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Influence of Offshore Wind Farm on Shore Crab *Carcinus maenas* Population Dynamics

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Abstract

Many governments have initiated programs of energy production from renewable sources in response to climate changes induced by gases from burning fossil fuels. Use of wind energy is considered a sustainable way of reducing the carbon emission, and offshore wind power generation capacity is expected to grow significantly as the world is trying to make a transition to a lower carbon economy. Though the advantages of renewable energy on a global scale are not in doubt, the effects on the local environment must also be carefully considered. The aim of this study was to investigate the influence of offshore windfarm on shore crab (*Carcinus maenas*) population dynamics. Data were collected in the Öresund strait in Southern Sweden at Lillgrund offshore windfarm and in two adjacent control areas, Sjollen and Bredgrund. The mark-recapture method was applied to make population size estimation, and the catch per unit effort index was calculated as a measure of abundance. Data on catch per unit effort were also calculated for 8 previous years with data collected from earlier studies in the areas. In addition, size, sex ratio, condition and color were recorded. Due to few recaptures, reliable population size estimations could not be achieved. The population of shore crab within the windfarm was found to be significantly more abundant than those in the control areas in 2012. However, analysis of catch per unit effort in a long term perspective of 10 years, show no effect of the offshore windfarm on shore crab abundance. There was not found any effect of the presence of wind farm on shore crabs regarding size, sex ratio, condition or color.

Sammendrag

Klimaendringer forårsaket av utslipp av drivhusgasser fra forbrenning av fossile brenselskilder, har ført til at flere regjeringer tatt initiativ til program for produksjon av energy fra fornybare kilder. Vindkraft er ansett som en bærekraftig måte å redusere utslipp av karbon, og i takt med en overgang til et lavere karbonutslipp, er det forventet at kapasiteten til offshore vindenergi produksjon vil vokse betydelig. Selv om fordelene av en omlegging til fornybare kilder er utvilsomme på en global skala, må effekter av fornybare energikilder på det lokale miljøet også tas hensyn til. Målet ved dette studiet var å studere effektene av offshore vindkraft på populasjonsdynamikken til strandkrabbe, *Carcinus maneas*. Datainnsamling ble utført i Ösresund, Sør Sverige i Lillgrund offshore vindpark og i nærliggende kontrollområder, Sjollen og Bredgrund. For å kunne gjøre et populasjonsestimat ble fangst-gjenfangst metoden benyttet, og fangst per enhet innsats indeksen ble brukt som et mål på forekomst. Data fra fangst per enhet innsats ble også regnet ut for 8 tidligere år med data fra andre studier i området. I tillegg ble størrelse, kjønnsratio, fysisk tilstand og farge på krabbene dokumentert. På grunn av for liten gjenfangst av merkede krabber kunne ikke pålitelige populasjonsestimat kalkuleres. Forekomsten av strandkrabbe i 2012 ble målt til å være signifikant større i Lillgrund enn i kontrollområdene. I midlertidig viser analyser av fangst per innsats enhet over et lengre tidsrom at det ikke er noen effekt av offshore vindkraftparken på forekomsten av strandkrabbe. Det ble ikke funnet noen effekt av vindkraftparken på krabbenes størrelse, kjønnsratio, fysisk tilstand og farge.

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1. Introduction

In a response to climate changes induced by the production of greenhouse gases from burning fossil fuels, many governments have initiated programs of production of energy from renewable sources. Wind energy is currently considered as an indigenous, sustainable and competitive way to reduce future carbon emission and to reach renewable energy targets (Kaldellis and Kapsali, 2013). As the world is trying to make a transition to a lower carbon economy, offshore wind power generation capacity is expected to grow significantly (Wilhelmsson, 2010). Offshore wind energy has a great resource potential as the wind is higher and steadier in the open shore than onshore. This effect generally increases with distance from the shore, and is therefore the main motivation of moving offshore (Kaldellis and Kapsali, 2013). By the end of 2011 there were almost 1400 offshore wind turbines fully grid connected, comprising 53 wind farms spread over ten European countries (Kaldellis and Kapsali, 2013). Although the advantages of renewable energy on a global scale are not in doubt, the effects on the local environment must also be carefully considered (Inger et al., 2009).

1.1 Effects of offshore wind turbines on the environment

1.1.1 Potential positive effects of offshore wind turbines

Marine renewable energy installations may have the potential to produce some positive impacts on the environment (e.g. Langhamer et al., 2009)). The foundations of the wind turbine and scour protecting revetments can be considered as hard substratum, and act as reefs (Petersen and Malm, 2006), thus increase the amount of habitat available for some taxa (Inger et al., 2009). Artificial reefs can be defined as structures placed in the sea, either to create new habitat, or to protect and/or enhance the existing ones for marine animals and plants (Summerhayes and Thorpe, 1996). Many so-called artificial reefs are created incidentally by engineering work, such as supports for bridge (Wilhelmsson et al., 2006), oil platforms (Love et al., 1999, Helvey, 2002, Ponti et al., 2002), breakwaters (Stephens et al., 1994). Artificial reefs have become an important and popular resource enhancement technique, as they are thought to improve fishing (Bohnsack and

Sutherland, 1985). In relation to the construction of artificial reefs it has been discussed whether these reefs facilitate recruitments in the local population, or if they simply aggregate or redistribute biomass that already exists (Inger et al., 2009). This will depend on species and its limitation by refuge, food, territory and/or behavioral requirements.

The foundations of the wind turbines may also act as fish aggregation devices, as they cut through the water column with various steel devices protruding horizontally from the main structure (Wilhelmsson et al., 2006). Leaving floating objects in the water to attract fish is a known strategy among fishermen as these objects seem to concentrate fish stocks. The aggregation of fish around floating object may simply be caused by change in distribution with no direct effects on averaged long-term gains of fish biomass, and may even have potential detrimental effects such as increased exposure to fishing devices or vulnerability to predators (Wilson et al., 2010). As fishing is not allowed within offshore windfarms the foundations of the turbines and the potential aggregation of fish can be seen as a tool for conservation (Inger et al., 2009).

Within the marine renewable energy installations area, fishing by many types of gear will not be possible due to the possibility of collision and gear entanglement and may therefore act as marine-protected areas to most fisheries (Inger et al., 2009). A marine protected area is defined by IUCN as «A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values» (ProtectPlanetOcean, 2010). As a consequence of overexploitation of most seas, there is an increasing demand from most ecologist and conservationists of areas representing no-take zones like marine protected areas (Sanchirico et al., 2006). Establishment of marine renewable energy installations that exclude fishing and trawling in this areas, may enhance fish populations, fish size and species richness in a degree comparable to marine protected areas (Halpern, 2003). A marine protected area created by marine renewable energy installations may then lighten the pressure from fisheries on commercial and/or overexploited species.

1.1.2 Potential negative effects of offshore wind turbines

The potential negative effects of marine renewable energy installations will vary between the construction, operational and decommission stages (Gill, 2005). Some of the negative impacts will be generic, but there are also impacts that will be specific to the marine renewable installation.

