Distribution of harbour porpoise prey species in the Baltic Sea

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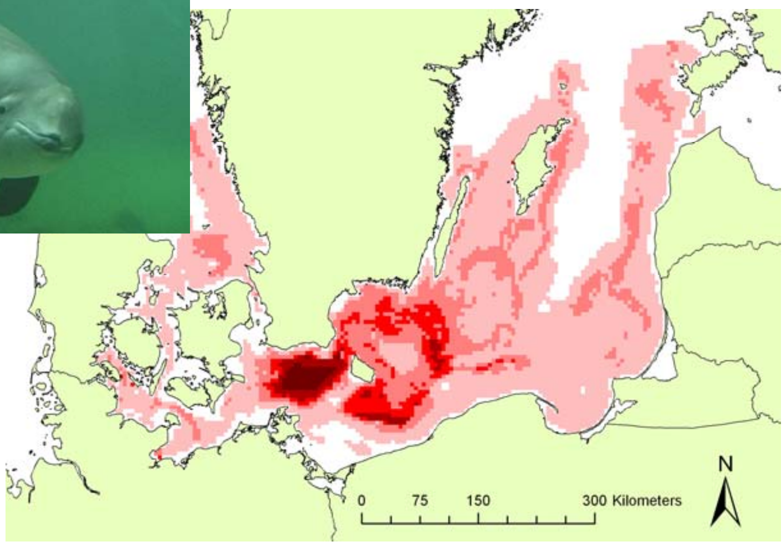

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Sammanfattning

Idag är kunskapen om tumlaren (*Phocoena phocoena*) i Östersjön begränsad, och skötseln av denna hotade population är därför en svår uppgift. För närvarande planeras ett internationellt projekt med målet att ta fram en pålitlig populationsuppskattning och geografisk distribution av tumlaren i Östersjön.

Som ett första steg i detta projekt finansierade Naturvårdsverket under 2007 en studie för att undersöka distributionen av viktiga bytesarter för tumlaren i Östersjön. Tre arter modellerades rumsligt; torsk, sill och skarpsill. Resultaten från denna studie kommer att användas för att undersöka relationerna mellan tumlare och deras bytesdjur, samt för att förutsäga den geografiska distributionen av tumlare i Östersjön.

Den rumsliga modelleringen gjordes med hjälp av generella additiva modeller i mjukvaran GRASP. Miljövariabler, eller prediktorer, i form av GIS-skikt används i modelleringen. Djup, lutning och lutningsriktning beräknades från ett batymetriskikt som är tillgängligt för vetenskapliga ändamål. Årsmedelvärden av bottentemperatur, pyknoklinens djup, bottensalinitet och bottenströmmarnas hastighet, samt bottensediment och fotiska zoner, tillgängliggjordes av det internationella projektet BALANCE. Ytsalinitet från Svenska Nationalatlasen användes också.

Som responsdata användes tråldata från ICES internationella undersökningar BITS (Baltic International Trawl Survey) och BIAS (Baltic International Acoustic Survey). Data från flera år användes i modelleringen för att få fram generella modeller av den geografiska distributionen av de aktuella arterna.

Modellerna för torsk för första och fjärde kvartalet av året har Spearman r_s-värden på omkring 0,5. Detta måste anses som bra för biologiska modeller som beskriver utbredningen av mobila arter. Viktiga prediktorvariabler i båda modellerna var djup, bottensalinitet, bottentemperatur och lutning. De största mängderna av torsk syns söder om Skånska kusten och kring Bornholm. Under första kvartalet finns områden med hög abundans söder om Skånska kusten samt söder om Bornholm, medan de under fjärde kvartalet är mer koncentrerade mellan Skåne och Bornholm.

Modellerna för stor och liten sill var inte riktigt så stabila som torskmodellerna, och r_s-värdena ligger på omkring 0,43. Den viktigaste prediktorn i båda modellerna är ytsalinitet, vilket är den enda tillgängliga variabeln som inte är direkt relaterad till bottenförhållanden. Eftersom sill är en pelagisk art så är det logiskt att denna variabel är viktig, och bristen på pelagiska prediktorer kan vara en anledning till att sill-modellerna inte blev helt tillfredsställande. Att modellera alla storleksklasser av sill tillsammans fungerade inte bra; modellen fick ett r_s-värde på 0,34. Detta visar att storlek hos sill kan ha inflytande på vilka miljöfaktorer som är ekologiskt relevanta för utbredningen av fisken. Både stor och liten sill förekommer i hög abundans norr om Gotland utanför de svenska skärgårdarna samt längs Estlands och Lettlands kuster, främst i öppna vatten utanför kustzonen.

Modellen för skarpsill är den mest stabila i denna studie. Modellen får ett r_s-värde på 0,60 och den viktigaste prediktorn är ytsalinitet. Trots att skarpsill precis som sill är en pelagisk art så verkar det som om de framför allt bottenrelaterade prediktorvariabler som fanns tillgängliga i denna studie är tillräckliga för att ta fram goda modeller för utbredningen av skarpsill i Östersjön. Även skarpsill är mer frekvent förekommande i de öppna vattnen norr om Gotland.

