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Cod pots in a Baltic fishery: are they efficient and what affects their efficiency?

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With the growing grey seal population in the Baltic Sea, the inshore cod fishery has suffered dramatic increases in both catch losses and damage to fishing gear. To mitigate this situation, cod pots were evaluated as an alternative to traditional gillnets and longlines. During a 3-year study, cod pots were used by commercial fishers in two areas off the coast of Sweden. Using the data from this study, we evaluated catches from pots in relation to other gear types and investigated the effects of environmental and fisheries-related variables such as depth and soak time. The comparison of pots with other gear types showed that, during the first half of the year, the pot fishery generated lower daily catches than the gillnet and longline fisheries at comparable fishing efforts. During the second half of the year, catches in the pot fishery exceeded or were equal to those in the traditional fisheries. Using generalized additive models to evaluate the impact of environmental and fisheries-related variables on pot catches, we showed that, in both areas, the catch per unit effort (cpue) of legal-sized cod was affected by the water depth, the time of year (months), and the soak time. In one of the areas, cpue was also affected by the direction of the water current in relation to the orientation of the string of pots. The cpue of undersized cod was affected by topographic variables such as the slope and the complexity of the bottom, in addition to the water depth, month of the year, and soak time. The results from the study indicate that pots can be a useful alternative gear in the Baltic cod fishery, at least during part of the year. By using our information on how catches are affected by environmental and fisheries-related variables, the pot fishery may be further optimized to increase catches.

Keywords: catch per unit effort, catching efficiency, cod pot, environmental and fisheries-related effects, GAM, gillnet and longline fisheries.

Introduction

Seal-inflicted damage to fishing gear and catch losses have increased rapidly along the coast of the Baltic Sea, and many small-scale coastal fisheries have been severely affected (Westerberg *et al.*, 2006; Bruckmeier and Höj Larsen, 2008; Hemmingsson *et al.*, 2008). The gillnet and longline fisheries for Atlantic cod (*Gadus morhua*) have experienced extensive surges in damage caused by grey seals (*Halichoerus grypus*) since around the year 2000 (Königson *et al.*, 2009). This has led to the development of seal-safe alternative fishing gear, such as baited cod pots. Cod pots are preferable to traditional methods in areas prone to seal predation, as they enclose the caught fish in a compartment which can be made seal-safe, meaning that it is much harder for the seals to get at the fish than when they are caught in a gillnet or hooked on a line (Königson, 2011; Ovegård *et al.*, 2011). The environmental impact of traps and pots is also considered less severe than that of trawls and other active fishing gear (Jennings *et al.*, 2001; Thomsen *et al.*, 2010). Pots are classified as LIFE (low impact and fuel efficient) fishing gear due to their low energy use, effective species selectivity, and low gear construction costs (Suuronen *et al.*, 2012). At the time of writing, there is no production of commercial cod pots that meet the criteria of being practical to handle, seal-safe, and effective. Fishing gear manufacturers are in the process of further developing cod pots in collaboration with fisheries scientists. However, more knowledge of what affects the pots' catching efficiency is needed to optimize the pots.

Catch levels in baited fishing gear such as cod pots are affected by two main factors—the fish density around the gear and the catching efficiency of the gear (Engås and Løkkeborg, 1994; Arreguín-Sánchez, 1996). Fish distribution, that is fish density around the gear, varies due to factors such as prey and predator abundance, overall environmental conditions, and migratory behaviour (Aro, 1989). The large-scale distribution of cod in the Baltic Sea is determined by hydrographic factors such as oxygen concentration and salinity, along with density-dependent factors such as the size of the cod population in relation to its spatial distribution (Tian *et al.*, in preparation). At smaller spatial scales, factors such as seabed topography and bottom currents also influence fish distribution (Bergström *et al.*, 2011).

The catching efficiency of the gear is affected by environmental variables influencing fish activity, feeding motivation, and the ability of the fish to detect, locate, and consume the bait (Stoner, 2004). These variables could include light levels, currents, temperature, density, size distribution of competitors, and the abundance of natural prey (Quinn *et al.*, 1985; Engås and Løkkeborg, 1994; Sigler, 2000). The pots' catching efficiency is also related to the "active space" of the fish pots, which includes the area over which feeding attractants from the bait are present in concentrations above the response threshold of the fish. This active space is determined by the release rate and transport of chemical cues through the water as well as the chemosensory threshold for an individual fish at a specific time (Løkkeborg *et al.*, 1995). These components are, in turn, dependent on several of the above-mentioned environmental variables. Additionally, it is only a proportion of the fish in the active space that respond to bait or can be lured into the pot and be caught (Furevik, 1994; Løkkeborg, 1994; Kaimmer, 1999; Stoner, 2003).

One aim of the present study was to evaluate environmental and fisheries-related variables affecting the catch in a pot fishery for cod in the Baltic Sea. In addition, we extrapolated catches to correspond to the effort that would be used in a commercial fishery, and compared these with catches from other commercial gear types in the same area. By simultaneously evaluating the influence of both fisheries-related and environmental variables, the relative effects of these factors can be separated, thereby aiding an understanding of factors determining the catching efficiency of the pot fisheries.

Material and methods

Experimental set-up

Fishing with pots was conducted in collaboration with local commercial fishers in two areas along the Swedish coastline (Figure 1). In area 1, Hanö Bight, fishing trials were carried out over 2 years, from February 2009 until December 2010. In area 2, Karlskrona archipelago, fishing trials continued over 3 years, from 2009 until