Marine renewable energy installations will introduce extra noise (mostly during construction but also while operating), which is likely to have an impact on marine life (Nedwell and Howell, 2004), and particularly species as marine mammals that are acoustically sensitive. Electromagnetic fields created by submarine electrical cables that transfer power between the different marine renewable energy installations devices, may affect animals that use electrical fields and Earth's magnetic fields behaviorally and to navigate (Gill, 2005). Wind turbines both on land, near- and offshore represent a collision hazard to avian species (and bats). The collision effects of birds with wind farms remains a contentious issue, and many factors are still unclear (Inger et al., 2009). Peterson et al. (2004) found that the number of divers, Common Scoters and Gulls had increased in the Horn Rev offshore wind farm in Denmark the year after the wind turbines had started working compared to previous years (Petersen et al., 2004). It has however been observed that wind farms in general have a negative impact on abundance on many of the local bird species (Stewart et al., 2007), which may be due to avoidance rather than the effect of collision (Desholm and Kahlert, 2005). Additional effects from offshore wind turbines may be shadow and changed hydrological conditions (Peterson et al., 2001). The installation of marine renewable energy installations will also include a loss of habitat or degradation of habitat. The degree of impact will vary depending on the type and size of the installation (Inger et al., 2009), and although offshore marine renewable energy installations in general are considered unlikely to generate significant habitat loss, it is thought that inappropriate siting has the potential to cause delirious effects for some taxa.

1.1.3 Synergistic effects

As marine renewable energy installations have the potential to have a significant influence on the marine environment, it is possible that the positive and negative effects can interact in complex and unpredictable ways (Witt et al., 2012). Potential effects may be cumulative, both in time and with an increasing number of marine renewable energy installations; hence it is important that the wider marine ecosystem are taken in consideration. Changes in the environment may lead to unforeseen community-level changes leading to trophic cascades. Trophic cascades are generally characterized by top-down control of the community structure by predators, conspicuous indirect effects and a persistence of alternative community states (Shears and Babcock, 2003). It is therefore required that the interaction between the main positive and negative effects and how they may offset each other are investigated (Witt et al., 2012).

The design of the marine renewable energy installations can affect their impact on the environment. Ecological design is a concept which purpose is to eliminate or greatly reduce the effect of human activity upon the environment, and emphasize use of landscape through sensitive planning and design (Van der Ryn and Cowan, 2007). A related term, ecological footprint, is a measure of the human mark upon the landscape (Primback, 2010). Through ecological design, it can be possible to reduce the ecological footprint of the marine renewable energy installations. Although effort should be made in minimizing the marine renewable energy installations detrimental effect on the environment, their possible ecological value should also be elevated (Perkol-Finkel et al., 2012).

A significant increase in number of published scientific articles about renewable energy over the last 10 years, illustrates the growth of interest in this subject (Gill, 2005). But still, the evidence for the impacts of marine renewable installations is poor, and there exists an urgent need for additional multi and interdisciplinary biodiversity oriented research (Inger et al., 2009, Petersen and Malm, 2006).

1.2 Study area

Lillgrund wind farm is situated in the Öresund strait, between Sweden and Denmark, about 7 km from coast of Sweden and 9 km off the coast of Denmark (55° N, 12° W)(Figure 1). It consists of 48 offshore windmills that have been operating since the beginning of 2008. The windfarm has an annual production of 330 000 MWh, which provides approximately 60 000 homes with electricity (Vattenfall, 2013). The total height of the wind turbines is 115 m, and the turbines have a rotor diameter of 90 m. Mean wind speed for the area at 65 meters height has been estimated to be 8.5 m/s (Jeppson et al., 2008). The seabed in this area consists of limestone, stones and sand, and the depth varies from 4-9 meters (Hammar et al., 2008). Because of differences in salinity between the water masses coming from the brackish Baltic Sea in the south and the salt Atlantic Ocean in the north, the salinity in Öresund is related to the water currents (Bergström et al., 2012), but ranges normally from 0.8-1.5‰ down to 10-15 m depth (Lindkvist et al., 2008).

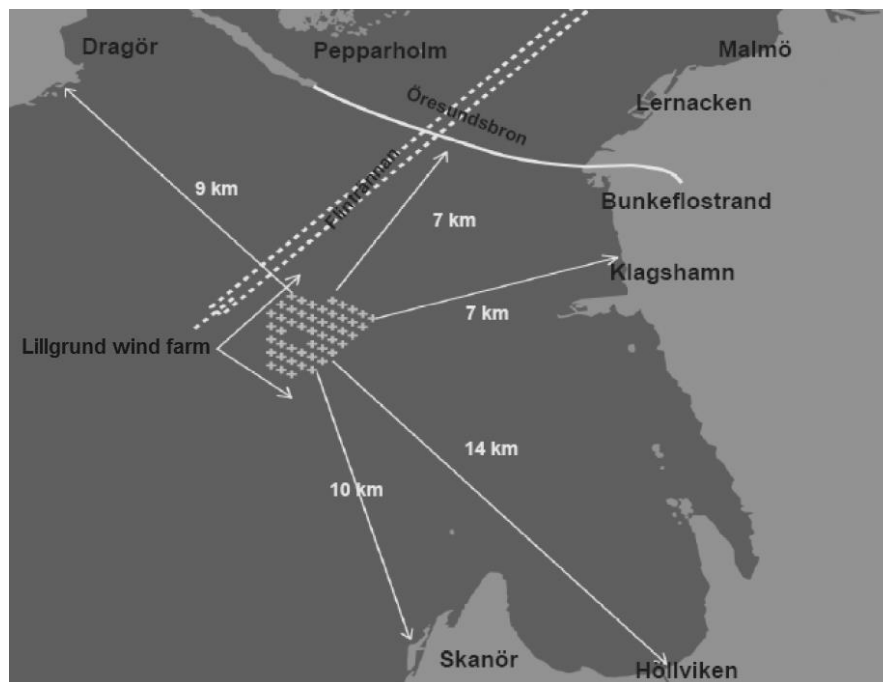


Figure 1. Map of Öresund and the position of Lillgrund wind farm (Karlsson, 2008).

The construction of the foundation with its scour protection constitutes the part of the wind turbine that may act as artificial reef. The foundations of the wind turbines in Lillgrund are gravity based (Jeppson et al., 2008). As the seabed in the area is not all flat, five different foundations with different heights were used (Jeppson et al., 2008). The bottom slab of the foundations is six-sided, where each side is approximately 8 m. The whole area of the seabed around each foundation is covered with a rock-filled scour protection to prevent the ocean currents from undermining the stability of the foundations by moving seabed (Flodéus, 2008)(Figure 2).

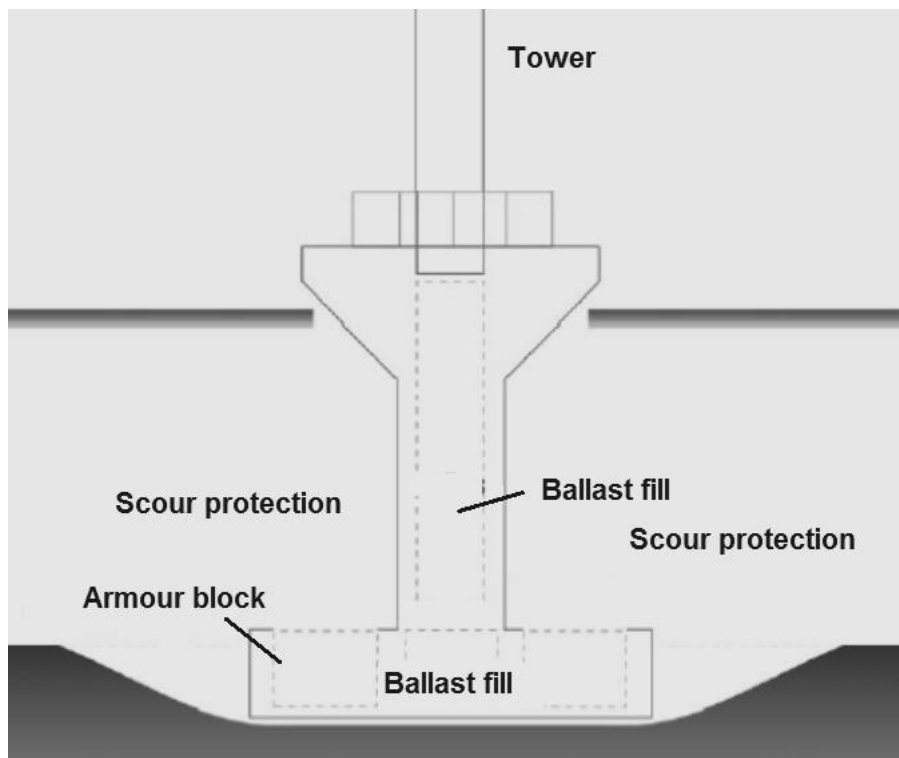


Figure 2. Simplistic draft of the gravity foundation of the wind turbines in Lillgrund, its place in an excavated pit in the seabed and placement of scour protection to prevent erosion (Hammar et al., 2008).