Summary

Today, there is limited knowledge about the Baltic Sea harbour porpoise (*Phocoena phocoena*), and the management of this endangered population is therefore a difficult task. Presently, an international project with the aim to obtain a reliable estimate of the population size and geographic distribution of harbour porpoises in the Baltic Sea, is being planned.

As a first stage to this project, the Swedish Environmental Protection Agency financed a study to investigate the distribution of important harbour porpoise prey species in the Baltic Sea during 2007. Three species has been modelled; cod, herring and sprat. The results will be used to study the relationship between porpoises and their prey, and to predict the distribution of porpoises in the Baltic Sea.

Spatial modelling was done using general additive modelling (GAM) in the GRASP software. Environmental variables, or predictors, in the form of GIS layers, were used for modelling. Depth, slope and aspect were derived from a bathymetry grid freely available for scientific purposes. Annual means of bottom temperature, pyknocline depth, bottom salinity and bottom current velocity, and bottom sediments and photic zones were all made available from the international BALANCE project. Surface salinity from the Swedish national atlas was also used.

Response data were trawling data from ICES international Baltic surveys BITS (Baltic International Trawl Survey) and BIAS (Baltic International Acoustic Survey). Data from several years were used in modelling to achieve general models of the distribution of the target species.

The models for cod during the first and fourth quarters of the year have spearman r_s-values of about 0.5. This must be considered good in biological models describing the distribution of mobile species. Important predictor variables in models for both the first and fourth quarters were depth, bottom salinity, bottom temperature and slope. The highest abundance of cod in the study area appears south of southern Sweden and around Bornholm. The area of high abundance is south of Sweden and south of Bornholm in the first quarter, while in the fourth quarter high abundances are more concentrated between southern Sweden and Bornholm.

Models for large and small herring are not quite as stable as the cod models, and r_s-values are around 0.43. The most important predictor in both models is surface salinity, which is the only variable not related to the bottom. As herring is a pelagic species this is logic, and the lack of pelagic predictor variables may also be the reason the herring models are not completely satisfying. Modelling all sizes of herring together did not work well, with an r_s-value of about 0.34. This shows that size in herring may have an influence on what environmental factors are ecologically relevant for the distribution of fish. Both large and small herring occur in higher abundances north of Gotland outside the Swedish archipelagos and the coasts of Estonia and Latvia, primarily in open waters away from the shallow coastal areas.

The model for sprat is the most stable one. The r_s-value is 0.60 and the most important predictor is surface salinity. Even though sprat is also a pelagic species just like herring, the mostly bottom related predictor variables available here seem to be enough to produce good models and predictions of sprat distribution in the Baltic Sea. Like herring, sprat is most abundant in the open waters north of Gotland

Introduction

Today, there is limited knowledge about the Baltic Sea harbour porpoise (*Phocoena phocoena*), and the management of this endangered population is therefore a difficult task. International organisations such as HELCOM and ASCOBANS have recommended that the bycatch should not exceed 1% of the total population. According to the Swedish national management plan for the harbour porpoise, this goal should be reached at 2010. The Swedish Board of Fisheries is working to estimate bycatch in commersial fisheries in accordance with EU regulation 812/2004. To evaluate the impact of the bycatch and to know if the goal of 1% is achieved, the bycatch must be assessed in relation to the size of the population. However, available population size estimates for the Baltic Sea are imprecise and based on very few observations.

The harbour porpoise is also listed in the EU habitat directive, which means their habitat should be protected within the Natura 2000 network. However, the geographic distribution and habitat use of the harbour porpoise in the Baltic Sea is unknown.
The fact that porpoises are rare in the Baltic has a number of implications for how a survey to obtain abundance estimates should be performed. Traditional methods using observations from airplanes or ships in line transects that have been used in the Baltic (Berggren et al 2004) are considered ineffective in areas of such low densities (ASCOBANS Jastarnia plan).

Harbour porpoises is one of the smallest cetaceans in the world, and because of its small size and cold water environment, it is not capable of saving enough energy to go without food for long periods of time (Kastelein & Lavaleije 1992 and Kastelein et al 1997). It is therefore believed that porpoises have to search for food regularly and that their distribution is closely connected to that of their prey. This is the case for most cetaceans (Gaskin 1982).

Presently, an international project with the aim to obtain a reliable estimate of the population size and geographic distribution of harbour porpoises in the Baltic Sea, is being planned. The project will use Static Acoustic Monitoring (SAM) devices to achieve this. It will also investigate what environmental determinants influence the spatial and temporal distribution of porpoises, using general additive modelling (GAM).

The first part of the project, financed by the Swedish Environmental Protection Agency during 2007, includes a literature study about preferred food species in Baltic Sea harbour porpoise, field work using SAM devices in Danish waters, collecting available data on environmental variables that may influence distribution of harbour porpoises in the Baltic Sea, and modelling the spatial distribution of certain important prey species, to achieve surface covering habitat maps. The spatial modelling of prey species will be presented in this report.

