted. This can be beneficial for adjacent fauna.

Sea pens are heavily affected by physical disturbance such as fishing especially trawling due to their sedentary lifestyle with the exposure on the sea bed [3]. They play an important ecological role by adding structural complexity to a homogeneous habitat. They provide shelter, substrate, are parasitized and provide feeding ground for other species such as benthic invertebrates and small planktonic species and thereby help increase the biodiversity [4]–[6].

Their important ecological role and the vulnerability of pennatulaceans to human activities have led to the classification of sea pen forests as essential fish habitats, habitats for invertebrates and vulnerable marine ecosystems [7]. Sea pens and burrowing megafauna communities have also been classified as threatened and declining habitats by the OSPAR convention [8]. As the majority of the sea pen species and burrowing megafauna communities belong to non-economical species, less attention is paid to assessments of distribution and often fundamental information on their ecology is lacking [6], [9]. Non-destructive survey tools such as under water imagery from remotely operated vehicles (ROVs) and towed sledges can be used to provide a better understanding of the distribution of sea pens and to establish in situ monitoring [10], [11]. These methods can also be used to assess the sea pen fauna around wave power generators.

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Several studies have shown that restrictions in marine activities such as restriction in fishing in offshore renewable energy parks after finalising the deployment can have positive influence on biodiversity and abundance of species [12], [13], [14], [15], [16].

So far, there is no study on the effects of wave power generators or other offshore renewable energy devices and the possible concomitant effects due to restriction in marine activities on sea pens. The aim of this study is to investigate the distribution and abundance of two sea pen species *Pennatula phosphorea* and *Virgularia mirabilis* around wave energy generators at the Swedish west coast using the ROV video footage from the *Nephrops norvegicus* assessment survey [17] around wave energy generators and to reveal possible effects on their distribution and abundance.

II. Materials and Methods

A. Study site

The wave power park "the Sotenäs Project" started as a joint project between the developer company Seabased, the utility company Fortum and the Swedish Energy Agency. The park is situated on the Swedish west coast, about 120 km north of Gothenburg, near the municipality of Smögen (Fig. 1.). The site is located approximately 5 km

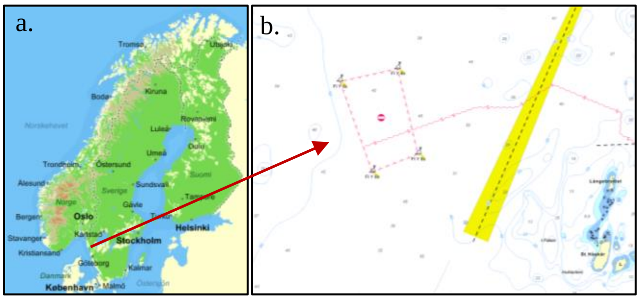

Fig. 1. a. Location of the study area "the Sotenäs project" on the west coast of Sweden; b. sea chart with the wave power area and outgoing underwater cable.

offshore with a depth of 50 m. Since 2014 and 2015 a total of 36 gravity based linear generators were deployed. Each generator foundation has a 6 m side length and covers an area of 36 m^2. Fishing and boat traffic in general is prohibited in the approximately 0,8 km^2 wave power park (approximate GPS coordinates: north west 58° 23' 14.8" N, 11° 7' 42.8" E, north east 58° 23' 20.3" N, 11° 8' 27.9" E, south west 58° 22' 37.7" N, 11° 8' 7.8" E, south east 58° 22' 45.3" N, 11° 8' 43.6" E). The site has a homogeneous flat muddy seabed with little relief and rocky slopes characterize the nearby shoreline of islands. The area is exposed to predominantly westerly winds and waves. The Lysekil research site is relatively sheltered with a wave climate of 2.6+0.3 kW/m and with a low tidal range of max. 0,3 m [18], [19]. Water surface temperatures range from 15°C - 20°C in summer and around 0°C - 2°C in winter [20]. Salinity in the area is on average 25 ‰ [20].

B. Species of interest

Sea pens or pennatulaceans belong to the phylum Cnidaria, Order Pennatulacea and are colonial marine octocorals. They have a generally feather-like appearance with a modified axial polyp which forms the stem. This supports the secondary polyps. At the bottom of the modified axial polyp there is a bulb shaped peduncle that is anchoring the sea pen to the sediment [9]. Gorgonians but also sea pens are known to be associated with planktonic and benthic invertebrate fauna and to provide shelter, substrate, feeding and nursery ground [4], [5], [21]. This study focus on the two sea pen species *Pennatula phosphorea* and *Virgularia mirabilis* which are present at the *Nephrops norvegicus* ground at the Swedish west coast.