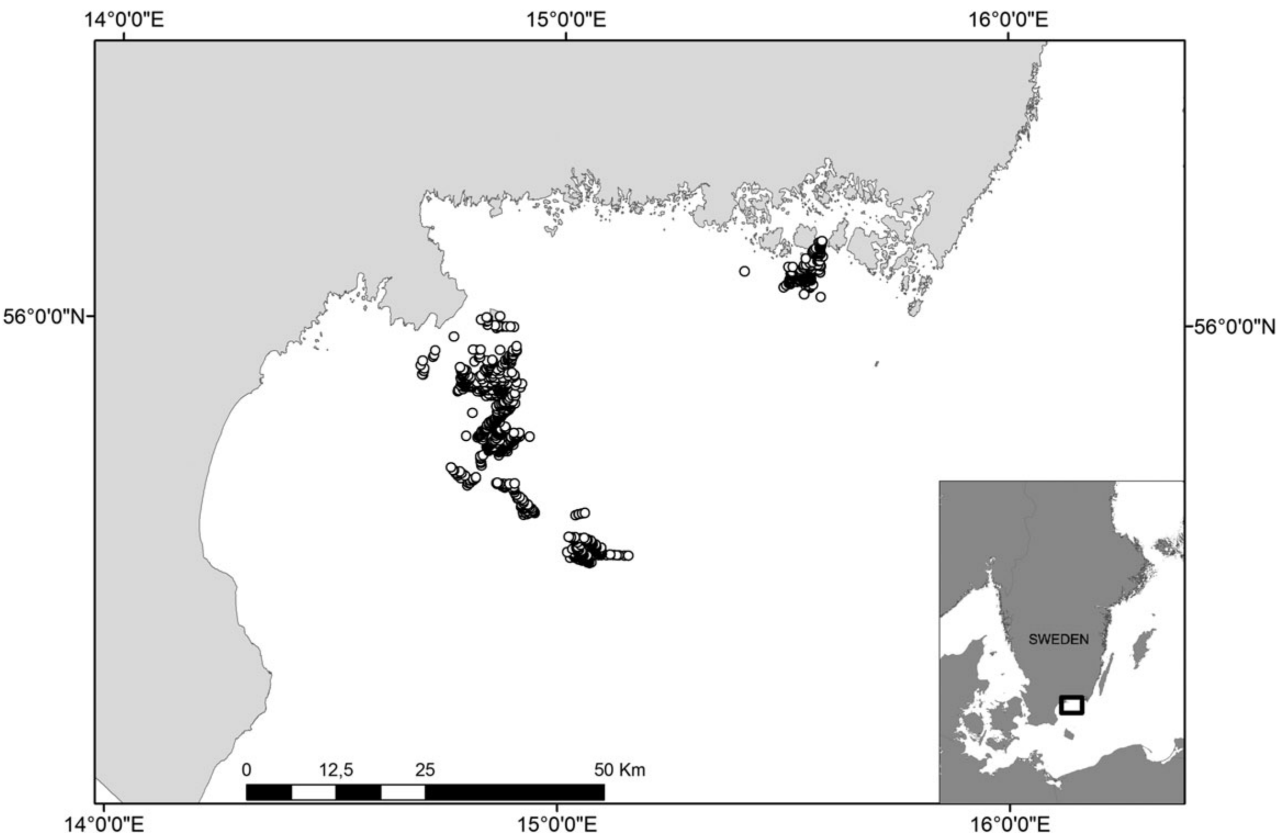

Figure 1. Map of the cod pot fishing areas in the Hanö bight. One dot on the map is the position of a string set during one fishing trip. The dots on the left side of the map are included in area 1 and the dots on the upper right are included in area 2.

2011. Pots used in the study were two-chambered, single-entranced floating cod pots as described by Furevik *et al.* (2008) and Ovegård *et al.* (2011). The pots are collapsible and built with a steel frame in the bottom and two aluminium frames on top. Floats on the top frame produce enough lift in the water to unfold the pot. The pot is 100 cm wide, 150 cm long, and 120 cm high (Figure 2).

Pots were baited with 250 g of fresh chopped herring (*Clupea harengus*) and were deployed in sets, with 2–8 pots along the same connecting bottom line, defined as one string. Pots were attached to the bottom line at a spacing of 50 m between pots, meaning that string lengths varied between 100 and 400 m. Fishers in area 1 deployed up to 12 strings, with 4–8 pots in each string. In area 2, the fisher set up to four strings, with 2–8 pots in each string. Soak time varied between 1–14 d in area 1 and 1–12 d in area 2. Soak time was dependent on weather conditions and the fishers's logistics. The fishers noted the position of the fishing location, the soak time, and the date and time of emptying the pots and the catch size (weight and number) for each pot. Cod catches were divided into two size classes: cod <38 cm in length and cod 38 cm or longer (the minimum legal landing size for Baltic cod), and in certain strings the length of each fish was measured. Fish under 38 cm were returned to the sea. On a large number of fishing trips in area 1, observers joined the fishers on their daily fishing trips. In area 2, observers were only occasionally on board, although regular contact was still maintained to quality check the data.

During the experimental period, some pots were modified and tested for increased fishing efficiency, for example, either by affixing lights to the pots to attract fish (Bryhn *et al.*, 2014), or by fitting escape panels for studying size selectivity. These pots were excluded from the analyses of environmental and fisheries-related effects on pot catches, because the modifications might have affected the catch levels. However, when comparing pot catches with gillnet and longline catches, data from pots with modifications which gave an equal or higher catching efficiency were included. Pots were excluded from the dataset when they had torn meshes or were twisted around the bottom line.

From March 2010, all pots were fitted with an escape panel, with square meshes with the length of the mesh side 45 mm, on one side of the pot, replacing the ordinary mesh panel with a mesh side of 27 mm, to reduce the catch of undersized cod. Ovegård *et al.* (2011) found that a 45-mm square mesh panel significantly reduces the catch of cod smaller than 38 cm. In that study, the estimated length at 50% retention was modelled, using the SELECT method, and thereby found to be 38 cm when escape panels were used. However, looking at the actual counted data presented in the article, comparison of cod lengths between pots with escape panels and without escape panels indicated that all cod >38 cm were retained in the pots. In this study, we have assumed that cod ≥38 cm was retained in pots equipped with an escape panel. The length distribution of the fish caught, in pots without an escape panel, shows that only 3% of the cod are 38 cm. Therefore, considering the small number of cod with this length caught in pots with escape panels and the 50% retention probability at 38 cm, it is unlikely that the assumption mentioned above will affect the results.

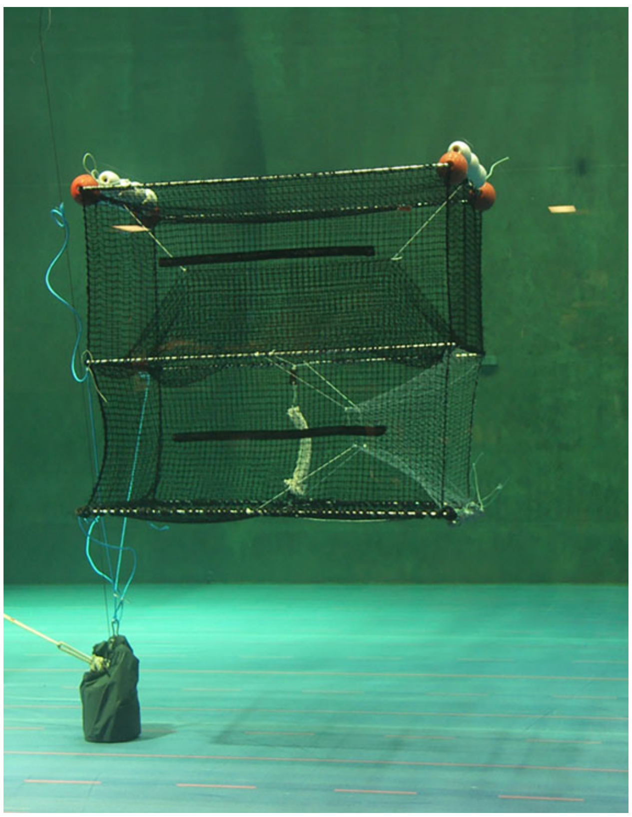

Figure 2. The floating pot with one entrance facing downstream (length: 150 cm, width: 100 cm, and height: 120 cm). The pot is made of a material with a square mesh with the length of the mesh side 27 mm and black 1.5 mm polyethylene twine.

