Effects of Wave Energy Generators on *Nephrops norvegicus*

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***Abstract*— Wave energy research is primarily focused on the technical developments of energy conversion but the parallel evaluation of environmental effects related to wave energy is also essential and reflects sustainable development of renewable energy. At the west coast of Sweden, 120 km north of Gothenburg, the Wave Energy Park "Sotenäs Project" is located. This area has been the location of environmental impact studies from wave energy generators on the macro crustacean species *Nephrops norvegicus* (Linnaeus, 1758), the Norway lobster. The Norway lobster is an ecologically as well as economically important species in Sweden and across Europe. The aim of this preliminary study was to detect possible positive or negative effects on numbers of individuals by the presence of the wave energy generators and the created "no take" zone. For that purpose, ROV aided seabed recordings of the characteristic Norway lobster burrow entrances were conducted inside the Wave Energy Park and respective control areas in 2016 and 2017. Preliminary results do not show a clear distinct result between the different transects and years. Long-term observations and complementary studies are necessary to draw conclusions and outweigh extreme and rare events of annual one-time samplings.**

***Keywords*— Wave power, Norway lobster, ROV, Environmental studies, Marine renewable energy**

I. Introduction

For early stage marine renewable energy projects such as point absorber wave power generators, the level of uncertainty in understanding environmental impacts results in the need for environmental assessment [1]. Beside legal requirements, early environmental investigations enable chance for mitigation [2]. At the Swedish west coast, the "Sotenäs Project" was initiated in 2011 and resulted in a deployment of 36 point absorber wave power generators in 2014 and 2015. Environmental assessments like benthos investigations were started. This study focused on the economically as well as ecologically interesting macro crustacean species *Nephrops norvegicus*, known as the Norway lobster. Benthic habitat conditions of the Sotenäs site with an average depth of 50 m, about 5 km offshore and past glacial muddy sediments represents a suitable habitat for the Norway lobster. The species distribution ranges from the Northeast Atlantic to the Mediterranean Sea [3]. Characteristic burrows are excavated in muddy sediments ranging from 20 m - 800 m depth and can have several entrances [4].

Counting the entrances of those characteristic burrows is a common method in Norway lobster fisheries stock assessments to determine the number of individuals and compare the presence of individuals within different fishing areas and for different populations [5]. A common method using towed sledges equipped with high-resolution camera systems to record the seabed are utilised to count Norway lobster burrow entrances and thus stock estimating according to numbers of burrows.

We adapted a similar method using a ROV for the purpose of monitoring Norway lobster in the wave energy park "Sotenäs Project". The aim of the ROV survey was to investigate possible differences and changes in numbers of burrows and thus numbers of individuals inside the wave power park and in relation to appropriate control areas.

The ROV survey has been so far conducted for two years and will continue in line with a long term environmental monitoring study to detect possible changes over time and minimize the outweigh of extreme and rare events of one day per year sampling.

II. Materials and Methods

A. Study site

The wave power park "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 Smögen and Kungshamn (Fig. 1). The site is located approximately 5 km offshore with a depth of 50 m. Since 2014 and 2015 a total of 36 gravity based linear generators were deployed at site. Fishing boats and boat traffic in general is prohibited in the approximately 0,8 km^2 wave power park (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 with a low tidal range of max. 0,3 m [6]. Water surface temperatures range from 15°C - 20°C in summer month and around 0°C - 2°C in winter month [7]. Average salinity in the area is 25 ‰ [7].

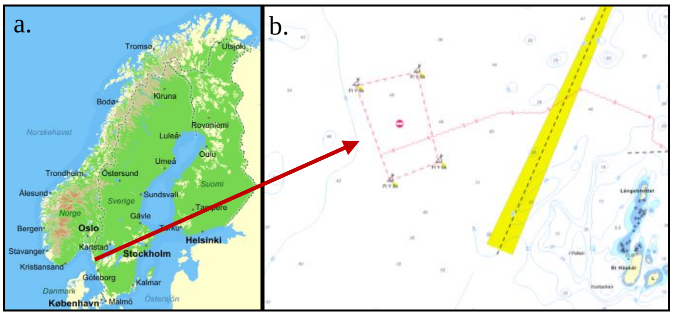

Fig. 1 a. Location of the wave power park "Sotenäs project" on the west coast of Sweden and 1 b. sea chart with the wave power park and outgoing underwater cable (modified after: https://kartor.eniro.se/)

B. *Species of interest, survey method and data analyses*

During 1st June 2016 and 5th July 2017 respectively ROV recordings of Norway lobster burrow entrances on the seabed were conducted in the wave power park "Sotenäs Project" and suitable control areas east and west of the park. Bad weather in 2017, choppy sea and the requirement of particular calm sea conditions to use the ROV, the survey had to take place one month later than anticipated.