Pennatula phosphorea can grow up to 40 cm in length (including the peduncle), with only around half of this protruding above the sediment (Fig. 2. a.). The axial polyp is firm and fleshy and contains red sclerites, which give it its red colour and also the Latin name [9]. It can retract to some extent into the sediment and has been recorded in sandy or muddy sediments between 15 m and 100 m depth [9].

Virgularia mirabilis is a long and slender sea pen, up to 60 cm in length and usually off-white to beige in colour (Fig. 2. b.) [9]. The polyps form clusters of 3–8 in two opposing rows on the rachis. This species of sea pen has a highly muscular peduncle allowing it to burrow and retract completely into the sediment. It is therefore thought to be less susceptible to damage from physical disturbance [9].

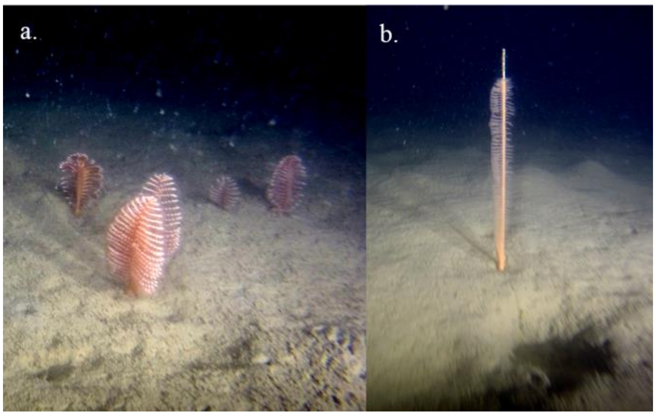

Fig. 2. Photograph of the two sea pen species during the ROV survey 2017: a. *Pennatula phosphorea*; b. *Virgularia mirabilis*.

C. Survey method

During 1st June 2016 and 5th July 2017 respectively, ROV recordings of the seabed were conducted in the wave power park "Sotenäs Project" and suitable control areas east and west of the park. In 2017, the survey had to take place one month later than anticipated due to choppy sea and the requirement of particular calm sea conditions to use the ROV. The survey material was primarily made to assess the Norway lobster community [17] but could be suitable to assess burrowing megafauna such as the sea pens. Underwater Television (UWTV) surveys are suitable for studying benthic habitat and Norway lobster stocks but also sea pen fauna [9], [22]–[24]. The task of an UWTV benthos survey is relatively simple compared to pelagic

Fig. 3. ROV V4ST, attached with grabber, laser pointer, GoPro camera, high-resolution camera and tether.

surveys, which attempt to track relative abundance of highly mobile species in three dimensions often with variable performance of sampling gears [22]. The survey procedure was modified as further described. The ROV V4ST (Fig. 3.) was equipped with a high definition camera system and two additional light sources, two laser pointers, 10 cm apart, attached to either side of the grappler for size estimation of scanned seabed width. ROV recordings were conducted at a constant speed within each transect, see Table I.

Three seabed transects were recorded each year (2016, 2017). All three survey transects (inside the wave power

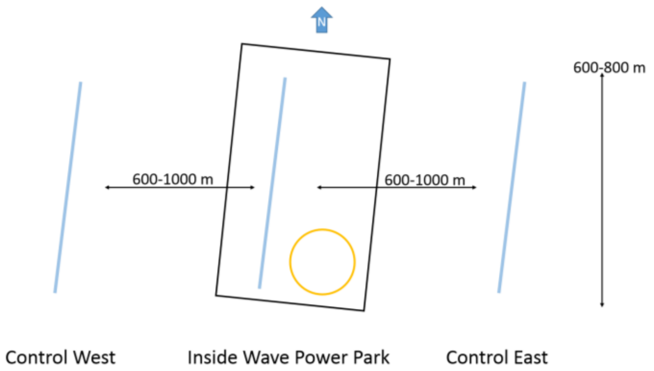

Fig. 4. Schematic of the experimental set up (not in scale). The black rectangular represents the wave power park, prohibited for boat traffic and the yellow circle displays the position of the 36 wave power generators in the park area. The three light blue lines show the three transects (inside the wave power park, IWP, control west, CW and control east, CE) of the ROV survey in both years 2016 & 2017. Black arrows give dimensions for transect lengths and distances.

park, IWP, control east, CE, and control west, CW) were in parallel and in a north - south orientation. The distance between the transects were between 600 m - 1000 m in both years. The total lengths of the transects varied between 600 m - 800 m in 2016 and 2017 (Fig. 4). Due to quality differences of the recorded material such as far distance from the sea floor, high turbidity or too fast driving of the ROV, the useable video material length of the transect resulted in 470 m IWP, 638 m in the CW and 506 m in the CE. Transect length for both years was adjusted including associated numbers of sea pens for comparison between the years within one transect. Amount of excluded material from analyses due to bad quality of the video represent the difference of transect length total and analysed in Table I.