Comparison of pot catches with commercial gillnet and longline catches

The mean weight of cod in kg per pot (WPUE) for each month was calculated for February 2009 until December 2009 for the test fishing conducted in area 1. Only cod with a length of 38 cm or more were included in the analysis. Data from this area and year were chosen due to the fact that in this area the test fishing was more extensive, using more strings of pots than in the other area where data were available. Moreover, in 2010, the catches from the entire cod fishery in the Hanö Bight, including the gillnet and longline fisheries, decreased dramatically, and a large proportion of the cod in this area were found to be in an unusually poor condition, for as yet unknown reasons (ICES, 2011; Ovegård *et al.*, 2012). For this reason, only the 2009 trials were included in the comparison between catch rates in the pot fishery and the gillnet and longline fisheries. In the inshore Baltic cod fishery, both gillnets and longlines are used, often by the same fishers who alternate the two different fishing methods. Therefore to get an estimate of the total daily catches in the combined fishery, gillnet and longline catches have been merged.

The mean WPUE per month from the cod pot trials was used to calculate the potential catches per day and per month in a full-scale commercial fishery, assuming one fishing boat would haul 120 pots per day. That assumption is based on the fact that during the trials the fishers were able to haul up to 96 pots in a day, at the same time as counting and weighing every fish and keeping detailed protocols as regards position, effort, and time. Data on catches from gillnet and longline fisheries conducted in the same area as the pot fishery were extracted from the official EU logbook. All licensed commercial fishers in Sweden are required to keep records and report their catches in accordance with the EU official logbook system and national requirements. For fishing vessels with a length of 8 m or more, cod catches must be reported daily, together with information on gillnet type, length, and location of gillnets. Only active fishing vessels catching >10 tonnes of cod per year were included in the analysis; the 25 boats concerned represented 56% of all licensed fishing vessels operating in the Hanö area. The mean catch per fishing day and fishing vessel were calculated and compared with the pot fishery data.

Analysis of environmental and fisheries-related effects on pot catches

Explanatory variables

Generalized additive models (GAMs) were applied to explain the variability in catches of cod. For these analyses, a suite of data of potential explanatory variables (predictors) was gathered. Both environmental predictors linked with cod habitat use and predictors related to the fishery were used. Environmental variables included in the analyses were water depth, seabed slope, and seabed complexity, together with bottom current velocity and the angle between the bottom current and the line of orientation of the string of pots. The bathymetric raster was constructed from point measurements obtained from the Swedish Maritime Administration. The raster had a spatial resolution of 20 m, and the underlying depth measurements were usually situated around 10 m apart. Seabed slope and complexity were calculated from the bathymetric raster by the slope– function in the extension Spatial analyst of ArcGis 9.3 (ESRI software). The slope–function in ArcGis fits a plane to the depth values of a 3 × 3 cell neighbourhood around each cell. The slope values of this plane are calculated using the average maximum technique (Burrough and McDonnell, 1998). Complexity is calculated as the first derivative of the slope, assuming that changes in the slope provide a measure of the heterogeneity of a habitat (Ardron, 2002). Bottom current data were obtained using a HIROMB Version 4.0 model set-up and developed by the Swedish Meteorological and Hydrological Institute (SMHI). The HIROMB model is a three-dimensional baroclinic model and the set-up used for this study was a 1-nm grid resolution covering Swedish waters from the Skagerrak to the Bay of Bothnia. The meteorological forcing such as wind, temperature, precipitation, and cloudiness among others for the model run was from the SMHI operational atmospheric model HIRLAM. Also, river run-offs are forcing the model. According to Lagemaa *et al.* (2010), the HIROMB model predicts a reasonable match with the observed subsurface currents in most of the cases, where the modelled currents correlate with the observed counterparts often yielding values above 0.5 in both low and high frequencies.

However, the model's uncertainty probably increases with depth and bathymetry. Seabed slope and complexity were log-transformed to reduce the skewness of the data.

In addition to the environmental variables, two temporal variables were included as predictors: fishing month and soak time (the number of days of active fishing). Fishing month captures the seasonal variability in catches, whereas the soak time variable primarily estimates the effect on catch efficiency of bait freshness. To avoid collinearity problems, that is the existence of correlation between the explanatory variables, variance inflation factors were calculated for the explanatory variables included in the models. The threshold value for the variance inflation factor was set at 3 for the final models, as recommended by Zuur *et al.* (2010).

Statistical modelling

The mean numbers of cod per pot (catch per unit effort, cpue) for each string (referred to as the response variable) for both small (<38 cm) and large (≥38 cm) cod as a function of the explanatory variables were described by the use of GAMs (Hastie and Tibshirani, 1986). If pots were equipped with escape panels, only cod ≥38 cm were included in the determination of cpue, and in pots lacking escape panels, two cpues were calculated, one using cod <38 cm and another using those ≥38 cm. GAMs employ a class of equations called smoothers: algorithms which attempt to generalize data into smooth curves by local fitting to subsections of the data (Beck and Jackman, 1998). Data from areas 1 and 2 were analysed using different GAMs. In an initial data exploration phase, cpue was analysed at two spatial grains, i.e. sizes of units of measurement: per individual pot and per string. The shape of the response curve was similar for the two grain sizes, while the deviance given by the models was considerably higher at the string level. This probably indicates that there is a large random component in the catches at the individual pot level, which is eliminated when grain size is increased. Individual pots in a string are likely not independent either. Consequently, all subsequent GAM analyses were performed at the string level, using mean catch per pot in each string. As a string could include 2–8 pots, the total string length was up to 400 m. To avoid overfitting the models and to obtain ecologically relevant responses that were easier to interpret, the final models were kept simple (Lehmann *et al.*, 2002; Sandman *et al.*, 2008), with the maximum number of knots for each of the smoothers limited to four ($k = 4$), allowing the smoother to divide the response from each explanatory variable into a maximum of three parts. Potential differences in responses between years were tested using interaction terms between the factor year and the explanatory variables in the initial GAMs. In this way, we got a separate response curve for each explanatory variable and year. Since these partial responses were similar between years, we decided to exclude the factor year from the analyses to get an average response over the 2 years.

The candidate model took the form:

$$\begin{aligned}\text{cpue} \sim{} & a + s^1(\text{depth}) + s^2(log(slope)) + s^3(log(\text{complexity})) \\ & + s^4(\text{current angle}) + s^5(\text{current speed}) + f\,(\text{month}) \\ & + s^6(soak\text{days}) + \varepsilon,\end{aligned}$$

where a is the intercept, s is a thin plate smoothing spline function, f is a cubic regression spline function, and ε is an error term.