1.3 Study species

The shore crab *Carcinus maenas* is among the best known intertidal animals. The fact that it is common, relatively large, easily found, measured, sex-determined and marked, makes it suitably for field study (Crothers, 1968). The shore crab is a widely distributed

epibenthic species of European coast and estuaries, and inhabit both soft and hard habitat (Baeta et al., 2005). The species has also been found in the north-western Atlantic, and has recently colonized some areas in Australia, southern Africa and the Pacific coast of North America (Cohen et al., 1995). It is considered to be one of the worst invasive species in the world (Lowe et al., 2000).

The life cycle of the shore crab is complex with four pelagic zoea stages and a megalopal (postlarval) stage that settle and metamorphose into the first benthic crab stage (Moksnes, 2002). *C. maenas* has been shown to consume an enormous variety of prey items, especially organisms belonging to the phyla Crustacea, Annelida and Mollusca (Cohen et al., 1995). It lives in both salt and brackish waters (Moen and Svensen, 2008) and on hard and soft substrate (Grosholz and Ruiz, 1996). Although the shore crab is most common on the coast and estuarine habitat, it is found up to 200 m below water surface (Moen and Svensen, 2008). The coloration of shore crab varies from a green to red carapace with darker marmoration and a yellow abdomen, and can reach a carapace width of 80 mm (Moen and Svensen, 2008). The different carapace color is an indicator of inter-moult duration, with red crabs having been in inter-moult longer than the green ones (Reid et al., 1997).

A great variability in behavior, morphology and physiology is commonly found in *Carcinus maenas* in relation to size, carapace coloration and sex e.g (Reid et al., 2009, McGaw and Naylor, 1992b, Ledesma et al., 2010). This variability reflects the phenotypic adaptive responses of individual crabs in relation to their ability to withstand environmental variability (McGaw and Naylor, 1992b, Warman et al., 1993, Abelló et al., 1997), and are expressed when organisms experience different ecological and environmental conditions (Reid et al., 1997). As shore crab inhabits a variety of habitats, it has been suggested as a useful model organism to examine how habitat quality affects individual and population level parameters (Amaral et al., 2009).

In connection to a control program of fish in Lillgrund windfarm, the Swedish Board of Fisheries has observed an increase in capture of shore crabs in Lillgrund and two control

areas, Sjollen and Bredgrund since the construction of the windfarm (Bergström et al., 2009).

1.4 Aim of study

In this master's thesis I will study the influence of offshore windfarm on the population dynamics of the common shore crab *Carcinus maenas*. The following hypothesis will be investigated:

- I. As offshore wind turbines may act as artificial reefs I expect to find a population of shore crabs that is larger and more abundant in Lillgrund compared to two control areas, Sjollen and Bredgrund.

- II. Due to artificially altered benthic environment in areas with wind turbines, I expect to find a difference in size, sex ratio, condition and coloration of shore crab populations in Lillgrund, compared to Sjollen and Bredgrund.

2. Material and methods

The field study of this project was carried out from 25 June to 20 July 2012 in Lillgrund wind farm and two control areas, Sjollen and Bredgrund (55° N, 12° W E). Sjollen and Bredgrund have many similar outer requirements as Lillgrund, with seabed consisting of limestone, stones and sand, and depth varying from 4-9 meters. Each of the three areas covers a region of about 6000 m². Bredgrund is situated about 8 km south of Lillgrund and closer to the coast, and Sjollen about 13 km to the north. These two control areas are able to account for the strong salinity gradient that are occurring in the area (Bergström et al., 2009).

2.1 Field methods

Shore crabs were captured with two linked double fyke nets at 10 different locations within the three different areas i.e. at 30 stations altogether (Figure 3). The same locations were used by The Swedish Board of Fisheries in studies of the effect of the windfarm in Lillgrund on fish and fisheries, although they operated with 24 (2002-2004) and 36 (2005, 2008-2009) stations within each area i.e. altogether 72 and 114 stations. The fyke nets had a height of 55 cm, they had three entrances and a five meter long arm. At each station the nets were set out during the morning and collected and emptied the following morning. On days with strong wind or strong current, the nets were left for two days or in one case, to later in the evening. In Lillgrund the fyke nets were placed out on the soft bottom between the foundations. Bait was added in the fyke nets after all stations in the areas had been visited twice and used through the rest of the project to increase the yield.

To get an estimate of the population size and density the mark- recapture method was applied. The crabs were marked with t-bar anchor floy tags (<http://www.floytag.com/uploads/floycatalog.pdf>) on the posterior margin of the epimural suture (Figure 4). In addition all captured crabs were sex determined, measured (mm) and released at the same location as they were caught. The size of the crabs was measured as the width of their carapace (mm). The majority of the captured individuals smaller than 42 mm were not marked. Any damage or loss of legs or claws on the caught crabs was

recorded. Crabs possessing any of these characteristics was classified as being in “reduced condition”, while those with no damage or reduced number of legs or claws were classified as being in “good condition”. The coloration of the crabs was classified as “green” or “red”, as recommended by McGaw and Nailor (1992). The whole procedure was done on the boat, about 1 minute was spent on each individual and all were released within 1 h back to the same location as they were caught. Any recapture of already caught and marked individuals was recorded. At each location in the three areas, five marking and 6 capture occasions took place and they were completed during a period of max 18 days for each of the areas. Permission for fishing with fish traps was given by the Swedish Board of Fisheries (Ref. nr. 23-2231-11).

The catch per unit effort index presents useful information concerning relative abundances of a population (Haggarty and King, 2006). In addition to data collected from field work June-July 2012, data from The Swedish Board of Fisheries (Bergström et al., 2012) and Olivia Langhamer (unpublished) was used to calculate and compare catch per unit effort for all three areas during the last decade. The Swedish Board of Fisheries recorded number of crabs caught within Lillgrund, Sjollen and Bredgrund in their studies 4 years before (2002-2005), and 3 years after (2008-2010) the construction of the wind farm in Lillgrund. Data on shore crabs from 2011 was gathered by O. Langhamer (unpublished). Catch per unit effort was standardized as the mean number of crabs caught in each station of the areas per day per double fyke net. Data from previous years were collected during different times of the year; in 2002-2005, 2008-2010 they were collected in two middle weeks of May and in 2011, the last week of July and the first week of August. In 2010 additional data was collected during the two last weeks of October.