In the above mentioned literature study, several of the reviewed papers show that herring, sprat and cod are important food items for porpoises in the Baltic Sea, and therefore the habitat modelling in this study was concentrated on those three species. These are also important species for the fisheries, and there are dedicated surveys for the distribution of those species organised by ICES, the data from which we have had the opportunity to work with in this study.

Material and methods

GAM modelling

Spatial modelling of three porpoise prey species was done in GRASP (Generalized Regression Analysis and Spatial Predictions), a set of S-PLUS/R functions developed for modelling and analysis of the spatial distribution of species (Lehmann et. al. 2002). GRASP communicates with ArcView, and resulting distribution maps are in ArcView format.

GRASP uses GAM, generalized additive models (Hastie and Tibshirani 1986), to fit predictor variables independently by non-parametric smooth functions. The best model is selected through a stepwise procedure where successively simpler models are compared with a measure such as Akaike's Information Criterion.

All modelling was done using map layers in the Swedish national projection RT90 2.5 GON W. Predictor layers and resulting map predictions were all in 5x5 km grids.

Abundance modelling

Maps created from models using abundance data shows the abundance of the species in question for each cell in a raster. In this case, where fish is modelled using trawling data, the response data was Catch Per Unit Effort (CPUE), and so the maps show predicted CPUE for each raster cell.

When modelling, degrees of freedom were set to two. It has been shown (Sandman et al in prep) that lowering the number of degrees of freedom reduces the risk of overfitting models.

In GRASP, evaluation of abundance models is done using cross validation. This means randomly chosen groups of the data points which have been used to create the model are also used to evaluate how well the prediction correlates with the observed values. This is not as strong as validating the predictions using an independent dataset, but since such a dataset is usually not available, cross validation is a commonly used and accepted method. The result of the cross validation is given as a cvCOR-value. GRASP also gives a COR value, which shows how good the model is at predicting in all the points used to create the model. The COR and cvCOR both corresponds to Spearman r_s-values.

Predictor variables

All predictor variables used in modelling must be available as GIS grid layers, to enable predicting and thus creating surface covering maps of the distribution of the response variable. Most predictor layers used here have been created for the BALANCE project, in an international effort to map seabed features of the Baltic Sea. These layers will be available for common use through the Balance website (www.balance-eu.org and http://maps.sgu.se/Portal/) when the Balance project is finished. For more detailed information these layers and how they have been created, please refer to Al-Hamdani & Reker, 2007.

All BALANCE layers was received as 200x200 m grids in UTM 34N, and resampled to grids of 5x5 km in RT90. Below is a short description of the layers used.

Depth
A bathymetry grid covering the whole Baltic Sea area with a resolution of about 1 nautical mile (Seifert et al 2001), which is freely available for scientific purposes, was resampled to a grid with the resolution of 5x5 km.

Slope and aspect
Slope and aspect were calculated using the depth layer in ArcGIS 9.1. The slope grid shows the slope in degrees, and the aspect grid shows the aspect in 9 classes as described below, where 0° equals north.
1 = flat
2 = 0-45°
3 = 45-90°
4 = 90-135°
5 = 135-180°
6 = 180-225°
7 = 225-270°
8 = 270-315°
9 = 315-360°

Bottom sediments
Map of bottom sediments from the BALANCE project. The grid contains five classes where
1 = Bedrock
2 = Hard bottom complex
3 = Sand
4 = Hard clay
5 = Mud

Photic zones
Map of photic zones from the BALANCE project. The grid contains two classes where
1 = Euphotic zone
2 = Non-photic zone

Surface salinity
A map of annual mean surface salinity in 13 classes from the Swedish National Atlas (Sjöberg 1992) were used. Classes were
1 = 0-3 psu
2 = 3-4 psu
3 = 4-5 psu
4 = 5-6 psu
5 = 6-7 psu
6 = 7-8 psu
7 =8-9 psu
8 = 9-10 psu
9 = 10-15 psu
10 = 15-20 psu
11 = 20-25 psu
12 = 25-30 psu
13 = >30 psu

Bottom salinity
Map of annual mean bottom salinity in psu from the BALANCE project.

Bottom temperature
Map of annual mean bottom temperature in degrees Celsius from the BALANCE project.

Pyknocline depth
Map of annual mean pyknocline depth from the BALANCE project. The pyknocline is a permanent vertical density gradient present in some areas of the Baltic Sea, due to gradients in both temperature and salinity. Here, the location of the pyknocline has been estimated as the depth with the strongest vertical density gradient. This approach always results in a depth value, even for areas with relatively weak gradients.

Bottom current velocity
Map of annual mean current velocity at the bottom, from the BALANCE project.