Different smoothing functions were used for the explanatory variables in the models. A cyclic cubic regression spline that forces the response to have the same start and endpoint was used to smooth the month predictor. The other predictors were modelled using a thin plate smoothing spline with an automatic penalizing function that can zero a term completely, i.e. exclude the effect of the explanatory variable from the model (Wood, 2006). A Poisson distribution was used for all models, and to account for overdispersion caused by a large proportion of zeros and low values in the dataset, standard errors were corrected using a quasi-model (Zuur *et al.*, 2010). Models were visually checked for spatial autocorrelation by plotting smoothed correlograms of model residuals (Björnstad and Falck, 2001). Correlograms were produced with the package ncf (http://onb.ent.psu.edu/onb1/R) of R (R Development Core Team, 2011).

The deviance and the statistical significance of the explanatory variables, given by a backward stepwise model selection procedure based on a generalized cross validation (GCV), were used to build a final model. At each step, the least significant variable was dropped until the remaining variables were statistically significant at a 5% level. In cases when all variables were equally significant, different combinations of explanatory variables were tested, and the combination with the lowest GCV score and highest deviance explained was chosen as the final model. The effect of the predictors in the final models was evaluated by partial response curves, which visualize the relationship between the response and the predictors.

To quantify the effect of the soak time on the catch, the mean number of cod per emptied pot was calculated from the partial response curves. Since a Poisson model uses a log-link function, the effect of soak time could be calculated by taking the corresponding exponential factor of the model intercept and the effect from the smoother. This gives a measure of the catch when the effects of all other predictor variables are subtracted. The analyses were performed using the mgcv package (Wood, 2001) of R (http://www.r-project.org/).

Results

Comparison of pot catches with commercial gillnet and longline catches

In the comparison between the pot fishery and the traditional gillnet and longline fisheries in the same area and during the same period, February to December 2009, data from 3995 hauled pots were used, along with 1651 daily fishing reports from 25 fishing boats fishing with gillnets and longlines. The mean length of gillnets set per fishing occasion was 5500 m, whereas a mean of 2600 hooks were used per occasion with the longlines. The comparison showed that on average over the year there was no difference in daily cpues between the cod pots and the traditional fishing gear consisting of gillnets and longlines (378 kg cod per fishing day and vessel for the pot fishery and 374 kg cod for the longline and gillnet fisheries). However the comparison shows that the pot catches were markedly more variable over the season than the catches in the gillnet and longline fisheries. From April until June, the pot fishery generated on average 52% lower daily catches than gillnet and longline fisheries. From August until November, catches in the pot fishery exceeded those in the gillnet and longline fisheries, with on average 54% higher catches (Figure 3).

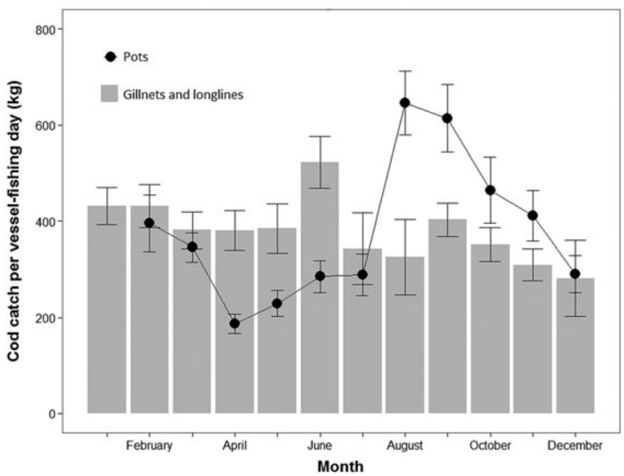

Figure 3. The monthly variation in 2009 for the mean daily catch of cod (kg) per fishing vessel for the pot fishery as well as the gillnet and longline fisheries carried out in area 1. Error bars represents 95% CI for the mean catch of cod per day and fishing vessel. In the pot fishery, error bars are based on catch per pot for the fishing vessel carrying out the experimental study. The 95% CI in the longline and gillnet fishery is based on the daily catch per fishing vessels fishing in the same area as the pot fishing was carried out in.

Analysis of environmental and fisheries-related effects on pot catches

Data used in the GAM analysis are summarized in Table 1. Pot fisheries' catches varied between the two areas and fishing periods. The cpue and WPUE in area 2 were lower than in area 1, and in both areas cpue and WPUE were higher in 2009 than in subsequent years (Table 1).

The GAMs showed that the variations in the cpues for cod $\geq$38 cm could be explained mainly by changes in depth, month, and the number of soak days (Table 2). In area 1 (Model A), cpue was also affected by the current's angle to the string. For small cod (<38 cm) depth, month, soak days, slope, and complexity were significant predictors (Model C). In location 2 (Model B), all variables apart from the current's angle to the string of pot were significant predictors for the cpues for large cod. Bottom current velocity did not contribute to any of the tested models. For cod smaller than 38 cm in area 2, there were not enough data to carry out the analysis. The deviance explained by the model was higher in Model A (32%) than in Models B and C (14.4 and 16.6%).

The partial effects of the predictors in each model are shown in Figure 4. The cpues of cod larger than 38 cm increased with depth in area 1. In area 2, on the other hand, catches were highest in the shallowest areas. In both areas, we observed a temporal variation, with peaks of cpue in September. Cpue increased with the number of soak days, peaking at 6–8 d. The increase was not as distinct in area 2 as in area 1. In area 1, the cpue increased with current angle (relative to the orientation of the string of pots) up to an angle of ~40°, when the response levelled out.

The catch variation for small cod, <38 cm, in area 1 is explained by depth, slope, complexity, month, and soak time. Cpue peaked at ~30 m depth, in areas with low slope but high seabed complexity. As for large cod, catches increased with soak time, in this case up

Table 1. Number of strings, pots emptied, cpue, and WPUE of cod with a length above 38 cm for each area and year included in the GAM model.

Area	Year	Number of strings hauled	Number of pots emptied	Mean number of cod per pot (cpue)	Mean kg cod per pot (WPUE)
1	2009	555	3420	3.4	3
1	2010	765	3608	2	1.4
1	2009–2010	1320	7028	2.7	2.2
2	2009	143	606	1.6	1.7
2	2010	278	1001	1.4	1.2
2	2011	152	1123	1.1	1
2	2009–2011	573	2730	1.4	1.3

Table 2. Result of GAMs for large cod in area 1 (Model A) and area 2 (Model B), as well as small cod in area 1 (Model C).

Area	GAMs	Deviance explained %	*n*	d.f.	GCV	Predictors	*F*	*P*
1	Model A: cpue ≥38 cm	32.0	1240	3	16.909	Depth	9.356	1.38*e* − 08
						Month	51.327	<2*e* − 16
						Soak days	35.346	<2*e* − 16
						Current's angle to string	6.552	5.80*e* − 05
2	Model B: cpue ≥38 cm	14.4	465	3	3.9653	Depth	1.791	0.01264
						Month	23.358	8.74*e* − 11
						Soak days	4.978	0.00109
1	Model C: cpue <38 cm	16.6	683	3	13.931	Depth	5.309	0.00075
						Month	14.014	4.99*e* − 07
						Soak days	13.215	9.77*e* − 10
						Slope	1.383	0.01931
						Complexity	3.169	0.01090

Deviance explained, number of replicates (*n*), degrees of freedom (d.f.), and GCV score for the model and significance level (*F* and *P*) of each predictor variable are provided.