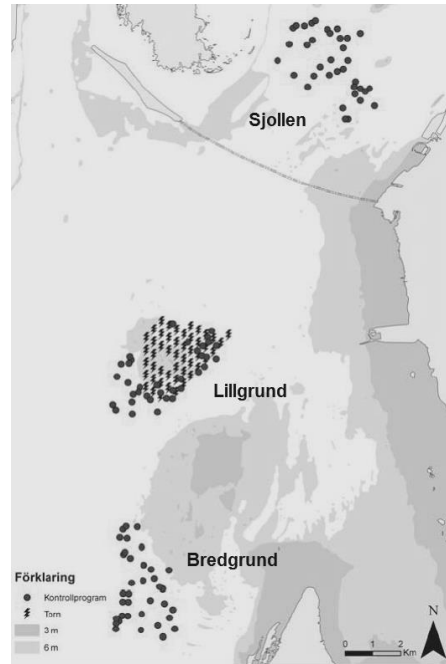


Figure 3. Map of stations in Lillgrund, Sjollen and Bredgrund used by The Swedish Board of Fisheries during the baseline study 2002-2005 and 2008-2009. The stations are represented by dots, while the other markings in Lillgrund represent the position of windturbines. Ten of The Swedish Fishery Board stations in each area were applied for fyke nets fishing June-July 2012. The figure is from Bergström et al., 2012.



Figure 4. Location of t-anchor floy tags on the posterior margin of the epimural suture of a marked crab (AlaskaDepartmentOfFishAndGame, 2013).

2.2 Data analyses

Statistical analyses were performed in SPSS 20.0 (SPSS, 2011). Continuous data were assessed for normality and log transformed if the assumption was not met. For all the statistical analyses a significance level of $\alpha = 0.05$ was applied.

Population estimation was done with the program MARK 6.2 (White, 2012). Only marked individuals were included in the data used for population estimations. The data set was treated as a Closed Captures in the analysis, as the collection of data was done in a short time span. The density (individuals/m²) was calculated from the estimated population size. One-way analysis of variance (ANOVA) with *Tukey's HSD* as *post hoc test* was used to analyze the effect of area on the catch per unit effort indexes of 2012. Because of non-normality, data on mean catch per unit effort from previous years of study were log transformed. Mean catch per unit effort before (2002-2005) and after (2008-2012) the construction was analyzed with area and an interaction between area and time in a nested ANOVA.

Nested ANOVA with *Tukey's HSD* as *post hoc test* was used to analyze mean size of shore crabs between the areas, males and females and if there was an interaction between area and sex.

Logistic regression was used to investigate relationship between categorical data. Data on sex, condition and coloration were treated as dependent variables, and expressed binary as either male (1) or female (0), in good condition (1) or reduced condition (0) and green (1) or red (0), with area as predictor. Lillgrund was set as control area in all three tests.

3. Results

A total amount of 1995 crabs was caught and measured in the three different areas. Of these a total of 1341 was marked, and 9 were recaptured (Table 1). Of all caught crabs, 6% were females. The number of individuals caught during each trapping event varied between the different areas, but generally increased (Figure 5). As crabs can reach a carapace width of 34 mm in their first year (Crothers, 1968) and no crabs smaller than 29 mm was caught, the results from this study primarily deals with the adult part of the shore crab population.

Table 1. Number of shore crabs captured, marked and recaptured in the different areas during field work in June-July 2012.

<i>Area</i>	<i>Captured (n)</i>	<i>Marked (n)</i>	<i>Recaptured (n)</i>
Lillgrund	1004	696	8
Sjollen	627	441	0
Bredgrund	364	204	1

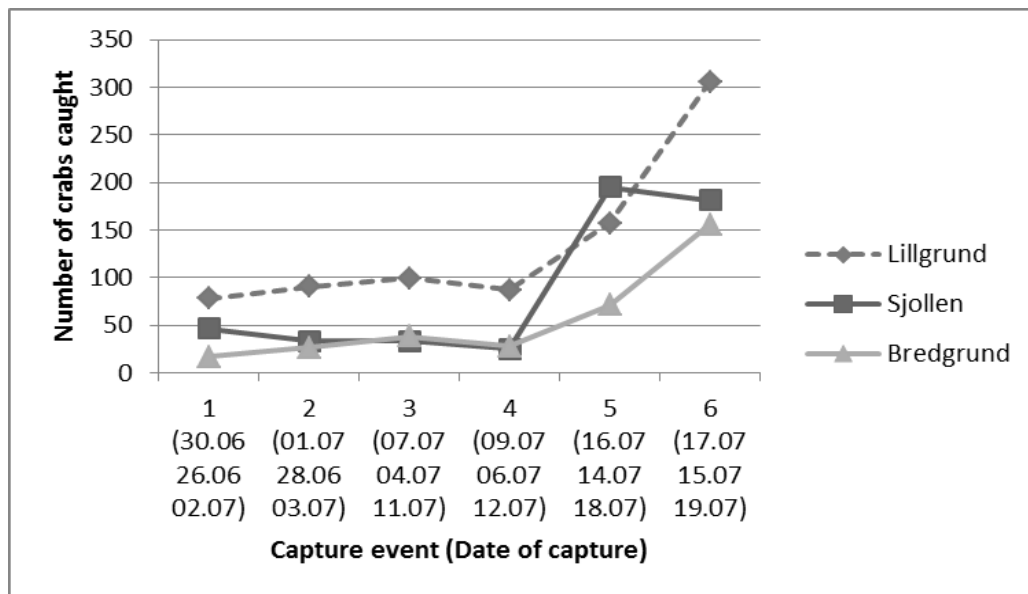


Figure 5. Number of shore crabs caught in each capture event in Lillgrund, Sjollen and Bredgrund, June-July 2012. The number of crabs caught in each capture event is standardized as crabs caught per night. Dates of the capture event for each area is represented in the paranteses along the x-axis in following order: Lillgrund, Sjollen and Bredgrund.

3.1 Population size, density and abundance

3.1.1 Population size estimations and density

Population estimates in MARK could not be performed for Sjollen as no marked crabs were recaptured. The population size in Lillgrund was estimated to be 7.8% larger than the population in Bredgrund (Table 2). As seen in the table, the 95% confidence intervals (CI) of the estimations are large for both areas.

Table 2. Estimations of shore crab population sizes and densities in Lillgrund and Bredgrund from June-July 2012, performed in program MARK.

<i>Area</i>	<i>N</i>	<i>p-hat*</i>	<i>Approximate 95% CI</i>		<i>Density (ind./ m²)</i>
			<i>Upper bound</i>	<i>Lower bound</i>	
Lillgrund	60 152	0.0028	139 519	31 313	10.0
Bredgrund	55 808	0.0011	290 610	10 953	9.3

*Estimated average capture probability of an individual

3.1.2 Catch per unit effort

The mean catch per unit effort for each station varied from 2.8 (Bredgrund) to 6.8 (Lillgrund). There was a significant difference in mean catch per unit effort between the areas ($F_{2,29} = 16.394$, $p < 0.001$). Mean catch per unit effort in Lillgrund was 60% and 143% larger than in Sjollen and Bredgrund, respectively (Figure 6).