Response variables

Cod
For modelling cod distribution we were able to use data from the ICES Baltic International Trawl Survey (BITS), which uses bottom trawls to investigate the amount and distribution of bottom dwelling species, mainly cod and flatfish. BITS is carried out twice a year, during the first quarter (Feb-March) and the fourth quarter (October). Data from both periods was used and cod was modelled separately for the first and fourth quarters. Data from the years 2000-2006 was used in modelling. A total of 1945 data points were available for the first quarter and 1321 data points for the fourth quarter (Figure 1).

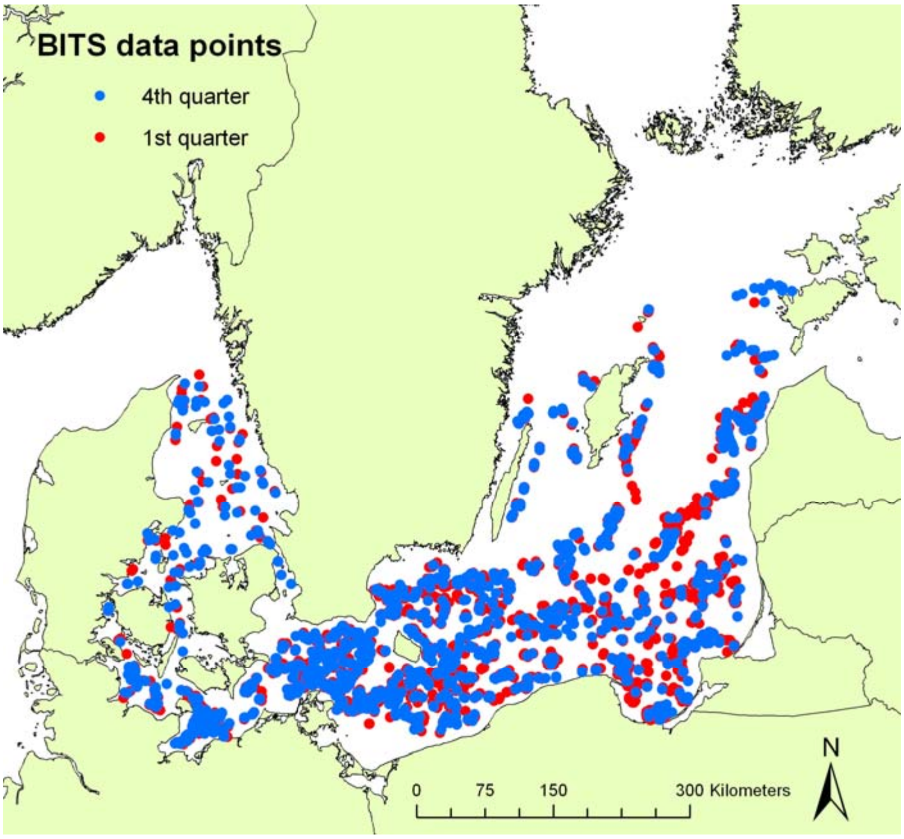

Figure 1. Available BITS data for the 1st and 4th quarters.

The data is presented as CPUE, here the number of fish per hour of trawling. This is also the unit given in the resulting maps.

The maximum depth of trawling in the dataset is 170 m, and the minimum is 8 m. However, we consider data to be sufficient for modelling in the depth interval of 15-110 m, and areas below or above this interval are not shown in the predicted maps. Also, because the response data do not cover the whole Baltic Sea, the predicted maps show results only in the areas from where data is available.

All cod larger than 30 cm were removed from the data, as these fish are not considered available as harbour porpoise prey because of their size.

Herring and sprat

For modelling the distribution of herring and sprat we were able to use trawling data from the ICES Baltic International Acoustic Survey (BIAS), which uses hydroacoustics and pelagic trawling to investigate the amount and distribution of pelagic species such as herring and sprat. BIAS is carried out once a year, during September/October. Data from the years 1999-2005 was used in modelling, and a total of 672 data points from surveys made by Sweden, Germany, Poland and Latvia were available (Figure 2). The reason we could not use data from all Baltic country surveys was that the database where data is stored were being reconstructed, and at the time not all data had been refitted to the new format. However, the data used cover most of the range of the surveys.

The data is presented as CPUE, here the number of fish per hour of trawling. This is also the result of modelling and predicting, and the resulting maps show a grid of expected CPUE in each grid cell.

The maximum depth of trawling in the dataset is 242 m, and the minimum is 17 m. However, we consider data to be sufficient for modelling in the depth interval of 20-200 m, and areas below or above this interval are not shown in the predicted maps. As for BITS data, because the response data do not cover the whole Baltic Sea, the resulting predicted maps show only the areas from where data is available.

For modelling, herring was divided into two size classes which were modelled separately. Small herring refers to herring up to 15 cm length, and large herring to length classes above 15 cm. This division was done because the size of herring may have an effect for porpoises – small size herring are likely more accessible to juvenile porpoises than the larger fish. All size classes of herring were also modelled together. Because sprat does not grow as big as herring, no division into length classes were made for sprat.