1) Species of interest

Nephrops norvegicus (Fig. 2) is a macro crustacean species of special economic importance in Sweden and Europe [8], but also has ecological importance[4], [9]. It belongs to the order of Decapoda and to the family Nephropidae [10]. Its occurrence ranges from 20 m - 800 m depth but is limited to muddy habitat, and requires sediment with a silt and clay content of between 10 % - 100 % to excavate its burrows [10]. The Norway lobster has a rhythmic burrow emergence and spends a great part of time in their burrows [11]. Their activity behaviour is influenced by factors e.g. time of year and light intensity [12] or can be scheduled by other aspects such as currents in turbid or deep water [13]. The Norway lobster is a stationary and territorial species [14]. It does not migrate or move more than a few hundred meters over their lifespan from where it settles as juvenile lobster after its pelagic larval stage [15]. However, compared to the European lobster, *Homarus gammarus* (Linnaeus, 1758), little is known about the larval stages and development of the Norway lobster [16].

Fig. 2 *Nephrops norvegicus* during the measuring procedure of the cage fishing study for Norway lobster in the Wave Power Park "Sotenäs Project" and respective control areas (in preparation)

2) Survey method

Underwater Television (UWTV) surveys are ideal for studying benthic habitat and Norway lobster stocks [5], [9], [17]. The task of an UWTV benthos survey is relatively simple compared to pelagic surveys, which attempt to track relative abundance of highly mobile species in three dimensions often with variable performance of sampling gears [9].

The survey procedure was modified as follows described. The used ROV V4ST (Fig. 3) was equipped with a high definition camera system, two laser pointers attached aside the grappler for reference of scanned seabed width as well as two additional light sources. ROV recordings were conducted at a constant speed within each transect.

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

A total of three seabed transects were recorded in 2016 and 2017 respectively (Fig. 4). All three survey transects (inside the wave power park, control east and control west) 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. Due to quality differences of the recorded material, the useable video material length of the transect resulted in 499 m inside the wave power park, 710 m in the western control and 591 m in the eastern control in 2016. In 2017 in 508 m inside the wave power park, 634 m in the western control and 511 m in the eastern control.

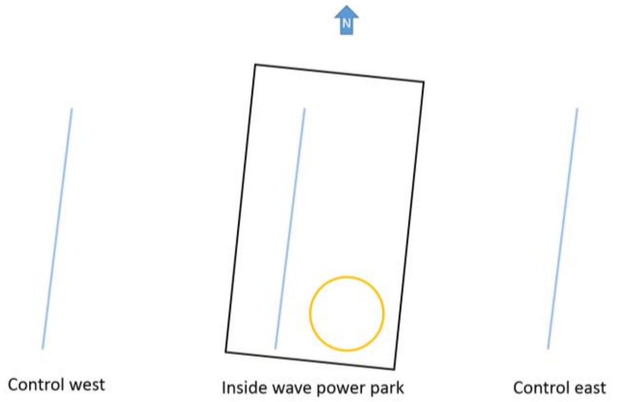

Fig. 4 Schematic of the experimental set up (not in scale). The black rectangular represents the wave power park, prohibited for boat traffic and the yellow circle displays the position of the 36 wave power generators in the park area. The three light blue lines show the three transects (inside the wave power park, control west and control east) of the ROV survey

The width of the recorded area was ca. 0,3 m which results in a total analysed area of ca. 150 m^2 inside the wave power park, ca. 213 m^2 in the control west and ca. 177 m^2 in the control east in 2016. In 2017 the area inside the wave power park was ca. 153 m^2, ca. 190 m^2 in the control west and ca. 153 m^2 in the control east in 2017. The survey information on the transects are summarised in Table I. However, the previous described ROV aided survey method could be also suitable to survey other benthic species such as se pens or others.