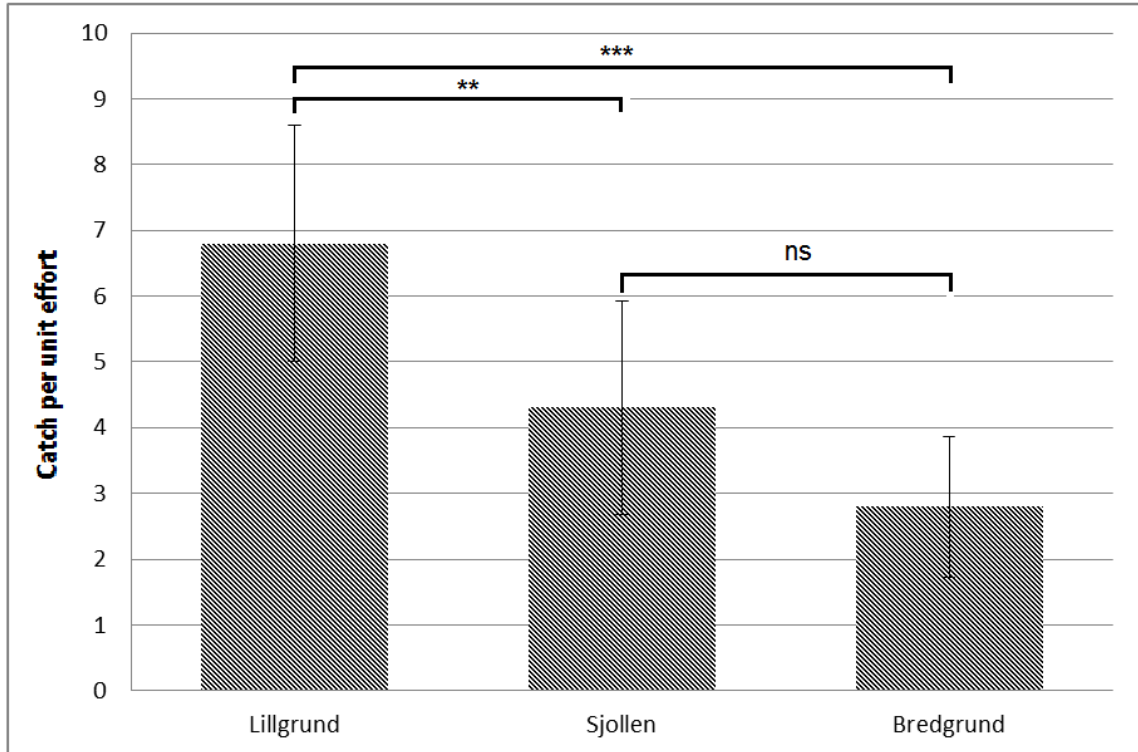


Figure 6. Mean catch per unit effort of shore crab in Lillgrund, Sjollen and Bredgrund, June-July 2012. Bars represent standard errors. Statistical significant difference in catch per unit effort between areas are denoted by asterisks (** $p < 0.01$, *** $p < 0.001$, ns = not significant).

Comparison of catch per unit effort from the first year of monitoring in the baseline study until 2012 show interannual variation, especially for 2010 and 2011 (Figure 7). There was a significant increase in catch per unit effort from before to after the construction of the wind farm ($F_{1,26} = 11.45$, $p < 0.01$) (Figure 8). There were however no difference in catch per unit effort between the areas ($F_{2,26} = 2.98$, $p = 0.73$) nor any interaction between time and area ($F_{2,26} = 0.43$, $p = 0.66$).

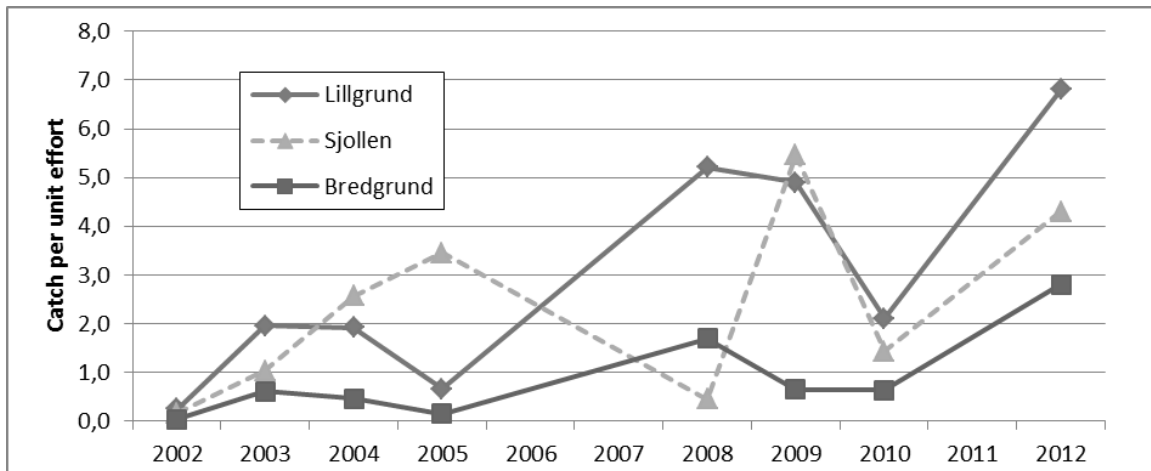


Figure 7. Catch per unit effort in Lillgrund, Sjollen and Bredgrund during the years before (2002–2005) and after (2008–2012) the construction of the wind farm in Lillgrund. Catch per unit effort for all years from 2002 and 2010 are calculated from data from The Sedish Fishery Board (Bergström et al., 2012), data from 2011 are from Olivia Langhamer (unpublished).

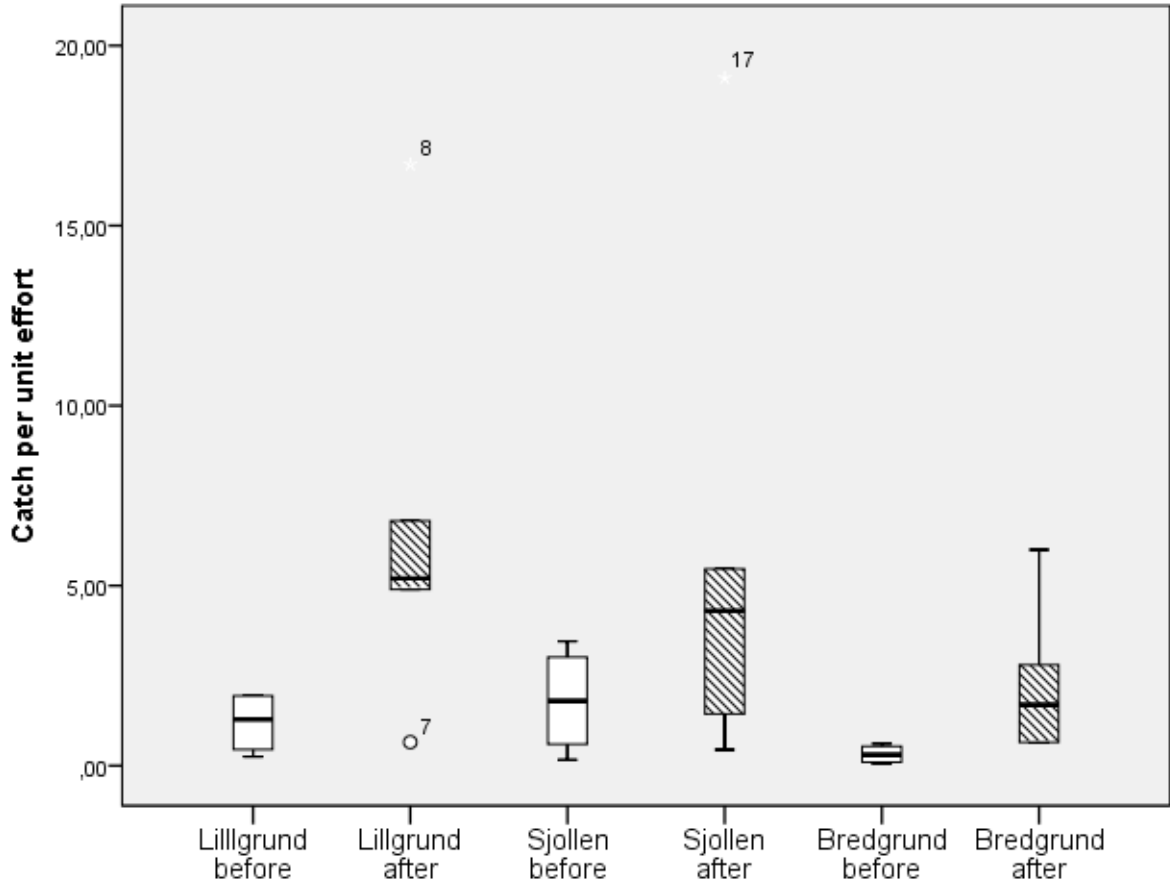


Figure 8. Boxplot of catch per unit effort in Lillgrund, Sjollen and Bredgrund from the years before (2002-2005) and after (2008-2012) the construction of the wind turbines. The low outlier for Lillgrund after construction is catch per unit effort for 2010, and the high outlier for Lillgrund and Sjollen after the construction is catch per unit effort recorded for 2011.