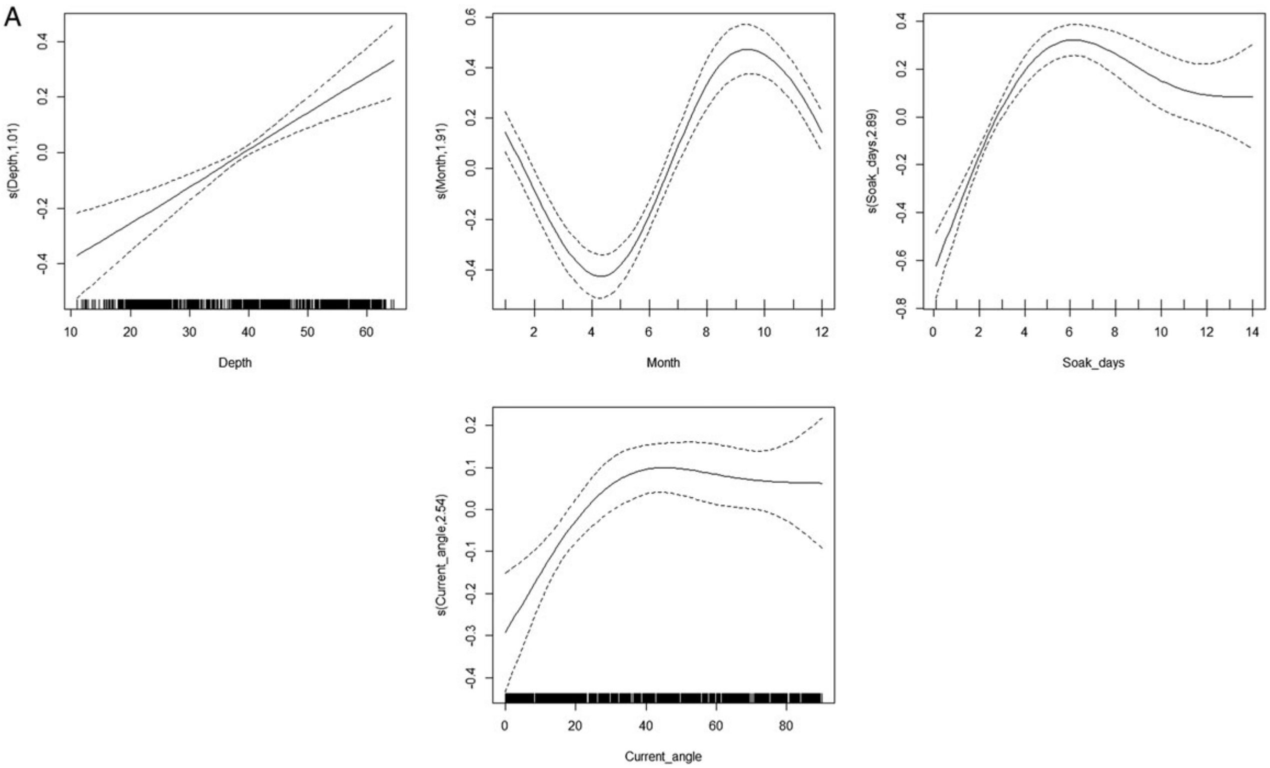

Figure 4. Partial response curves for model A, B and C of the GAMs for cod cpues in relation to environmental and fisheries variables. All graphs show the partial effects of each predictor on the cpues. Values above 0 indicate a positive effect of the predictor on the cpues.

to ∼9 d. The catches differed between months, but the pattern was almost opposite to that for the catches of small cod, with the lowest catches in June to October.

To isolate the effect of soak time on the cpue, the mean cpue was calculated from the partial response curves. In area 1, the effect was stronger than in area 2. The increase in cpue went from 1.4 cod per pot after 1 soak day to 2.9 cod per pot when the pots were left in the water for 6 d. In area 2, the increase was from 1.1 after one soak day to 1.6 after 7 d (Figure 5).

Discussion

In the process of developing and implementing an alternative fishing gear, it must be emphasized to evaluate if catches from the experimental gear are comparable with those using the traditional types of gear. Comparable or higher catches with the same input of effort are the most solid argument for fishers to change from a familiar to an alternative type of gear. It must also be emphasized to evaluate how catches are affected by environmental and fisheries-related factors to develop and increase the effectiveness of the new fishery. Pots' catching efficiency is shown to be variable and dependent on many factors, such as season, depth, soak time, and their placement in relation to the prevailing current. However, they do generate commercially viable catches overall and can certainly be seen as a potential alternative fishing gear to commercial gillnet and longline fisheries.

The fishery conducted in 2009 in area 1 most closely resembled a commercial fishery and was therefore used in comparison with the traditional fishery in the same area. On average over the whole year,