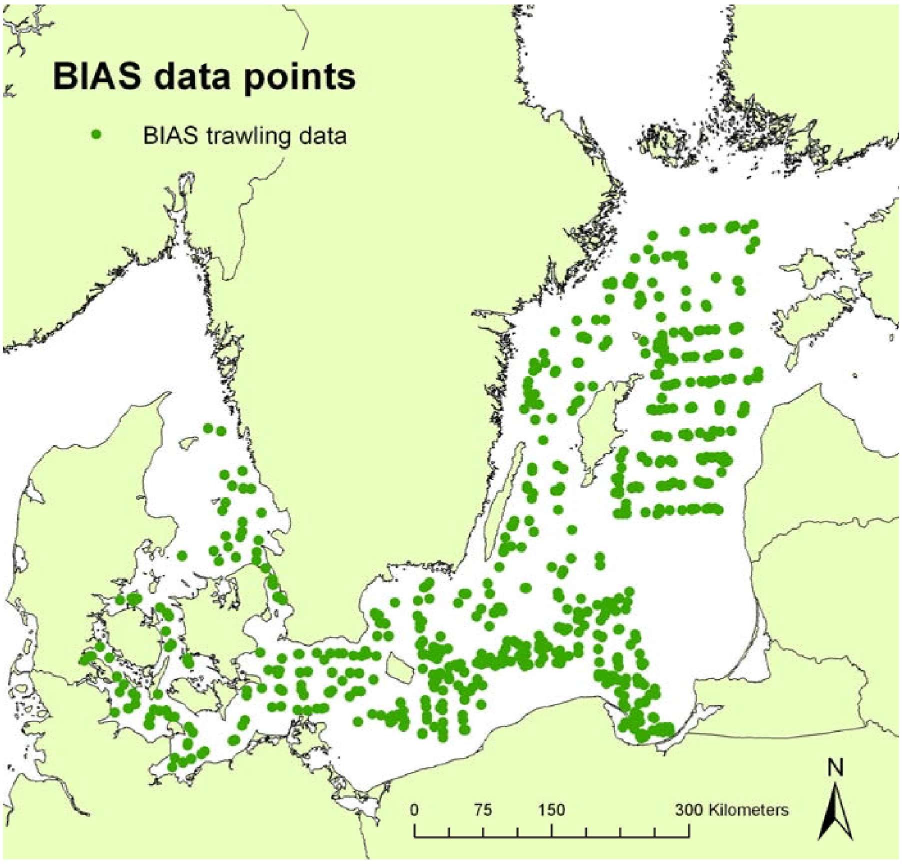

Figure 2. Available BIAS trawling data.

Results

Cod, first quarter

The best model for the distribution of cod in the first quarter was based on the predictor variables depth, bottom salinity, bottom sediment, bottom temperature and slope. The pyknocline depth was removed from modelling because of its strong correlation with depth (*r*=0.89). The evaluation of the model gave a COR=0.506 and cvCOR between 0.49-0.50. The resulting map is seen in Figure 3. The highest abundances are found south of southern Sweden and south and east of Bornholm. The Bornholm Deep east of Bornholm show low abundances, which is consistent with common knowledge. This is most likely due to the oxygen deficient environment in deep areas of the Baltic Sea.

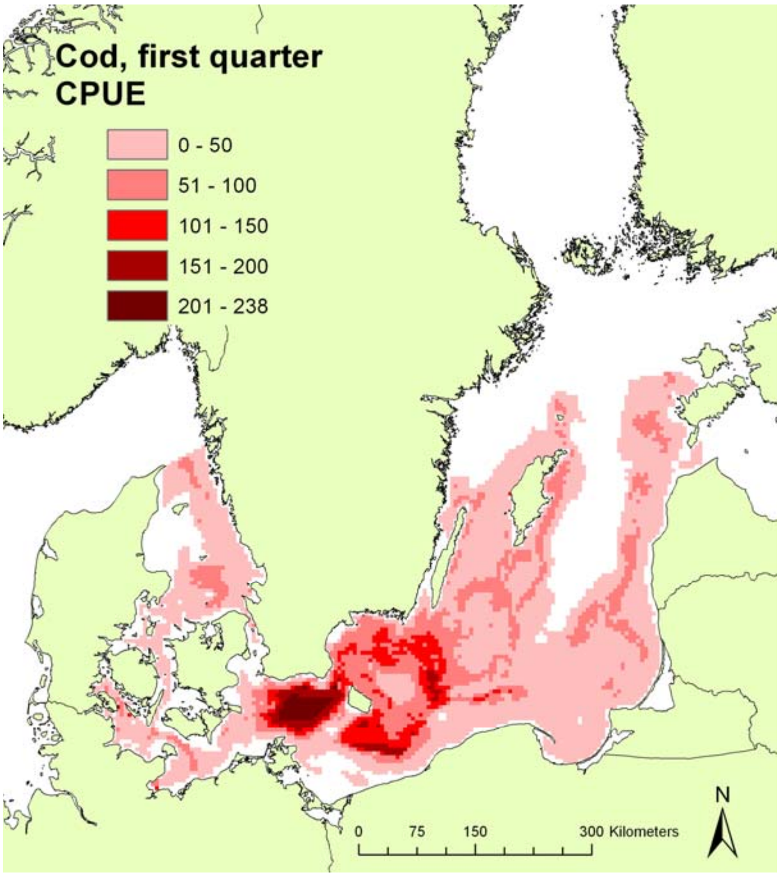

Figure 3. Predicted map of CPUE of cod in the first quarter.Please note that the legend is different from cod in the fourth quarter. The CPUE for the first quarter shown here is lower than for the fourth quarter.