3.2 Morphological traits, sex ratio and condition

3.2.1 Size

The size of the crabs varied from the smallest caught being 29 mm (Sjollen) to the largest of 79 mm (Lillgrund). Mean size of the crabs differed significantly between the areas ($F_{2,1994} = 16.778$, $p < 0.001$). The mean size of crabs in Lillgrund and Bredgrund were respectively 6% and 6.5% larger than those in Sjollen (Figure 9). A test of between subject effects showed that male crabs were 30% bigger than females ($F_{1,1994} = 529.534$, $p < 0.001$), and that there were no effect of area on the size of male and female crabs ($F_{2,1994} = 0.195$, $p = 0.822$).

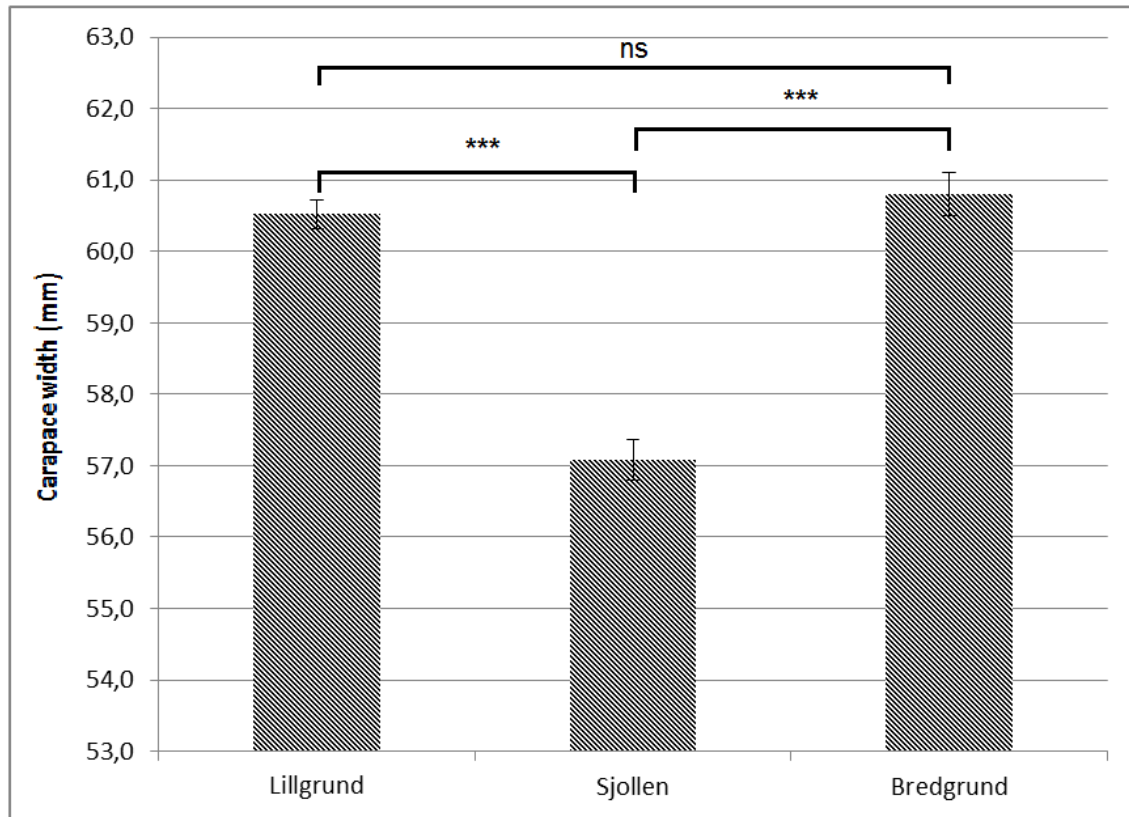


Figure 9. Mean size of shore crabs in Lillgrund, Sjollen and Bredgrund, June-July 2012. Bars represent standard errors. Statistical significant difference in mean size among areas are denoted by asterisks (***) $p < 0.001$, ns = not significant).

3.2.2 Sex ratio, condition and coloration

The proportion of males and females in the crab populations varied between the different areas from 93.0% of all caught crabs being males in Lillgrund to 94.2% in Bredgrund and 95.7% in Sjollen. The proportion of males was significantly larger in Sjollen compared to Lillgrund (OR = 1.66, 95% CI = 1.05 - 2.62, $p < 0.05$). There was no difference in proportion of males in Bredgrund compared to Lillgrund (OR = 1.22, 95% CI = 0.74 - 2.02, $p = 0.44$). Nagelkerkes R^2 was estimated to 0.007.

The condition of the caught crabs varied from 80.0% of all crabs being in good condition in Bredgrund to 81.8% in Sjollen and 83.1% in Lillgrund. There was no difference in proportion of crabs in good condition neither in Sjollen (OR = 0.92, 95% CI = 0.71 -

0.1.19, $p = 0.5125$) nor Bredgrund (OR = 0.81, 95% CI = 0.57 - 0.1.10, $p = 0.173$) compared to Lillgrund.

The proportion of green crabs varied from 38.8% in Lillgrund, 48.6% in Sjollen and 30.7% in Bredgrund (Figure 10). The proportion of green crabs were significantly larger in Sjollen (OR= 1.45, 95% CI=1.22 - 1.83, $p < 0.001$) and smaller in Bredgrund (OR=0.70, 95% CI = 0.55 - 0.91, $p < 0.01$) compared to Lillgrund. Nagelkerkes R^2 was estimated to 0.02. To control for differences of the color morph between the control areas Sjollen and Bredgrund, logistic regression was performed with Sjollen as reference area. There was significantly lower proportion of green crabs in Bredgrund Bredgrund (OR= 0.47, 95% CI = 0.36-0.619, $p < 0.001$) compared to Sjollen.