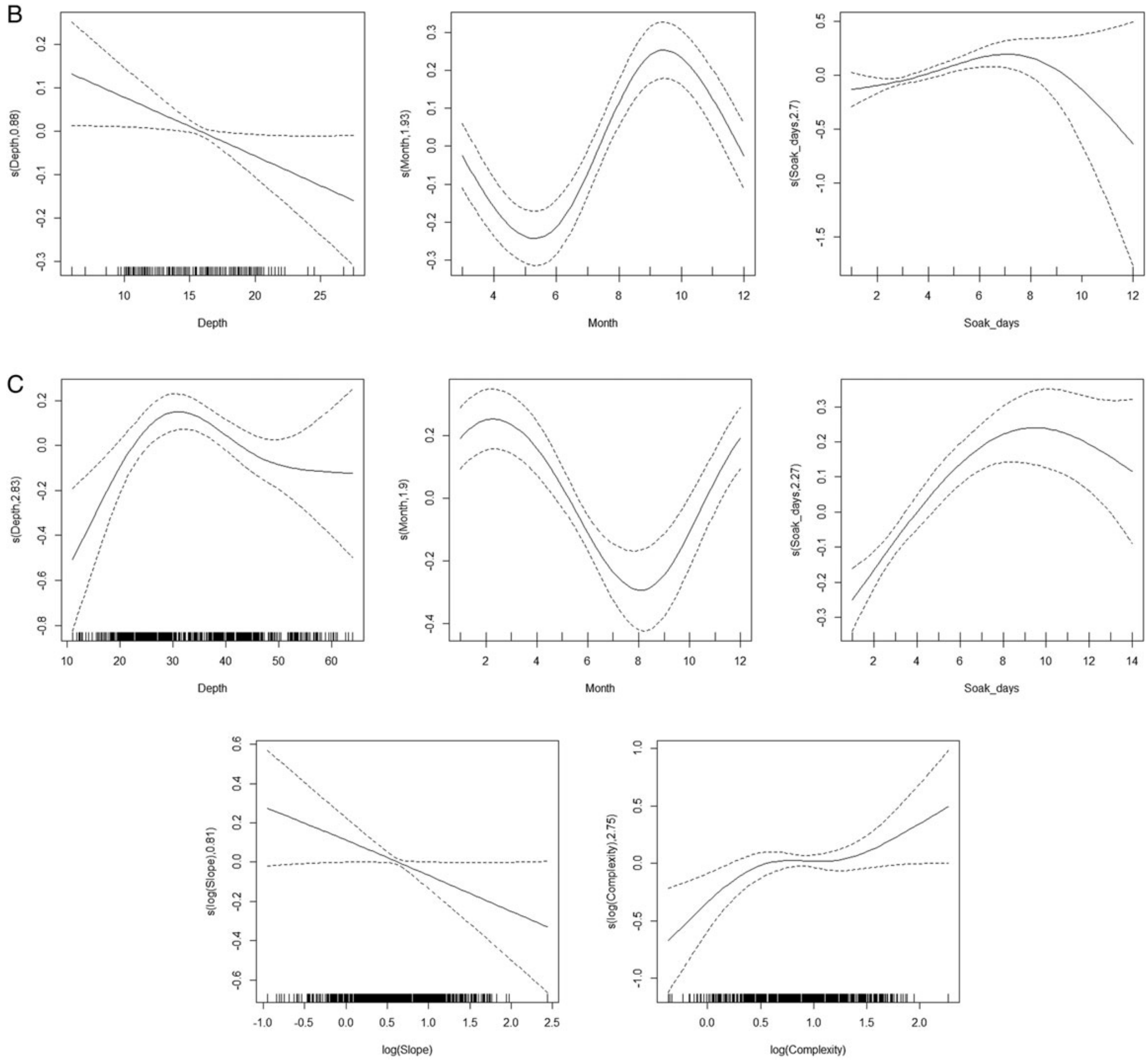

Figure 4. Continued

daily catches per fishing day and vessel were equal in both fisheries. However, the catch levels in the pot fishery varied over the season compared with the catches in the longline and gillnet fisheries. The pot fishery gave lower daily catches per vessel at the beginning of the fishing season, while from August until November it gave higher catches. This shows how cod pots have the potential to generate large enough catches to be economically sound in the Hanö Bight. However, another study has shown that cod caught in pots and on hooks are generally in worse condition and of older age classes than cod caught in gillnets (Ovegård *et al.*, 2012). This could contribute to a lower catch value for the cod caught in pots, which also needs to be taken into account. In the southern part of the Baltic Sea, where the study was carried out, there is relative little seal interference in the gillnet and longline fisheries compared with in areas further north in the Baltic. However, as the seal fisheries, conflict is expected to increase and spread southwards in the future due to growing seal populations (Anon, 2012), a seal-safe pot fishery might in the future be the only economically sustainable option even for the south Baltic inshore fishery. It should also be noted that the fishers trying out the pots were inexperienced when it came to fishing with baited fishing gear. This might have affected the catches negatively at the beginning of the study period.

In the models evaluating the effects of environmental and fisheries-related variables, time of the year (month) was a significant predictor affecting the cpue, corroborating the pattern seen in the comparison with gillnet and longline fisheries. The model showed that, in both areas, the highest catches were in August and September and the lowest catches in April. Most cod in the area originate in the spawning area in the Bornholm basin, where spawning takes place in summer (Wieland *et al.*, 2000; Bleil *et al.*, 2009). Cod are known to undertake distinct seasonal migrations to specific feeding and spawning areas (Aro, 1989). It is therefore likely that the high cpues in autumn reflect migration patterns, when post-spawning cod migrate to productive coastal feeding grounds, i.e.

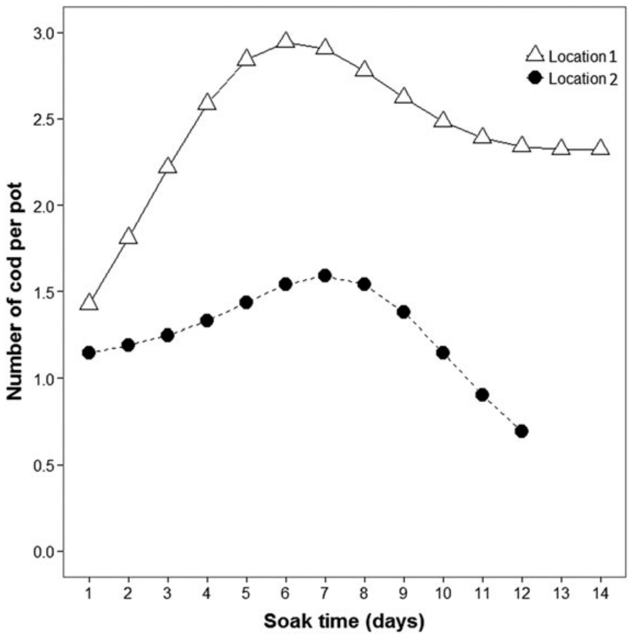

Figure 5. The cpue calculated from the partial response curves for pots set in the water for 1–10 soak days. In location 2, there were no pots emptied after 12 d.

the fishing grounds in this study. However, environmental variables also contribute to structuring the abundance and distribution of the stocks, which in turn show up as variations in the catches (Hoffman and Powell, 1998).

Other variables which helped to explain variations in the cpues for large cod were water depth, soak time, and current angle to the string. The response of the cpues to water depth was opposite in the two study areas. This might reflect the difference in spatial extent and range of the water depths covered in the two areas, both being much larger in area 1 than in area 2. Another explanation might be that, in area 2, the pots were set further inshore than in area 1, where a lot of fishing was carried out offshore. In shallow inshore waters, other depth-dependent factors might affect where the fish are and therefore where cpues might be high, such as the abundance of prey which in turn might be affected by temperature. In deep waters, other factors such as the oxycline might also affect the abundance of cod.

The direction of the current in relation to the string turned out to be a significant factor in area 1, but not in area 2. In area 1, the more perpendicular the string of pots was to the direction of the current the higher catches. The bait plume is thereby spreading over a larger area, which also enables attraction of cod over a greater area. In area 1 of the study, the bathymetry is relatively simple and the general current patterns should be captured. It must, however, be stressed that there are many sub-grid processes that can affect the current which are not resolved by the 1-nm model (i.e. finer than 1 nm × 4 m). However, Lagemaa *et al.* (2010) predicted a reasonable match with the observed subsurface currents giving us a general view of the dominant current direction and velocity. The only way to determine the actual currents acting on each string of pots would be to measure currents *in situ*. This was not possible and therefore, the model was the only way to estimate the dominant direction of the current as well as the current velocity at the time in the area. In area 2, an area closer inshore and located in Karlskrona archipelago which consist of around 1650 islands, the bathymetry is most likely more complex. This increases the uncertainty of the model and could be the reason the cpue was not explained by the current's angle to the string.