TABLE I
DETAILED INFORMATION ON TRANSECT LENGTH, AREA, TIME, MEAN SPEED AND NUMBER OF BURROWS OF THE ROV SURVEY CHARACTERISTICS FOR THE THREE DIFFERENT SITES AND BOTH YEARS, 2016 AND 2017

Transect Location		Control West		Inside Wave power Park		Control East	
Sampling Year		2016	2017	2016	2017	2016	2017
Transect length (m)	total	819	751	569	568	640	567
	analysed	710	634	499	508	591	511
Area m^2 (transect length x 0,3 m)	analysed	213	190	150	153	177	153
Time (sec)	total	6848	1845	6980	2461	6016	3700
	analysed	5909	1558	6190	2203	5431	3336
Mean ROV speed (m/sec)	total	0,120	0,410	0,080	0,230	0,110	0,150
Number of burrows	total	1207	2475	1372	2315	1245	806
	per m^2	5,66	13,01	9,17	15,18	7,02	5,26

3) Data analyses

All video material was viewed manually and all Norway lobster burrow entrances were counted according to Norway lobster burrow identification training of International Council for the Exploration of the Seas (ICES) [18], [19]. Video material was split 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. Mean number of burrow entrances (± SD) were calculated for each transect. Poisson analyses and 95 % confidence interval with two-sample Poisson rates were calculated for the following combinations and tested for significant differences using Minitab®. The following combinations were tested (2016: inside wave power park – control area west, inside wave power park – control area east and control area east – control area west. 2017: inside wave power park – control area west, inside wave power park – control area east and control area east – control area west and inside wave power park 2016 – inside wave power park 2017, control area west 2016 – control area west 2017, control area east 2016 – control area east 2017).

Figure 5 a. shows a sample image of the seabed recording 2017 in the control site west with an individual of a Norway lobster on the seabed and picture 5 b. shows a characteristic burrow entrance highlighted with a red circle.

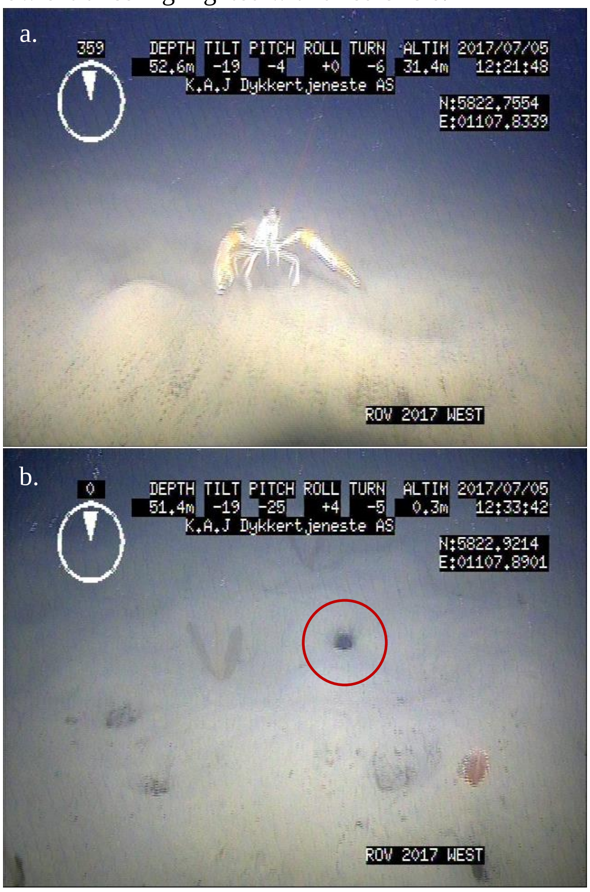

Fig. 5 Two sample pictures of seabed recordings during the ROV survey 2017; a. The Norway lobster walking on the seabed; b. characteristic burrow entrance highlighted with a red circle

III. Results

The average number of burrows per m^2 inside the wave power area was 9, in the control area west 6, and 7 in the control area east in 2016. In 2017 estimated average burrow entrances were 15 inside the wave power park, 16 in the control west and 5 in the control east. The results are visualized in a cluster chart (Fig. 6). In 2016 the seabed inside the wave power area had approximately 9 burrows per m^2 the highest amount, followed by the control east with 7 burrows per m^2. The control site west showed with 6 burrows per m^2 the lowest number. In 2017 the picture was different. In the control area west the number of burrow entrances was with 16 per m^2 highest, followed by the area inside the wave power park with 15 burrows per m^2 and lowest with 5 burrows per m^2 in the control east. The number of burrows per m^2 was higher in 2017 compared to 2016 with the exception of the control east.