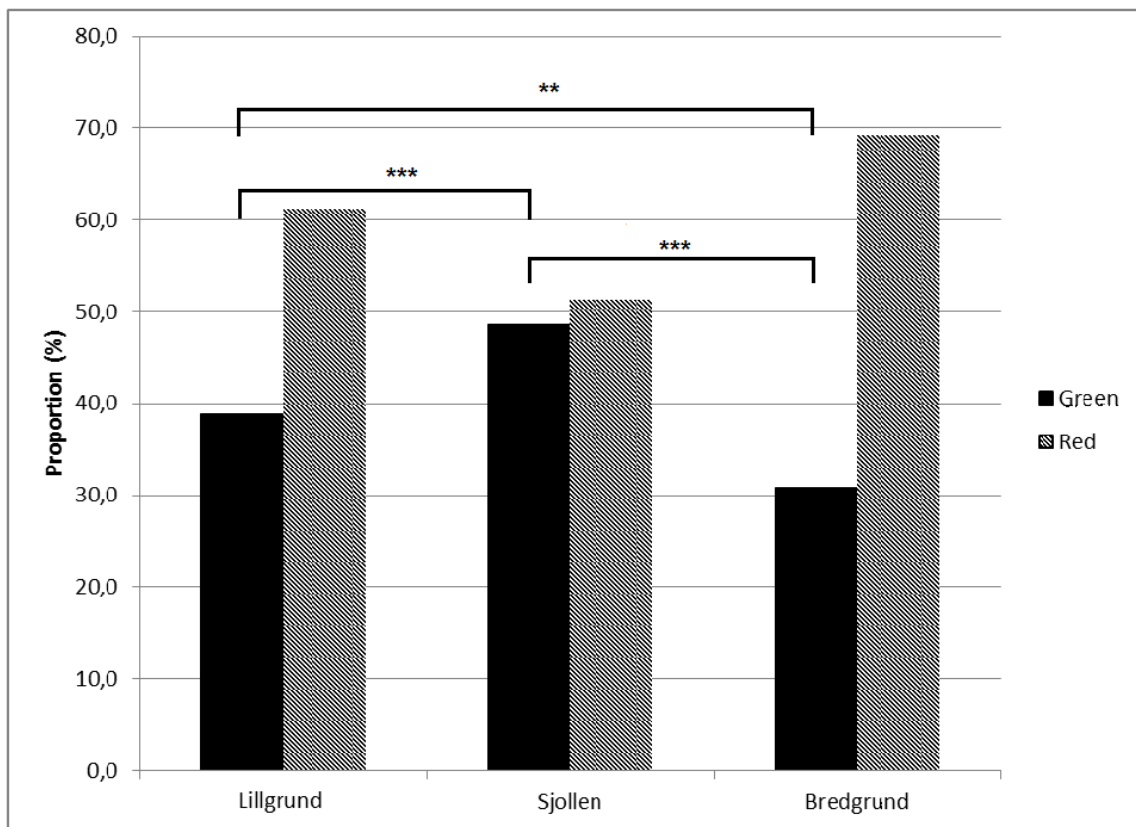


Figure 10. Proportion of crabs of green and red colour in Lillgrund and the control areas Sjollen and Bredgrund, June-July 2012. Differences in odds ratios are denoted as asterisks (** $p < 0.01$, *** $p < 0.001$).

4. Discussion

The foundations and scour protection of offshore windturbines have been suggested to act as artificial reefs and create changes in the benthic environment. These changes may have an effect on shore crab population dynamics. My results show that the catch per unit effort of shore crab in 2010 was higher in Lillgrund compared to the control areas, Sjollen and Bred, but that in a long term perspective of 10 years, there is no difference in abundance of shore crab in Lillgrund compared to the control areas. The size of crabs in Sjollen has been shown to be smaller than those in Lillgrund and Bredgrund. I have found that there are proportionally more males in Sjollen than Lillgrund, no difference in condition of crabs between the areas, and that the proportion of green and red crabs are different between all three areas.

4.1 Population size, density and abundance

4.1.1 Population size estimation and density

There is not possible to make an evaluation of the differences in populations size between Lillgrund and Bredgrund based on the population size estimation done in this study. The assumption behind the mark-recapture method is that the proportions of marked individuals that are recaptured represent the proportion of marked individuals in the whole population, which is not reasonable to assume in this study with only 9 recaptures of 1341 marked individuals. The average capture probability (\hat{p}) was low for both Lillgrund (0.0028) and Bredgrund (0.0011). Otis et al. (1978) suggested that average capture probability of at least 0.1 per session are necessary for reasonable results, but at population sizes above 100 individuals, a lower capture probability will however suffice (Lettink and Armstrong, 2003). Although much more than 100 individuals were capture in each area, the capture probability for estimations in Lillgrund and Bredgrund are probably still too low to give a certain estimation, which is underlined by the large 95% confidence intervals for the estimations.

The low recapture rate is probably not caused by change in behavior or mortality of tagged individuals. An earlier study by McPherson (2002) on survival of Blue swimmer

crab marked with t-anchor floy tags on the posterior suture of the carapace, found no change in behavior of tagged crabs that could be related to the tagging. Neither was the survival of the tagged crabs severely reduced: only one out of 24 crabs tagged with a standard T bar anchor tag died a short time after tagging (McPherson, 2002). Although the tags may not cause changes in behavior of the crabs, it may still be changed by the initial capture event, causing them to be either captured more frequently (“trap happy”) or less frequently (“trap shy”) (Lettink and Armstrong, 2003). A change to “trap shy” behavior could be an explanation of the low recapture rate. Another factor that may have had an influence on the recapture rate was the observed increase in number of caught crabs in all three areas during the field work (Figure 5). An increase in number of caught crabs during fishing has also been observed by Sheehan et al. (2008) in a survey on the effects of crab-tiling on the abundance of shore crab on intertidal sandflats and mudflats in estuaries. They found an increase in the abundance of shore crab in the areas where this kind of fishery occurred, which is thought counter-intuitively from what would normally be expected in a population that is fished (Sheehan et al., 2008). This increase in abundance was associated with an increase in available habitat, created by the crab-tiling. It is possible that the observed increase in number of captured crabs during the capture events can have an impact on the recapture rate, as an increase in number of unmarked crabs will probably reduce the chances to recapture already marked individuals. To get a reliable estimation of the population size, more recaptures are needed, and it is possible that a larger proportion of the populations should have been marked. This could be achieved by fishing at more stations within each area, assuring that a larger proportion are caught, and increasing the chance of recapture of crabs that disperse or change their behavior after initial capture.

Regarding density of shore crab, the population density of adult shore crab (30 – 70mm) in Europe has been shown to vary between 0.1 to 20 individuals per square meter in suitable habitats during summer (Munch-Petersen et al., 1982, Janke, 1990). As the estimated densities of shore crab in Lillgrund (10.0/m²) and Bredgrund (9.3/m²) lie within the range of other density estimations of this species, it seems that the populations size in both areas are not notably different than from other areas in Europe.

4.1.2 Catch per unit effort

4.1.2.1 Catch per unit effort in a short term

Catch per unit effort analyses from 2012 showed a significantly higher abundance of shore crabs in Lillgrund compared to the control areas. An increase in population of shore crab in the wind farm area could be due to available shelter and/or because there is more food available there (Maar et al., 2009). A semi-quantitative study of shore crab population around the wind farm foundations in Nysted offshore wind farm in Denmark found a high abundance of shore crabs in the area of the wind farm (Maar et al., 2009). The biomass of the shore crab population suggested that their food demand could not be sustained by the biomass of the soft bottom surrounding fauna community, indicating that the offshore wind farm foundations must enhance production of organisms that are consumed by the shore crab (Maar et al., 2009). The foundations and pillars of the wind turbines in Lillgrund have been found to be colonized by blue mussels and the barnacle *B. improvises* short time after the construction of the wind farm (Malm and Engkvist, 2010), and may serve as both protection and food source for the shore crab. Other studies have also observed an attraction of different crab species to artificially created hard substratum (e.g. Page et al., 1999, Langhamer and Wilhelmsson, 2009).

4.1.2.2 Catch per unit effort in a long term

In terms of stock assessment, it is the inter-annual variation of abundance that is of most interest (Murray and Seed, 2010). The analysis of catch per unit effort before and after the construction showed that there has been a significant increase in abundance in all three areas, and that this increase does not differ between the areas (Figure 8). This increase within all three areas was also noted by Bergström et al. (2009), and was suggested to be a signal of a change of greater scale in the ecosystem. Similar evaluation of the area has been done by Göransson (2002), as there has been found changes in species compositions in Öresund from early 1900s to surveys performed in 1989 – 2000. He further suggest that some of these changes can be due to eutrophication, as they seem to have occurred during the last decades, parallel with increased nutrient load to the

coastal waters (Göransson, 2002). Another large scale change that may also affected the shore crab abundance is the ongoing global warming.