Cod, fourth quarter

The best model for the distribution of cod in the fourth quarter was based on the predictor variables depth, bottom salinity, bottom current velocity, bottom temperature and slope. The pyknocline depth was removed from modelling because of its strong correlation with depth (*r*=0.89). The evaluation of the model gave a COR=0.491 and cvCOR around 0.47. The resulting map is seen in Figure 4. For the fourth quarter, cod seem to occur in higher abundances but in smaller areas than during the first quarter. The highest concentration in the fourth quarter occurs between Bornholm and southern Sweden. When comparing the distribution between the first and fourth quarter, please note that the legends are different between the two figures, and that the CPUE is higher for the fourth quarter than for the first.

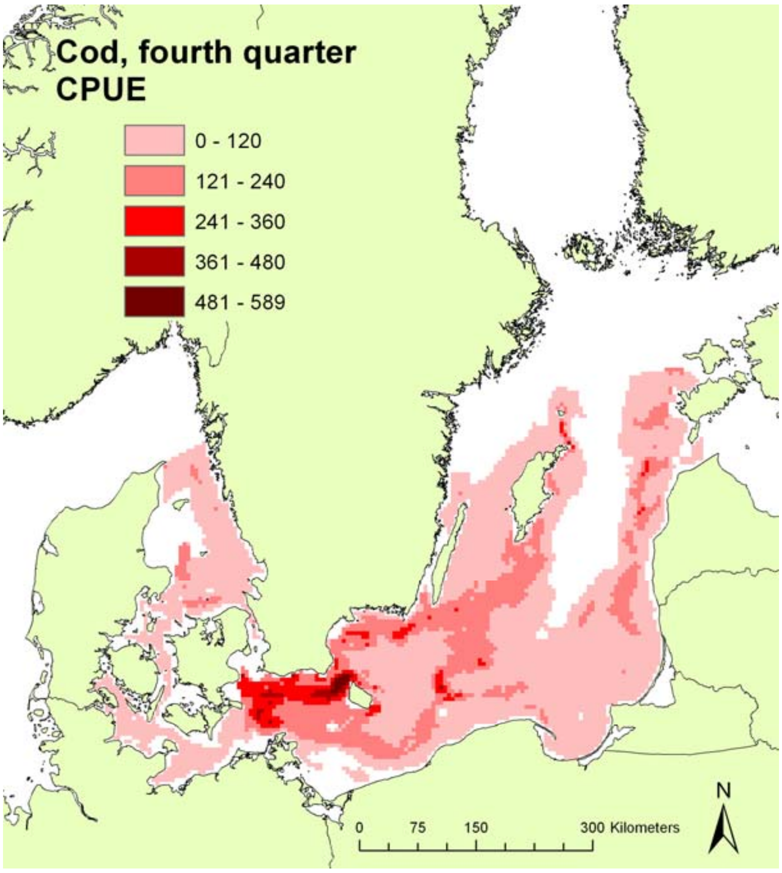

Figure 4. Predicted map of CPUE of cod in the fourth quarter. Please note that the legend is different from cod in the first quarter. The CPUE for the fourth quarter shown here is higher than for the first quarter.