A two sample Poisson rate analyses was performed with Minitab® in order to detect possible differences in number of burrow entrances between the years and the three transects.

Significant differences in number of burrow entrances were found between the transect control west 2016 and control west 2017 ($p < 0{,}001$) and furthermore between the two years 2016 and 2017 inside the wave power park ($p = 0{,}001$). The control area east did not show differences between the years ($p = 0{,}20$). Comparing the three areas within the year 2016, both controls east and west were significant different from the area inside the wave power park (control west $p = 0{,}001$; control east $p = 0{,}045$), but both controls did not differ in 2016 ($p = 0{,}33$). In 2017 the control west did not differ from the area inside the wave power park ($p = 0{,}89$). The control east was significant different from the control west ($p < 0{,}001$) as well as from the area inside the wave power park ($p < 0{,}001$).

When analysing each year independently a trend of higher numbers of burrow entrances inside the wave power area in 2016 can be seen but not in 2017. However, the variation between the two years was high (Fig. 6).

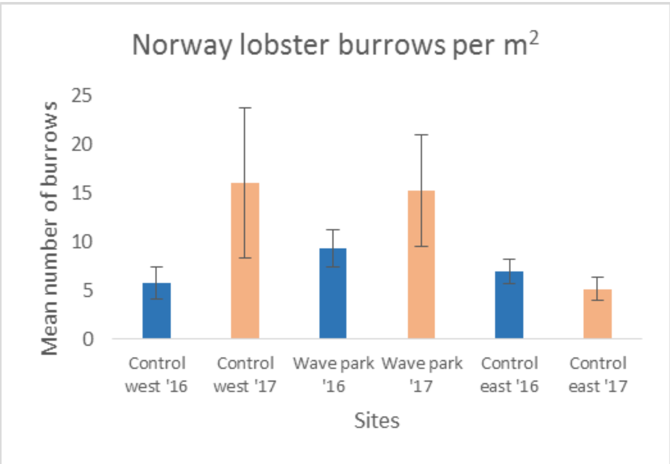

Fig. 6 Cluster chart with mean number of Norway lobster burrows per m^2 and the standard deviation (± SD) with a confidence interval of 95% for all three sites (inside wave park, control west and control east) sites and for both years 2016 (dark blue) and 2017 (light orange)

IV. Discussion

In 2014 and 2015, 36 wave power converters were deployed onto the seabed around 5 km offshore the Swedish west coast close to Smögen and Kungshamn. The study aim was to detect possible changes in numbers of Norway lobster burrow entrances and thereby individuals between the area inside the wave power park "Sotenäs Project" and the two control areas east and west over two different years.

Analysing the two ROV surveys conducted in June 2016 independent from the results of 2017, number of burrow entrances and following the number of individuals are highest inside the wave power park compared to the two control areas. The number of Norway lobster burrows per m^2 was the highest inside the wave power park compared to the two control areas. Looking at the survey results from 2017, highest number of burrows were found in the control west but very similar to the number of burrows inside the wave power park. No clear conclusions can be drawn.

In 2014 cable development and preparations of the wave power park begun and the park area offshore was prohibited for fishing and boats to pass. Parts of the surrounding areas are frequently trawled and cage fished for Norway lobster on a annual basis. Thereby the wave power area started to reflect a marine protected area, a "no take zone". Higher numbers of individuals inside the wave power park were assumed to be found. However, in personal communication with a local fisherman from the site reported about several occurred violations in the past of this requirement.

The Norway lobster is a stationary and territorial species [14]. The time difference 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 and make own burrows can be very different and longsome [20]. This can be one explanation for low numbers of individuals in 2016 and higher numbers in 2017. However, this does not explain the high numbers of individuals in the control area west in 2017 when we consider the main effect to come from the no take zone.