Regarding the interannual comparison of catch per unit effort, these indexes for Lillgrund and Sjollen are very low in 2010 and very high in 2011 compared to the other years (Figure 7 and Figure 8). This may be due to differences in time of year when fishing was done; shore crabs seem to avoid both too high and low temperatures and regulates this by migration to locations of preferred temperature (Murray and Seed, 2010). This migration can influence the catch per unit effort, and the strong association between temperature and catch per unit effort may mask the underlying changes in abundance (Murray and Seed, 2010). In 2010 the bottom temperatures varied between 8.1-11.0°C (May) and 11.2-14.2°C (October). Klein Breteler (1976) found in a study on migration pattern of shore crab in the Dutch Wadden sea that adult crabs became less abundant in the intertidal zone from the beginning of October and onward, and suggested that this could be because adults crab migrate towards deeper sea and bury themselves in the bottom during winter (Klein Breteler, 1976). Regarding the sampling in May 2010 the bottom temperature in the sampling areas was a little lower than for 2008 (10.5-13.1°C) and 2009 (9.2-17.1°C). The colder bottom temperatures in May and the fact that crabs are less active in October may have influenced the capture rate for 2010. As temperature was not recorded in 2011, it difficult to make any assumptions about the reason of the high catch per unit effort this year, other that it was sampled in the middle of the summer, with probably a higher temperature.

4.1.3 Possible effects of increased shore crab populations

Whether caused by large scale changes or wind farms, an increase in abundance and biomass of species may have considerable ecological consequences (Cohen et al., 1995). If shore crab become widely abundant it may affect other organisms by predation, by being preyed upon, by competition for space or food, by disturbance of feeding behavior and by indirect effects (Cohen et al., 1995). The effect of generalist consumers are potentially greater on a community than those of feeding specialists because generalists

may reduce the abundance of preferred prey species to a very low level while gradually shifting to alternative prey (Enderlein and Wahl, 2004). Predation of shore crab has been shown to have an effect on recruitment success of cockles, *C. edule* (Flach, 2003), blue mussels, barnacles and diatoms (Enderlein and Wahl, 2004) and has been suggested to be a key factor contributing to size polymorphism in populations of *L. fabalis* (Kemppainen *et al.*, 2005). As shore crab is prey item for other species, an increase in the population may be positive for species in a higher trophic level, e.g. shore crab is the main prey item for 1- group cod living in the Gullmarsfjord at the west coast of Sweden (Pihl, 1982).

4.2 Size, sex ratio, condition and color

4.2.1 Size

The smaller mean size of crabs in Sjollen compared to Lillgrund and Bredgrund indicates that wind turbines do not have an effect on size of shore crabs. Smaller mean size of crabs in Sjollen could be caused by exposure to noise pollution from ships. The ship traffic in the Baltic sea is considerable, and has increased the last ten years (Sundblad, 2011). Sjollen are more exposed to ship noise than Lillgrund and Bredgrund as it is situated close to the shipping lane through the Öresund strait. As no ship traffic is allowed in Lillgrund area this is probably not an issue there, less ship traffic is also likely in Bredgrund as it is closer to the shore. A study of Wale *et al.* (2012) showed a size-dependent physiological responses of shore crabs to single and repeated playback of ship noise (Wale *et al.*, 2013). Crabs exposed to ship-noise playback had higher oxygen consumption than those experiencing playback of ambient harbor noise, and the response to the noise differed depending on their mass and number of exposure (Wale *et al.*, 2013). The response of shore crabs to a single ship-noise was size dependent, with heavier individuals showing a stronger response than the lighter ones.

4.2.2 Sex ratio

The poor representation of female in the samples (6% females of all crabs caught) can be due to the fact that adult female crabs behave different from that of males in the summer (Ropes, 1968). Oviparous females in the early summer months tend to seek deeper water

and show reduced feeding activity, and in the late summer a greater part are molting and mating (Munch-Petersen et al., 1982). Such behavioral patterns can reduce the catchability by traps of the females compared to the males during this time of year.

There was found a significant difference in sex ratio in Sjollen and Lillgrund, with proportionally more males in Sjollen (OR= 1.66) compared to Lillgrund. However, the small percentage difference between Lillgrund (93.0%) and Sjollen (95.7%) and a weak correlation (Nagelkerkes $R^2 = 0.007$) between area and sex suggest that area is not an important predictor of sex ratio. As no difference in proportion of males was found between Lillgrund and the other control areas Bredgrund, this analysis suggests that the presence of wind turbines does not have an effect on the sex ratio of shore crabs.

4.2.3 Condition

There were not found any difference in proportion of crabs in good condition between Lillgrund and the control areas. This indicates that there is no effect of the offshore windfarm on condition of shore crabs.

4.2.4 Color

There was a significant but weak correlation (Nagelkerkes $R^2 = 0.02$) between color and area. As there were differences in the proportion of green crabs not only between Lillgrund and the control areas, but also between the control areas Sjollen and Bredgrund (Figure 10), this result suggests that the presence of the wind turbines does not have an effect on the color of the crabs. One factor that may have an influence on color is differences in the benthic environment between the study areas. Although Sjollen and Bredgrund were chosen as reference areas due to many similar outer requirements, there are differences between the areas that can have an influence on the color morph of the crabs. The strong salinity gradient in the area could be a factor that affects the distribution of green and red crabs as the red color morph is less salinity tolerant than the green (McGaw and Naylor, 1992b, McGaw and Naylor, 1992a). Since Bredgrund is situated further into the Baltic Sea than the other two areas, a lower salinity gradient and hence a

lower proportion of the red morph would be expected here. However, the highest proportion of the red morph was found in Bredgrund, and the lowest was found in Sjollen, which is the opposite of what is expected. In addition to differences in salinity between the areas, the benthic structure in Bredgrund has been found to have a structure that is more similar to the Öland and Gotland part of the Baltic sea rather than Lillgrund, which it border to (Malm and Engkvist, 2010). This difference may be caused by oceanographic processes such as streams close to the shore that are important for the local benthic structure (Menge et al., 1997), and may have an effect on the color morph in Bredgrund. Sjollen has during the baseline study (2002-2005) also been shown to have a different species composition and development than Bredgrund and Lillgrund (Lagenfelt et al., 2005). This reflects that the Öresund strait is an area with very strong hydrographic gradients, making the water environment at Sjollen differ from both northern and southern areas during springtime (Lagenfelt et al., 2005).

5. Conclusions

In this study of the influence of offshore wind farms on shore crab populations I found that the abundance of shore crab in Lillgrund windfarm in 2012 was higher than in the control areas. I also found that in a long term perspective (10 years) there is no effect of the offshore wind farm on the abundance of chore. I did not find any effect of the windfarm on size, sex ratio, condition and color of the crabs. The mark-recapture analysis demonstrates the importance of a study design that ensures enough recaptures to be able to get reliable estimations. The comparison of catch per unit effort between years and areas states the importance of long term monitoring and several reference areas to get a proper impression of abundance.

Further effort should be directed towards long term investigations of the effects of offshore wind farms. Other species should also be investigates, as they may react differently to the offshore wind turbines than shore crab. Research in other areas than Lillgrund windfarm should also be conducted as differences in the environment may have an impact on the effect of the offshore windfarm.

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