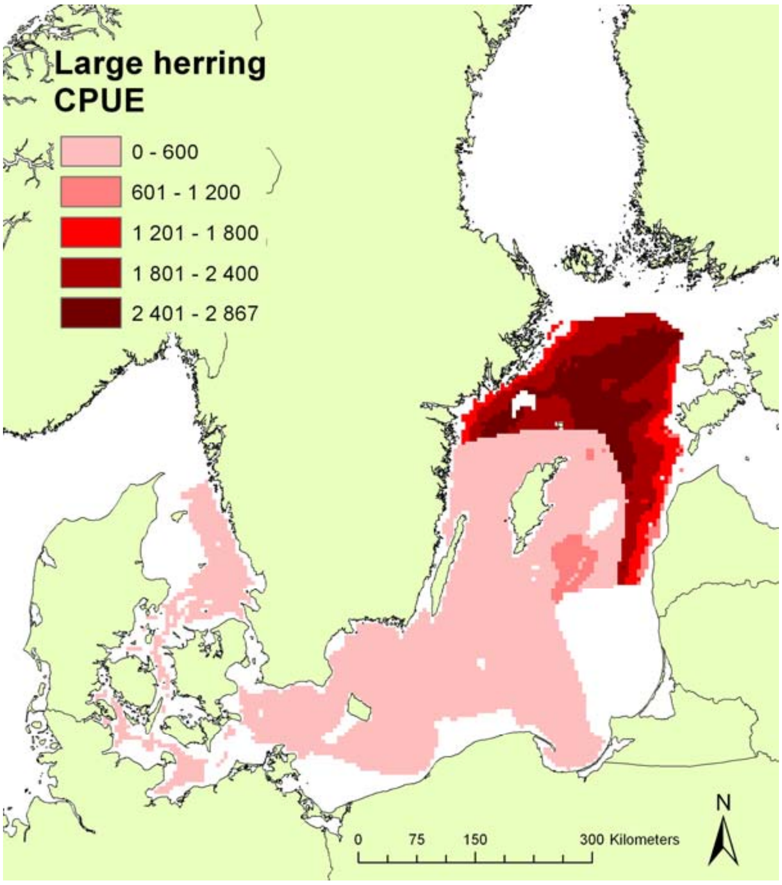

Figure 5. Predicted map of CPUE of large herring.

Large herring

The best model for the distribution of large herring was based on the predictor variables surface salinity, bottom temperature, bottom sediment and pyknocline depth. The bottom salinity was removed from modelling because of its strong correlation with surface salinity (*r*=0.85). One correlation remains between surface salinity and bottom temperature (0.83). However, because both surface salinity and bottom temperature has great influence on the model, they were both left in the model. The evaluation of the model gave a COR=0.432 and cvCOR around 0.375. The resulting map is seen in Figure 5. Large herring occurs primarily in the open waters north of Gotland and outside the coastal areas of Estonia and Latvia. The sharp limit between high and low abundance north of Gotland coincide with the limit between two surface salinity classes. Such clear limits can occur when a predictor has large influence in a model.

Small herring

The best model for the distribution of small herring was based on the predictor variables surface salinity, depth and slope. The pyknocline depth and bottom salinity were removed from modelling because of their strong correlations with other predictors. The evaluation of the model gave a COR=0.437 and cvCOR around 0.39. The resulting map is seen in Figure 6. As large herring, small herring occur in high abundances in the deep open waters north of Gotland.

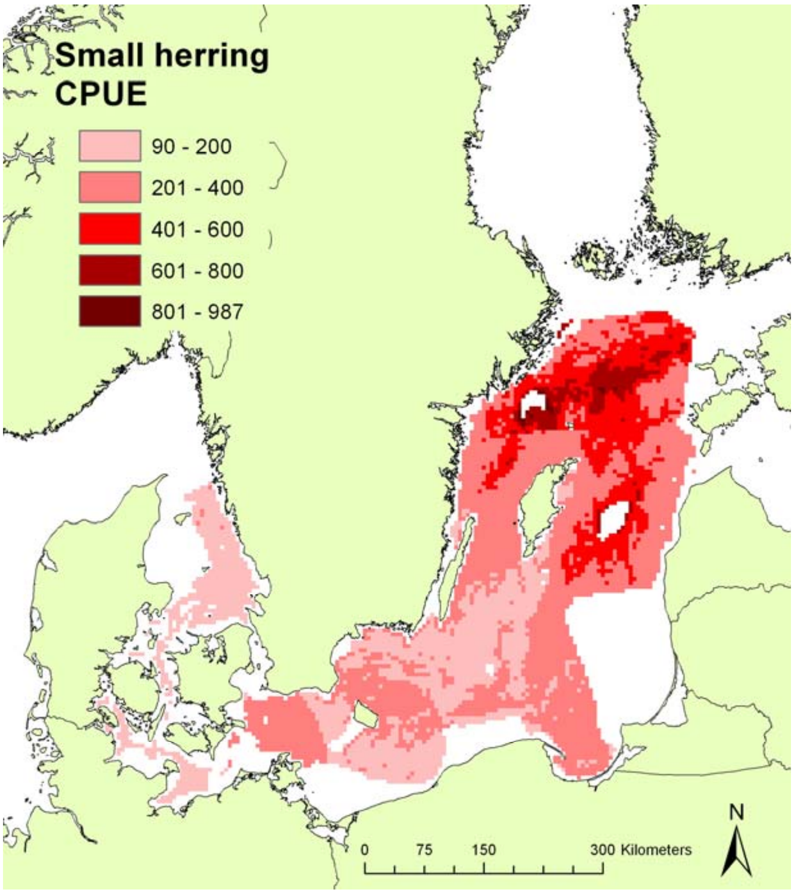

Figure 6. Predicted map of CPUE of small herring.

Total herring

The best model for the distribution of all herring size classes was based on the predictor variables surface salinity, bottom temperature, depth and bottom sediments. The evaluation of the model gave a COR=0.337 and cvCOR around 0.2. The results are not shown here as the model is not reliable.