Sampling occurred on 1st of June in 2016 and on 5th of July in 2017. Due to harsh weather conditions during June 2017, the actual sampling had to take place one month later than planned and conducted during the previous year. The Norway lobster stays in the vicinity where it first settles as a juvenile [15]. However, activity levels due to reproduction change between summer and wintertime [21] and this shift might had happened before the sampling in 2017 occurred but not before the sampling in 2016.

The survey setup followed in both sampling years the same protocol and was conducted and analysed by the same personnel. Looking at the details of the survey in Table I, the investigated area size for the three transects are comparable. However, the analysed time and speed of the ROV surveys differ between the two years. In year 2017 the driving speed of the ROV was higher and the analysed time thereby less. This circumstance resulted in poorer video material quality in

2017. Analyses of the video material recorded in 2017 was more difficult, especially the video material from the control area west which was recorded with the highest ROV survey speed of all videos from both years. This can be an explanation of high numbers of burrows in the control west in 2017 where ambiguous cases might have be evaluated more often as a positive case.

Field studies provide enlightening and important results and help in revealing answers about ecological topics and questions. Nevertheless, interpreting the results can be hard since it is impossible to control and understand all processes especially in marine environment where natural variation can be high. The choice of the control areas was done in all conscience but even small changes of the areas of e.g. the seabed conditions can generate high variation in the results. According to discussion with local inhabitants, fishing pressure is different in the two control areas. The control area west of the wave power park was fished by trawlers and with cages. The control area east instead was only fished with cages and not by trawls.

All mentioned factors and probably many more are contributing to the result. To draw conclusions complementary methods such as cage fishing studies in the same areas (in preparation) and further investigations over a longer time span are necessary to validate and verify preliminary results.

V. Conclusions

ROV aided benthic surveys are suitable to investigate changes in numbers of Norway lobster burrows and thereby numbers of individuals, if survey conditions are suitable like low and consistent ROV speed, constant seabed distance of the camera and others. Thus, this is a valuable method to assess renewable energy production sites such as wave power parks for environmental impacts. The present study aims to provide indications on how an array of linear wave power generators as well as areas banned for fishing and boat traffic can enhance abundances of species such as the Norway lobster using ROV surveys. Prohibition of highly destructive fishing methods like trawling but also all other fishing methods for those distinct areas such as the wave power park shows an indication of higher numbers of individuals compared to respective control areas. Waver power foundations imply habitat loss for soft bottom species, but can also provide habitat enhancement of mobile and hard bottom fauna. Attraction of mobile species can occur due to reef effects [22], [23] and possibly thereby provide higher prey availability for soft bottom species such as the Norway lobster. Further studies on real net production and spill-over effects to surrounding areas are important [24]. Long-term investigations and complementary study methods are necessary to evaluate the impact and outweigh extreme and rare events.

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References

[1] G. Harker-klime, A. Copping, and S. Eaves, “Environmental Monitoring – From Theory to Practice,” no. Figure 2, pp. 1–9, 2017.

[2] A. Bender, F. G. A. Francisco, and J. Sundberg, “A Review of Methods and Models for Environmental Monitoring of Marine Renewable Energy,” pp. 1–10, 2017.

[3] F. Sardà, “A review (1967-1990) of some aspects of the life history of Nephrops norvegicus.,” *ICES Mar. Sci. Symp.*, vol. 199, pp. 78–88, 1995.

[4] M. P. Johnson, C. Lordan, and A. M. Power, “Habitat and Ecology of Nephrops norvegicus,” in *Advances in Marine Biology*, 1st ed., vol. 64, Elsevier Ltd., 2013, pp. 27–63.

[5] N. Campbell, H. Dobby, and N. Bailey, “Investigating and mitigating uncertainties in the assessment of Scottish Nephrops norvegicus populations using simulated underwater television data,” *ICES J. Mar. Sci.*, vol. 66, no. 4, pp. 646–655, 2009.

[6] K. Johannesson, “The bare zone of Swedish rocky shores: why is it there?,” *Nord. Soc. Oikos*, vol. 54, no. 1, pp. 77–86, 1989.

[7] P. Åberg, “Size-based demography of the seaweed *Ascophyllum nodosum* in stochastic environments,” *Ecology*, vol. 73, no. 4, pp. 1488–1501, 1992.