The width of the recorded seabed area was ca. 0,3 m which results in a total analysed area of ca. 150 m² inside the wave power park, ca. 210 m² in the control west and ca. 180 m² in the control east in 2016. In 2017 the area inside the wave power park was ca. 150 m², ca. 190 m² in the control west and ca. 150 m² in the control east in 2017. The exact survey information on the transects are summarised in Table I.

TABLE I

INFORMATION ON TRANSECT LENGTH, AREA, SURVEY TIME AND THE MEAN ROV SPEED DURING THE SURVEY OF THE THREE DIFFERENT SITES (CONTROL WEST: CW, CONTROL EAST: CE, INSIDE WAVE PARK: IWP) AND BOTH YEARS, 2016 AND 2017

Transect Location		CW		IWP		CE	
Sampling Year		2016	2017	2016	2017	2016	2017
Transect length (m)	total	819	751	569	568	640	567
	analysed	638	638	470	470	506	506
Area m² (transect length x 0,3 m)	analysed	191	191	141	141	151	151
Time (sec)	total	6848	1845	6980	2461	6016	3700
	analysed	5317	1556	5875	2043	4600	3373
Mean ROV speed (m/sec)	total	0,120	0,410	0,08	0,230	0,110	0,150

D. *Data analyses*

All video material was viewed and individual sea pens were counted manually. Video material was recorded in 10 minutes sections and was viewed minute by minute with several repetitions in order to increase accuracy. Sequences of bad quality, too far distance from the seabed and high turbidity were excluded from the analyses. Sea pen community for the three transects was evaluated using the PRIMER v.6.0 software. The analysis was carried out using square-root-transformed data. Community patterns were assessed using non-metric multidimensional scaling ordination (MDS) based on a similarity matrix using Bray–Curtis coefficient. A two-way crossed analysis of similarity (ANOSIM) was performed to determine if there were any effects of site and year on the sea pen community structure. The Similarities Percentages procedure (SIMPER) of square-root transformed data was used to determine the contributions from individual species to the Bray–Curtis dissimilarities between sites and years.

III. Results

The number of individuals for both sea pen species of the ROV survey analyses from 2016 and 2017 are summarized in Table II.

TABLE II
NUMBER OF SEA PENS, *PENNATULA PHOSPHOREA* AND *VIRGULARIA MIRABILIS*, PER TRANSECT AND M² IN 2016 AND 2017

Transect Location		CW		IWP		CE	
Sampling Year		2016	2017	2016	2017	2016	2017
Number of *Pennatula phosphorea*	total	68	444	195	620	30	46
	per m²	0,34	2,36	1,34	5,2	0,17	0,28
Number of *Virgularia mirabilis*	total	85	206	17	77	28	25
	per m²	0,39	1,1	0,12	0,57	0,16	0,15

Pennatula phosphorea

The average number of sea pens per m² in 2016 inside the wave power area was 1,34 per m² for *Pennatula phosphorea*, in the control area west 0,34 per m² and in the control area east in 0,17 per m². In 2017 estimated average number of sea pens was 5,1 per m², in the control area west 2,36 per m² and in the control area east in 0,28 per m². The results are shown in Fig. 5. In 2016 the seabed inside the wave power area had approximately 1,34 *Pennatula phosphorea* per m² the highest amount, followed by the control west with 0,34 per m². The control site east showed with 0,17 individuals per m², the lowest number. In 2017 the picture was similar. The highest amount of *Pennatula phosphorea*, with 5,2 per m², was also found inside the wave power park area. Followed by the control west with 2,36 individuals per m². The lowest number was found in the control east with 0,28 per m². The number of *Pennatula phosphorea* per m² was generally higher in 2017 compared to 2016 with the exception of the control east.