As regards soak times, it has been found previously that the release rate of attractants from baits is initially high then declines rapidly, so that a pot will only fish effectively for a few hours (Løkkeborg, 1990; Furevik, 1994). However, our results showed increased catches with soak time, at least up to 6–7 d. The isolated effect of soak time on the cpue of the pots, i.e. where the effects of the other predictors had been eliminated, was estimated using the GAM. In area 1, the increase in catches with soak time is more pronounced, showing doubled catches after 6 d, whereas in area 2 the increase in catches is much smaller. In both areas, catches decrease after 6–8 soak days, indicating that fish have more time to escape from pots and thereby if pots are set out for too long more fish will escape than enter the pots. These results suggest that factors other than bait attract and lure fish into the pot. One explanation could be that the fish inside the pot attract other fish by the movement they create. After fish enter the pot most fish appear calm, however, aggressive behaviour along with instances where fish batter themselves against the net to try to escape can occur (Thomsen *et al.*, 2010). Another explanation could be that fish caught in pots might start chewing on the bait, and this could in turn expose new surfaces from which attractants might be released which in time attract even more fish. It has been shown that, due to low diffusivity, it is just a thin surface layer of the pieces of fish used as bait that will release its contents of odour (Westerberg and Westerberg, 2011). Therefore, Westerberg and Westerberg (2011) suggest that cutting bait in small pieces, exposing new surfaces, will increase the concentration of attractants in the plume.

The model explaining cpues of small cod in area 1 came out different from that for the large cod. The difference was that the bottom topography, described by the slope and complexity of the seabed, affected the cpue for small cod but not the cpue for large cod. Juvenile cod abundance in the Baltic Sea has been suggested to depend on a combination of depth and bottom topography, with the highest abundances found in relatively shallow areas with strong slopes (Bergström *et al.*, 2011). Another earlier study showed that the abundance of 1-year-old cod peaked in the shallow coastal waters of
ö Bight, while the greater part of the mature cod, i.e. 3- and 5-year-old fish, was found offshore in the deeper areas (Hjelm *et al.*, 2004). The lowest catches of small cod occurred at the same time as the highest peak in catches of large cod. One potential explanation for the differences observed in the models of cpues for small (<38 cm) and large (≥38 cm) cod, both with respect to month and depth, could be cannibalism, which is fairly common in the Baltic cod population (Neuenfeldt and Köster, 2000). It is also known that cannibalism takes place in pots. In pots without escape panels, where the large cod get the opportunity to feed on the small cod, stomach content analysis has shown that the frequency of cannibalism was several times higher than in cod caught in pots with an escape panel (Ovegård *et al.*, 2011). Thus, the negative relationship in cpues between small and large cod observed in the model may reflect the differences in spatial distributions over the year, further accentuated by cannibalism within the pots.

The deviance explained by the models was overall fairly low, reflecting the large variation in catches. In this study, we tried to minimize the variations by using data from strings of pots instead of solitary pots. Individual pots do get very variable catches and many pots catch no fish at all. Aggregating catches from pots in one string limits the variation between fishing occasions and reduces the number of zero catches. In addition to variability caused merely by random spatial distribution of the cod, the low percentage of deviance explained by the models might indicate that we are missing important explanatory variables. For example, oxygen levels and salinity are factors that affect the abundance of cod in the Baltic (Hjelm *et al.*, 2004; Tian *et al.*, in preparation).

Another factor that can influence the pots' catching efficiency is the sea temperature, which affects the way the cod use their habitat (Ljungberg, 2013). To further improve the catching efficiency of the pots, one obvious task will be to look more closely into the effects of the local environment on cod behaviour around pots.

The results of this study show that cod pots can be a valid alternative to traditional fishing gear. They also indicate that both fishing practices and the environmental conditions of the fishing grounds may have substantial effects on catch levels. By exploring these relationships further and taking them into account when fishing, catching efficiency of the pots is likely to improve considerably.

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References

Anon. 2012. Swedish National Management Plan for Grey Seals Stocks in the Baltic. Nationell förvaltningsplan för gråsäl i Östersjön, Havs- och vattenmyndigheten. 66 pp. https://www.havochvatten.se/download/18.576c1bad139e467697d80006088/1348912841150/forvaltningsplan-grasal-120924.pdf (last accessed 29 December 2014).

Ardron, J. A. 2002. A GIS recipe for determining benthic complexity: an indicator of species richness. *In* Marine Geography: GIS for the Oceans and Seas, pp. 169–175. Ed. by J. Breman. ESRI Press, Redlands, CA, USA. 224 pp.

Aro, E. 1989. A review of fish migration patterns in the Baltic. Rapports et Procès-Verbaux des Réunions du Conseil International pour l'Exploration de la Mer 1989, 190: 72–96.

Arreguín-Sánchez, F. 1996. Catchability: a key parameter for fish stock assessment. Reviews in Fish Biology and Fisheries, 6: 221–242.

Beck, N., and Jackman, S. 1998. Beyond linearity by default: Generalized additive models. American Journal of Political Science, 42: 596–627.

Bergström, U., Bergström, L., Carlén, I., and Isaeus, M. 2011. GIS-baserade metoder för att kartlägga fiskars livsmiljöer i grunda havsområden. Swedish Environmental Protection Agency Report, 6427: 74 pp.

Björnstad, O. N., and Falck, W. 2001. Nonparametric spatial covariance functions: Estimation and testing. Environmental and Ecological Statistics, 8: 53–70.

Bleil, M., Oeberst, R., and Urrutia, P. 2009. Seasonal maturity development of Baltic cod in different spawning areas: importance of the Arkona Sea for the summer spawning stock. Journal of Applied Ichthyology, 25: 10–17.

Bruckmeier, K., and Höj Larsen, C. 2008. Swedish coastal fisheries-From conflict mitigation to participatory management. Marine Policy, 32: 201–211.

Bryhn, A. C., Königson, S., Lunneryd, S.-G., and Bergenius, M. 2014. Green lamps as visual stimuli affect the catch efficiency of floating cod (*Gadus morhua*) pots in the Baltic Sea. Fisheries Research, 157: 187–192.

Burrough, P., and McDonnell, R. A. 1998. Principles of Geographical Information Systems. Oxford University Press, Oxford, UK.

Engås, A., and Løkkeborg, S. 1994. Abundance estimation using bottom gillnet and longline—the role of fish behaviour. *In* Marine Fish Behaviour in Capture and Abundance, pp. 134–165. Ed. by A. Fernö, and S. Olsen. Fishing News Books, Oxford. 217 pp.

Furevik, D. M. 1994. Behaviour of fish in relation to pots. *In* Marine Fish Behaviour in Capture and Abundance, pp. 28–44. Ed. by A. Fernö, and S. Olsen. Fishing News Books, Oxford. 217 pp.