Sprat

The best model for the distribution of sprat was based on the predictor variables surface salinity, pyknocline depth, slope and bottom temperature. The bottom salinity was removed from modelling because of its correlation with surface salinity (r=0.85). One correlation remains between surface salinity and bottom temperature (0.83). However, because surface salinity has such great influence on the model, it was left in the model. The evaluation of the model gave a COR=0.597 and cvCOR around 0.56. The resulting map is seen in Figure 7. Like herring, sprat occurs in high abundances in the open waters north of Gotland. Here, too, the sharp limit between two surface salinity classes can be seen, and is due to the large influence of surface salinity on the model.

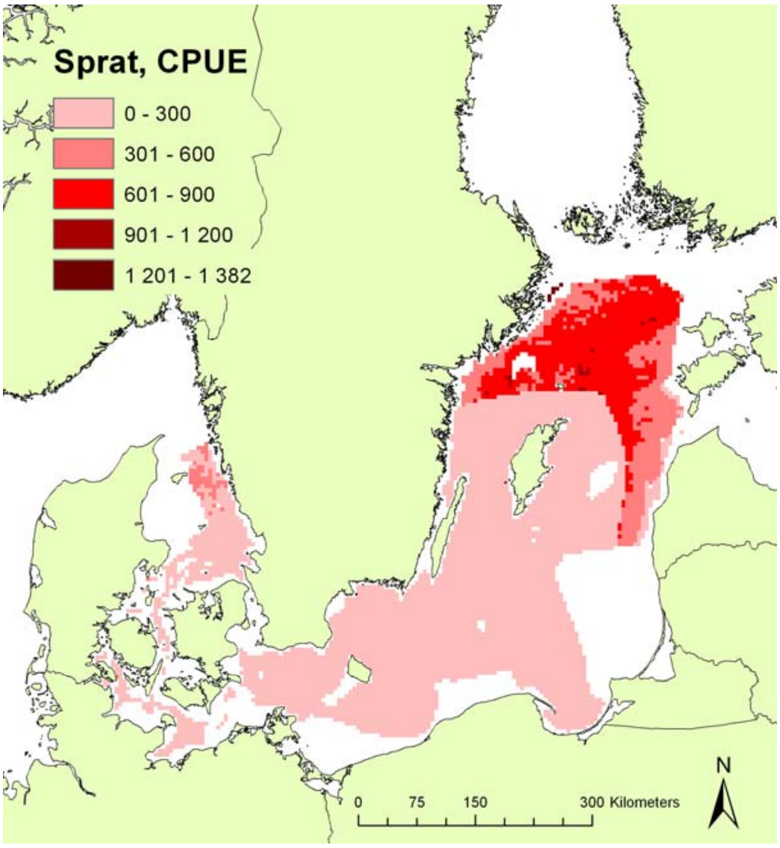

Figure 7. Predicted map of CPUE of sprat.

Discussion

For biological variables, $r_s = 0.5$, and thus a variance explained of 25%, must be considered good, especially when the target species is mobile, such as fish in this case. The models produced here for cod and sprat are rather satisfactory, while models for herring are not quite as good. The reasons for this may be that herring is a pelagic species, and because most of the predictor variables used here are bottom related, they may not be useful in describing the distribution of a pelagic species.

Pelagic fish also forms schools, which results in patchy distributions that cannot always be explained only by physical conditions. This may also reduce the possibilities to model the distribution of these species. However, by using data from several years, the predictions will describe the species' average distribution, and the effect of schooling behaviour on the model may be reduced.

The goal of this study was to achieve a general distribution of prey species, valid not only for one specific year, and therefore response data from several years was used together. This may influence the modelling capacity in a negative way if differences in distribution between years are large, because this would mean that the method used could not find clear patterns in the correlation between the response variable and the environmental parameters. If the distribution of herring is highly variable between years, this may be another reason that the herring models are not quite as stable as the models for cod and sprat.

The model for all sizes of herring combined shows very low evaluation parameters. This may indicate that size has an ecological effect on distribution and that small and large herring are not dependent on the same environmental factors. It could also indicate differences in habitat use between populations with different age structures and therefore different size distributions. Such differences in size between populations may occur as a consequence of different fishing pressures.

Most fish species migrate seasonally, and are found in different habitats in different seasons. The response data used here takes this into account by being collected in specific seasons. However, we have not been able to fully address the temporal aspect of fish distribution because, although we were very lucky to have access to the newly published data from BALANCE, these layers do not show the parameters for specific seasons but as a yearly mean. This makes it difficult to model season specific interactions between fish and their environment. Considering that the response data used is collected in concentrated seasons, this may result in less accurate matching between response variable and predictor variables. This does not seem to be the case for cod and sprat, as the models are quite good, but the less successful modelling of herring may suffer from this fact.

Salinity seems to be an important variable when modelling fish distribution, and either bottom salinity or surface salinity is present as a predictor variable in all models. Bottom temperature is also chosen by the AIC process in almost all models. This indicates that future studies may benefit from focusing on these parameters, and that it may be useful to have these layers in a more fine resolution on the temporal scale. Also, models would most likely be better if all parameters were available as continuous variables. Adding more pelagic parameters would clearly facilitate modelling of pelagic species, and so future studies may benefit from closer cooperation with oceanographic expertise.

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