MONTHLY VARIATION IN FINE-SCALE DISTRIBUTION OF HARBOUR PORPOISES AT ST. MIDDELGRUND REEF

Teknisk rapport fra DCE – Nationalt Center for Miljø og Energi nr. 97 2017

AARHUS UNIVERSITET
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Abstract: Store Middelgrund reef in Kattegat has been identified as harbour porpoise bycatch hot-spot. This study aims to examine the fine-scale harbour porpoise distribution at the Store Middelgrund reef by deploying passive acoustic monitoring stations (CPODS) in the area for one year (February 2016 – January 2017). The distribution was analysed and presented by monthly habitat-based distribution models (GLM), and the potential role of different kinds of environmental variables (e.g. water current strength, temperature, and salinity) as drivers for this distribution on a small spatial and temporal scale was examined. The study found that porpoises are present around the reef all year, but that the densities are higher in May to August with a peak in June on most stations while the period from September to December had the fewest detections. The most important drivers for harbour porpoise distribution as identified in the model was month, bathymetry and chlorophyll A. Porpoises occur mainly in the deeper part of the study area and not as frequent within the shallowest part of the reef that is designated as Natura 2000 for harbour porpoises.

Keywords: harbour porpoise, distribution, passive acoustic monitoring, CPOD, Store Middelgrund, GLM, model

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Preface

This report was commissioned by The Danish AgriFish Agency at the The Ministry of Environment and Food of Denmark ("Den gode bestilling" 12.01.2016).

A short desription of the content of "den gode Bestilling" are summarized here:

Based on remote electronic monitoring of fisheries 2014-2015 (by DTU Aqua), Store Middelgrund are assessed to be a hot-spot area for bycatch of harbour porpoises. The aim of this project is to examine harbour porpoise presence across the year in this area (Responsible party: DCE) and combine this information with data on fishery and bycatch (In a separate report. Responsible party: DTU Aqua), in order to understand why St. Middelgrund is a harbour porpoise bycatch hot-spot.

DCE will provide a project report including map material showing seasonal variation in distribution and presence of harbour porpoise in the St. Middelgrund area. The maps will illustrate porpoise distribution derived from monthly habitat-based density models built on passive acoustic detections of porpoises (Detected by CPODs). DCE will deploy 11 CPODs in a grid design determined in agreement with DTU Aqua. The CPODs should be deployed from February 2016 to January 2017 and a service of the stations will be performed in July 2016. After each download of CPODs (after service in July and after recovery in January), the data should be sent to DTU Aqua and the Agrifish Agency along with a short status report.

The CPOD data as well as two such status reports were sent 25 August 2016 and 14 March 2017, respectively. This final report, which illustrates the distribution of porpoises per month at and near St. Middelgrund reef, hereby concludes the DCE part of the project.

1 Summary

The study was commissioned by the AgriFish Agency, Ministry of Environment and Food of Denmark to explain the drivers for bycatch of harbor porpoises in gillnet fisheries by Store Middelgrund. Previous studies by DTU Aqua have shown St. Middelgrund to be a fishing area where a large number of porpoises drown in the gillnets. DCE was therefore asked to examine when and where harbor porpoises utilize the St. Middelgrund reef.

This report presents the monthly distribution of harbour porpoises (*Phocoena phocoena*) at and around St. Middelgrund reef in Kattegat. Presence data was obtained by means of passive acoustic monitoring using CPODs. 11 CPODs were deployed in a systematic grid at and around the reef for a year (February 2016 – January 2017), continuously collecting the presence of harbour porpoises based on the clicks they use for foraging and navigating. This yielded data on minutes and hours with porpoise clicks, so called porpoise positive minutes or hours. Data were analyzed using a generalized linear model (GLM) to relate hourly porpoise presence to six environmental predictor variables including water current strength, temperature, and salinity in order to assess their potential role as drivers for porpoise presence at the St. Middelgrund Reef. The GLM was used to produce monthly maps of porpoise presence in the area.