Furevik, D. M., Humborstad, O. B., Jorgensen, T., and Lokkeborg, S. 2008. Floated fish pot eliminates bycatch of red king crab and maintains target catch of cod. Fisheries Research, 92: 23–27.

Hastie, T., and Tibshirani, R. 1986. Generalized additive models. Statistical Science, 1: 297–318.

Hemmingsson, M., Fjälling, A., and Lunneryd, S. G. 2008. The pontoon trap: Description and function of a seal-safe trap-net. Fisheries Research, 93: 357–359.

Hjelm, J., Simonsson, J., and Cardinale, M. 2004. Spatial Distribution of Cod in the Baltic Sea in Relation to Abiotic Factors—a Question of Fish-Age and Area. ICES CM, 16. 35 pp.

Hoffman, E., and Powell, T. 1998. Environmental variability effects on the marine fisheries: four case histories. Ecological Applications, 8: S23–S32.

ICES. 2011. Report of the Baltic Fisheries Assessment Working Group (WGBFAS), 12–19 April, 2011. ICES Document CM 2011/ACOM, 10. 824 pp.

Jennings, S., Kaiser, M. J., and Reynolds, J. D. 2001. Marine Fisheries Ecology. Blackwell, Oxford, UK. 432 pp.

Kaimmer, S. M. 1999. Direct observations on the hooking behavior of Pacific halibut, *Hippoglossus stenolepis*. Fisheries Bulletin, 97: 873–883.

Königson, S. 2011. Seal and Fisheries: A Study of the Conflict and Some Possible Solutions. PhD thesis, Department of Marine Ecology, University of Gothenburg. http://hdl.handle.net/2077/25022 (last accessed 29 December 2014).

Königson, S., Lunneryd, S. G., Sundqvist, F., and Stridh, H. 2009. Grey seal predation in cod gillnet fisheries in the central Baltic Sea. Journal of North Atlantic Fisheries Science, 42: 41–47.

Lagemaa, P., Suhhova, I., Nõmm, M., Pavelson, J., and Elken, J. 2010. Comparison of Current Simulations by the State-of-the-Art Operational Models in the Gulf of Finland with ADCP Measurements. IEEE/OES US/EU, Baltic International Symposium (BALTIC). 11 pp. http://dx.doi.org/10.1109/BALTIC.2010.5621656 (last accessed 29 December 2014).

Lehmann, A., Overton, J. M., and Leathwick, J. R. 2002. GRASP: generalized regression analysis and spatial prediction. Ecological Modelling, 157: 189–207.

Ljungberg, P. 2013. Habitat choice and foraging behaviour in temperate coastal environments. PhD thesis, Lund University.

Løkkeborg, S. 1990. Rate of release of potential feeding attractants from natural and artificial bait. Fisheries Research, 8: 253–261.

Løkkeborg, S. 1994. Fish behaviour and longlining. *In* Marine Fish Behaviour in Capture and Abundance, pp. 9–27. Ed. by A. Fernö, and S. Olsen. Fishing News Books, Oxford. 217 pp.

Løkkeborg, S., Olla, B. L., Pearson, W. H., and Davis, M. W. 1995. Behavioural responses of sablefish, *Anoplopoma fimbria*, to bait odour. Journal of Fish Biology, 46: 142–155.

Neuenfeldt, S., and Köster, F. 2000. Trophodynamic control on recruitment success in Baltic cod: the influence of cannibalism. ICES Journal of Marine Science, 57: 300–309.

Ovegård, M., Bernt, K., and Lunneryd, S-G. 2012. Condition indices of Atlantic cod (*Gadus morhua*) biased by capturing method. ICES Journal of Marine Science, 69:1781–1788.

Ovegård, M., Königson, S., Persson, A., and Lunneryd, S. G. 2011. Size selective capture of Atlantic cod (*Gadus morhua*) in floating pots. Fisheries Research, 107: 239–244.

Quinn, T. J., Deriso, R. B., and Hoag, S. H. 1985. Methods of population assessment of Pacific halibut. Scientific Report No. 72. International Pacific Halibut Commission, Seattle.

R Development Core Team. 2011. R: a Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org (last accessed 29 September 2014), ISBN 3-900051-07-0.

Sandman, A., Isaeus, M., Bergström, U., and Kautsky, H. 2008. Spatial predictions of Baltic phytobenthic communities: Measuring robustness of generalized additive models based on transect data. Journal of Marine Systems, 74: 86–96.

Sigler, M. F. 2000. Abundance estimation and capture of sablefish (*Anoplopoma fimbria*) by longline gear. Canadian Journal of Fisheries and Aquatic Science, 57: 1270–1283.

Stoner, A. W. 2003. Hunger and light level alter response to bait by Pacific halibut: laboratory analysis of detection, location and attack. Journal of Fish Biology, 62: 1176–1193.

Stoner, A. W. 2004. Effects of environmental variables on fish feeding ecology: implications for the performance of baited fishing gear and stock assessment. Journal of Fish Biology, 65: 1445–1471.

Suuronen, P., Chopin, F., Glass, C., Løkkeborg, S., Matsushita, Y., Queirolo, D., and Rihan, D. 2012. Low impact and fuel efficient fishing—Looking beyond the horizon. Fisheries Research, 119–120: 135–146.

Thomsen, B., Humborstad, O.-B., and Furevik, D. M. 2010. Fish pots: fish behavior, capture process and conservation issues. *In* Behavior of Marine Fishes: Capture Processes and Conservation Challenges, pp. 143–158. Ed. by P. He. Blackwell Publishing. 392 pp.

Tian, H., Casini, M., Bartolino, V., Bergström, U., Jounela, P., Aro, E., Cardinale, M., *et al.* 2014. Spatio-temporal dynamics of a fish predator: density-dependent and hydrographic effects on Baltic Sea cod population. In preparation.

Westerberg, H., Lunneryd, S. G., Fjälling, A., and Wahlberg, M. 2006. Reconciling fisheries activities with the conservation of seals throughout the development of new fishing gear: A case study from the Baltic fishery–grey seal conflict. American Fisheries Society Symposium, 49: 587–598.

Westerberg, H., and Westerberg, K. 2011. Properties of odour plumes from natural baits. Fisheries Research, 110: 459–464.

Wieland, K., Jarre-Teichmann, A., and Horbowa, K. 2000. Changes in the timing of spawning of Baltic cod: possible causes and implications for recruitment. ICES Journal of Marine Science, 57: 452–464.

Wood, S. N. 2001. mgcv: GAMs and generalized ridge regression for R. R News, 1: 20–25.

Wood, S. N. 2006. Generalized Additive Models: an Introduction with R. Chapman and Hall/CRC, FL.

Zuur, A. F., Leno, E. N., and Elphick, C. S. 2010. A protocol for data exploration to avoid common statistical problems. Methods in Ecology and Evolution, 1: 3–14.

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