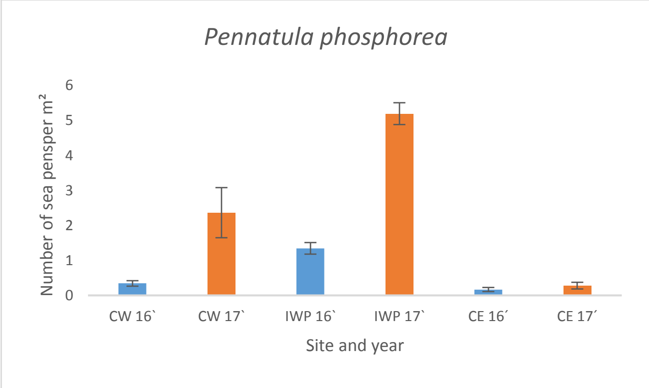

Fig. 5. Mean abundance per m² (±SE) of the sea pen specie *Pennatula phosphorea* per m² for the three transects inside the wave power park, IWP, and the two control areas east, CE, and west, CW, and the two years 2016 & 2017.

Virgularia mirabilis

The average number of sea pens per m² inside the wave power area was 0,12 per m² for *Virgularia mirabilis*, for the control area west 0,39 per m² and in the control area east 0,16 per m² in 2016. In 2017 the estimated average number of sea pens was 0,57 per m², in the control area west 1,1 per m² and in the control area east 0,15 per m² for *Virgularia mirabilis*, shown in a bar chart (Fig. 6.). In 2016 the seabed in the control area west had approximately 0,39 individuals per m² the highest amount, followed by the control east with 0,16 *Virgularia mirabilis* per m². The sea bed inside the wave power park showed with 0,12 *Virgularia mirabilis* per m² the lowest number. In 2017 the picture was similar. The highest amount of *Virgularia mirabilis* with 1,1 per m² was found in the control west. Followed by the area inside the wave power park with 0,57 individuals per m². The lowest number was found in the control east with 0,15 *Virgularia mirabilis* per m². The number of *Virgularia mirabilis* per m² was higher in 2017 compared to 2016 with the exception of the control east similar to the results of the *Pennatula phosphorea*.

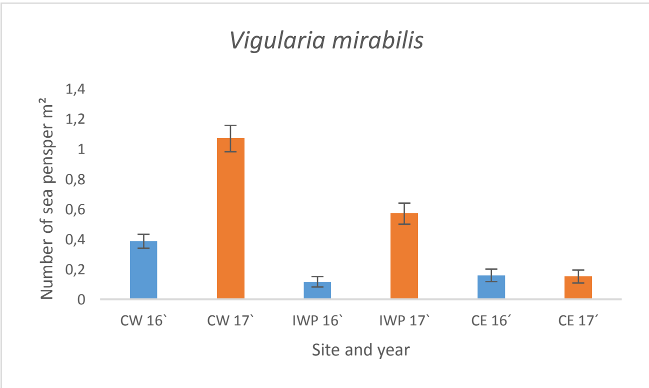

Fig. 6. Mean abundance per m² (±SE) of the sea pen species *Virgularia mirabilis* for the three transects inside the wave power park, IWP, and the two control areas east, CE, and west, CW, and the two years 2016 & 2017.

ANOSIM & MDS

The two-way crossed ANOSIM showed a significant difference between sites, Global R = 0,642 (P = 0,001) and years, Global R = 0,576 (P = 0,001). Furthermore, the ordination through NMDS revealed separation of the samples for the different sites (Fig. 7).

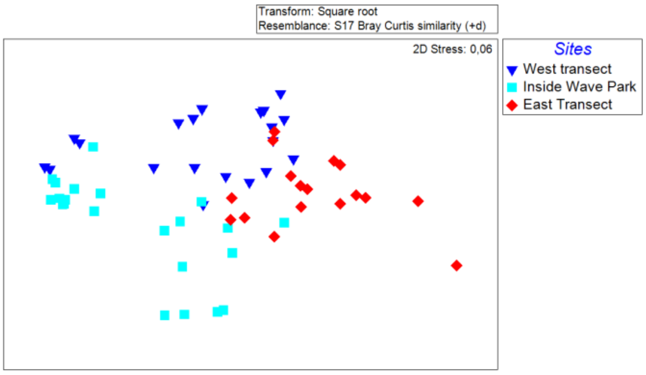

Fig. 7. Two-dimensional non-metric multidimensional scaling (NMDS) ordination of sea pens abundance at the three different sampling sites.

Pairwise tests show, however, that site west and east are not as well separated (Global R = 0,49, though still extreme with 999 permutations considered from the possible permutations very large, thus p > 0,001 again) as the sites inside and east (R = 0,842) and inside and west (R = 0,602), see Table III. This can also be seen in the MDS plot Fig. 7.