[8] F. Ziegler and D. Valentinsson, “Environmental life cycle assessment of Norway lobster (Nephrops norvegicus) caught along the Swedish west coast by creels and conventional trawls - LCA methodology with case study,” *Int. J. Life Cycle Assess.*, vol. 13, no. 6, pp. 487–497, 2008.

[9] “ICES: Workshop on the Use of UWTV Surveys for Determining Abundance in Nephrops Stocks throughout European Waters,” Heraklion, Crete, Greece, 2007.

[10] A. S. D. Farmer, “Synopsis of the biological data on the Norway lobster Nephrops norvegicus (Linnaeus, 1758),” 1975.

[11] V. Sbragaglia, F. Lamanna, A. M. Mat, G. Rotllant, S. Joly, V. Ketmaier, H. O. De La Iglesia, and J. Aguzzi, “Identification, characterization, and diel pattern of expression of canonical clock genes in Nephrops norvegicus (crustacea: Decapoda) eyestalk,” *PLoS One*, vol. 10, no. 11, pp. 1–17, 2015.

[12] C. Lordan, J. Doyle, R. Fitzgerald, S. O. Connor, D. Stokes, G. N. Chonchuir, and J. Gallagher, “FU19 Nephrops grounds 2015 UWTV survey report and catch options for 2016,” 2015.

[13] H. J. Wagner, K. Kemp, U. Mattheus, and I. G. Priede, “Rhythms at the bottom of the deep sea: Cyclic current flow changes and melatonin patterns in two species of demersal fish,” *Deep. Res. Part I Oceanogr. Res. Pap.*, vol. 54, no. 11, pp. 1944–1956, 2007.

[14] A. S. Farmer, “Nephrops norvegicus.,” *Mar. Biol.*, vol. 23, pp. 315–325, 1973.

[15] C. J. Chapman and A. L. Rice, “Some direct observations on the ecology and behaviour of the Norway lobster *Nephrops norvegicus*,” *Mar. Biol.*, vol. 10, pp. 321–329, 1971.

[16] U. T. C. All, “Early Life History and Recruitment Processes of Clawed Lobsters Author (s): J . Stanley Cobb and Richard A . Wahle Source : Crustaceana , Vol . 67 , No . 1 , Proceedings of the Fourth International Workshop on Lobster Biology and Management , 1993 (Jul,” vol. 67, no. 1, pp. 1–25, 2016.

[17] A. Ungfors, E. Bell, M. L. Johnson, D. Cowing, N. C. Dobson, R. Bublitz, and J. Sandell, “Nephrops Fisheries in European Waters,” in *Advances in Marine Biology*, 1st ed., vol. 64, Elsevier Ltd., 2013, pp. 247–314.

[18] D. June, J. Elson, C. Jim, and A. Umbsm, “2009 FU 17 Nephrops

Burrow Identification Training Course," Galway; Ireland, 2009.
[19] "ICES: Report of the Workshop and training course on Nephrops burrow identification," 2008.
[20] B. S. Halpern, "The Impact of Marine Reserves : Do Reserves Work and Does Reserve Size Matter," *Soc. Ecol. Appl. Ecol.*, vol. 13, no. 1, 2010.
[21] A. Powell and S. P. Eriksson, "Reproduction: Life Cycle, Larvae and Larviculture.," in *Advances in Marine Biology*, 1st ed., vol. 64, Elsevier Ltd., 2013, pp. 201–245.
[22] O. Langhamer, H. Holand, and G. Rosenqvist, "Effects of an offshore wind farm (OWF) on the common shore crab Carcinus maenas : Tagging pilot experiments in the Lillgrund offshore wind farm (Sweden)," *PLoS One*, vol. 11, no. 10, pp. 1–22, 2016.
[23] O. Langhamer, D. Wilhelmsson, and J. Engström, "Artificial reef effect and fouling impacts on offshore wave power foundations and buoys – a pilot study," *Estuar. Coast. Shelf Sci.*, vol. 82, no. 3, pp. 426–432, 2009.
[24] B. Sainte-Marie, M. G. Hoskin, R. A. Coleman, E. von Carlshausen, and C. M. Davis, "Variable population responses by large decapod crustaceans to the establishment of a temperate marine no-take zone," *Can. J. Fish. Aquat. Sci.*, vol. 68, no. 2, pp. 185–200, 2011.