TABLE III
SUMMARY OF ANOSIM RESULTS FOR DIFFERENCES BETWEEN GROUPS AND YEARS (P < 0,001 FOR ALL TESTS)

Test	R statistic
Global for sites	0,642
IWP, CW	0,602
IWP, CE	0,842
CW, CE	0,49
Global for Year	0,57

SIMPER

As an effect of site and year was indicated by the ANOSIM a SIPMER analyses was performed.The SIMPER analysis identified the species that typified levels of each factor (Table IV) and the species that were most responsible for distinctions between factor levels (Table V). The average similarity was 80,64 % for the site group west, 86,47 % for the site group inside wave park, and 63,02% for the site group east. The average dissimilarity was 33,16 % between the site groups west and inside wave park, 40,57 % between the site groups east and inside wave park, and 53,33 % between the site groups east and west. The average similarity was 80,16 % for year group 2017 and 77,51 % for the year group 2017. The average dissimilarity between both year groups was 35,99 %. *Pennatula phosphorea* contributed the most to within-group similarity and between-group dissimilarities with the exception for within-group similarity for site group east and west where *Virgulaia mirabilis* had a higher contribution.

TABLE IV
SUMMARY OF SIMPER RESULTS. AVERAGE ABUNDANCE (% COVER) OF TYPIFYING SEA PEN SPECIES IN EACH SITE AND YEAR GROUP, THEIR CONTRIBUTION (%) TO THE WITHIN GROUP SIMILARITY (90% CUT-OFF)

	Abundance	Contribution
Site IWP		
P. phosphorea	1,68	82,21
V. mirabilis	0,5	17,79
Site CW		
V. mirabilis	0,84	56,92
P. phosphorea	0,93	43,08
Site CE		
V. mirabilis	0,36	51,98
P. phosphorea	0,42	48,02
Year 2016		
P. pennatula	0,7	62,87
V. mirabilis	0,43	37,13
Year 2017		
P. phosphorea	1,41	61,01
V. mirabilis	0,72	38,99

TABLE V
SUMMARY OF SIMPER RESULTS. AVERAGE ABUNDANCE (% COVER) OF DISCRIMINATING SEA PEN SPECIES IN EACH SITE AND YEAR GROUP, THEIR CONTRIBUTION (%) TO THE DISSIMILARITY BETWEEN GROUPS (90% CUT-OFF)

	Abundance		Contribution
Site	IWP	CW	
P. pennatula	1,68	0,93	66,63
V. mirabilis	0,5	0,84	33,37
Site	IWP	CE	
P. pennatula	1,68	0,42	79,06
V. mirabilis	0,5	0,36	20,94
Site	CW	CE	
P. pennatula	0,93	0,42	51,54
V. mirabilis	0,84	0,36	48,46
Year	2016	2017	
P. pennatula	0,7	1,14	67,23
V. mirabilis	0,43	0,72	32,77

IV. DISCUSSION

In 2014 and 2015, 36 generators were deployed 5 km offshore the Swedish west coast close to the municipality of Smögen, around 120 km north of Gothenburg. This study primarily aimed to use the ROV video footage for *Nephrops norvegicus* burrow estimation in the wave power park and two control areas but is also suitable to investigate the distribution of two sea pen species in the three transects. Restrictions in marine activities such as fishing could be beneficial for the burrowing megafauna species *P. phosphorea* and *V. mirabilis*. Preliminary results show a significant difference between the transects and years. However, a clear reason for higher number of individuals inside the wave power park for the two sea pen species compared to the control transects are not identified.

Withdrawal behaviour of sea pens

Both sea pen species investigated in this survey are capable to withdrawal in a tube into the soft bottom. This behaviour is known from many sea pen species and for the two investigated species particularly pronounced for *V. mirabilis*. *V. mirabilis* can show rapid withdrawal behaviour with strong physical disturbance. This gives rise to considerable uncertainties in estimates of their true abundance [25]. Relatively slow speed of the ROV and the use of lamps for seabed scanning could contribute for an increased withdrawal behaviour of sea pens and thereby be invisible on the video. However, sea pens which were passed closely by the ROV and apparently touched by the ROV did not show fast withdrawal behaviour.

Fishing pressure and violations

Fishing pressure in the study area varies from year to year. Personal communication with the staff at the Swedish Agency for Marine and Water Management informed about 12,3 % lower catch rates of the Norway lobster from year 2016-2017 in the close vicinity of the study area. This lower fishing pressure might also have a direct effect on the numbers of sea pens. Sea pens are known to be vulnerable to physical disturbance such as fishing activities and could thereby be an explanation for higher numbers of sea pens. Sea pens and other marine benthic organisms are highly affected by fishing activities, especially trawling. Bottom trawling in general reduces habitat complexity, alters benthic communities, reduces benthic productivity, and most strongly affects fauna that live in regimes of low natural disturbance, especially soft-bodied, erect, sessile organisms such as sea pens inhabiting stable seafloors [26]. The gear used for beam trawl has been reported to kill between 5–65 % of the resident fauna and additional mix the top centimetres of the sediment [27]. Due to restricted marine activities in the wave power area number of individuals were expected to be higher inside the wave power park compared to the control areas. The results do not show this assumption for neither of the sea pens investigated. However, violation of the fishing ban in the area is not uncommon (personal communications with local fisherman). This might have lowered the effect expected by the "protected area".

Sea pens are slow growing

Sea pens are stationary, late mature, long-lived and slow growing animals [3], [26]. The rapid and high increase in number of individuals for some transects from year 2016 to year 2017 cannot be explained by sudden recruitment events between the two years. One explanation can be an inaccuracy in video analyses due to higher speed of the ROV in 2017 compared to 2016, or the previous mentioned withdrawal behaviour. The scanned transects are comparable, but working in a depth of 50 m, transects can be easily shifted by several meters. However, increased number of *N. norvegicus* burrows in 2017 compared to 2016 are also noted [17]. The difference in time between the beginning of the "Sotenäs Project" with first deployments in 2014 and the first ROV survey in 2016 was 3-4 years. The time to detect changes in community structure, recovery from long lasting fishing pressure, to reach a so called stable state or individuals to grow bigger is slow [28]. This can be an additional explanation for low numbers of individuals in 2016 and higher numbers in 2017. However, this does not explain the sudden high numbers of individuals in the control area west in 2017 when we consider the main effect to come from the no take zone.

Habitat

The choice of control transects was done in order to have comparable benthic conditions such as similar depth, substrate composition and adequate distance between the three transects. But habitat patchiness can always occur and influence the results. This can be an explanation for the generally lower number of both sea pen species in the control east. During the analyses of the video a hard bottom section, with typical adjacent fauna such as sea anemones, sea squirt and dead man's fingers occurred in a small area inside the wave power park. This section was excluded from the analyses. Small scale hard bottom patches might be found in the vicinity of the transects but do not appear in the video. This can locally change the composition of the soft bottom fauna and thereby further influence the results.

The installation of hundreds or more wave power devices on soft bottom habitat might reduce the amount of suitable habitat for burrowing megafauna such as the sea pen species investigated here. However, wave power has still not reached commercialization phase and parks in the previous mentioned dimension do not exist. The wave power park "Sotenäs project" covers a total of 800.000 m^2. Until now, 36 generators are deployed at the site. Each generator has a gravity based concrete foundation with 6 m side length and an area of 36 m^2. A total area of ca. 1300 m^2 is covered by concrete foundations which reflects 0,16 % of the dedicated wave power park area of the "Sotenäs Project". This is a very small part and the loss of habitat due to concrete foundations is thought to be outweigh by the protected area with restriction for any marine activities. Future increase in numbers of generators, covered sea bed area by foundations and thereby habitat loss for soft bottom species might influence or alter the results. Rough calculations on sea bed coverage by wave power generators in the "Sotenäs Project" and their foundations during a maximal degree of capacity utilization would still only result in a habitat loss of under 2 %. Hydrodynamic and safety reasons require a certain distance between the devices. Several examples of the past have shown, that simple upscaling the effects do not reflect the reality and further investigations are necessary.

V. Conclusion

ROV video surveys have shown to be suitable to assess the sea pen communities in and around wave power parks or seabed in general. However, numbers of individuals can be biased by withdrawal behaviour, habitat patchiness, video quality and, fishing pressure and violation of fishing ban in designated areas. Neither the presence of the wave power generators nor the restrictions for marine activities seem to have a noticeable effect on the two investigated sea pen species. Rather, year to year and natural variation may have higher influence.

The growth of wave power parks in the future to a larger scale and thereby larger covered area by foundations and habitat loss for soft bottom species might affect the results. However, the created "marine protected area" could balance the habitat loss. Simple linear upscaling of the effects from single devices to parks and arrays is not possible and further investigations and long term studies are thus necessary and required [28].

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