The study shows that porpoises are present around the reef all year, but that the densities are higher in May to August with a peak in June on most stations while the period from September to December had the fewest detections. Insufficient data in January prevented the creation of robust model, and thus all January data were excluded from further analysis and only 11 monthly harbour porpoise distribution maps were created (February – December 2016). The model that best explained presence / absence of porpoises per station and month included all the predictor variables suggesting that all variables in the full model were important for predicting the presence of porpoises at Store Middelgrund. Relative importance of each variable was calculated, which showed that month and bathymetry were the most important variables, followed by chlorophyll A. Porpoises occur mainly in the deeper part of the study area and not as frequent within the shallowest part of the reef that is designated as Natura 2000 for harbour porpoises.

2 Resumé

Undersøgelsen blev bestilt af Landbrugs- og Fiskeristyrelsen under Miljø- og Fødevareministeriet for at forklare hvilke faktorer der styrer bifangst af marsvin i nedgarnsfiskerier ved Store Middelgrund. Tidligere studier foretaget af DTU Aqua har vist, at St. Middelgrund er et område hvor mange marsvin drukner i nedgarn. DCE blev derfor bedt om at undersøge hvornår og hvor marsvin benytter St. Middelgrund-revet.

Denne rapport præsenterer den månedlige fordeling af marsvin (*Phocoena phocoena*) på og omkring St. Middelgrund rev i Kattegat. Data for dyrenes tilstedeværelse blev indsamlet vha. passiv akustisk monitering ved brug af CPODs. 11 CPODs blev placeret i et regulært grid design på- og omkring revet i et år (Februar 2016 – Januar 2017), hvor de kontinuerligt indsamlede data om tilstedeværelsen af marsvin baseret på de klik de udsender i forbindelse med fødesøgning og navigation. Dette gav data om minutter og timer med marsvine-klik, såkaldt marsvine-positive minutter eller timer. Dataene blev analyseret vha. en generaliseret lineær model (GLM) for at relatere tilstedeværelsen af marsvin til seks miljøvariable på time-basis for at vurdere om de kunne være styrende for fordelingen af marsvin på St. Middelgrund Rev. Disse variable inkluderede strømhastighed, temperatur og salinitet. GLM'en blev brugt til at producere månedlige kort over marsvinenes tilstedeværelse i området.

Studiet viser at marsvin er til stede ved revet året rundt, men at tæthederne er højere i perioden maj til august, med en tæthed som topper i juni på de flestes stationer. Perioden fra september til december havde færrest detektioner af marsvin. Mængden af data var ikke tilstrækkelig høj i januar til at lave en robust model for denne måned, så januar blev ekskluderet fra analyserne. Der blev derfor kun genereret månedlige kort for perioden februar–december 2016. Den model, som bedst forklarede tilstedeværelsen af marsvin per station og måned inkluderede samtlige undersøgte miljøvariable, hvilket tyder på at alle variable i den fulde model var vigtige for at forudsige tilstedeværelsen af marsvin ved St. Middelgrund. Den relative vigtighed af disse variable blev beregnet, og det viste at måned og havdybde var de vigtigste variable, efterfulgt at klorofyl A. Marsvinene findes primært i den dybeste del af det undersøgte område, og mindre hyppigt i den mest lavvandede del af revet, som er udpeget som Natura 2000 område for marsvin.

3 Introduction

The harbour porpoise (*Phocoena phocoena*) is the most common cetacean in Danish waters and some of the highest densities in Europe may be found at certain hot-spots in the inner Danish waters, such as the northern Sound, the Great Belt and Little Belt. In 2010, 16 Natura 2000 areas were designated for harbour porpoises in Danish waters. One of these areas is located at Store Middelgrund in Kattegat (Figure 4-1).

Throughout its range, the harbour porpoise faces the threat of entanglement in gillnets (e.g. Read 1994; Vinther 1999; Northridge et al. 2003). Determining the level of bycatch is difficult, but the ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas) has advised the maximum annual anthropogenic removal (incl. bycatch) should not exceed 1.7% of the best population estimate (ASCOBANS 2000). The discussion of how to best mitigate bycatch is ongoing: Pingers attached to the set nets are known to be efficient in decreasing bycatch (e.g., Carlström et al. 2009), but may also deter the harbour porpoises from important areas and thereby cause the population size to decrease (van Beest et al. 2017). Area or time-area closure for gillnet fisheries is another option to mitigate porpoise bycatch, but may have financial implications for individual fishermen in the area or at certain times of the year and at the same time increase fisheries and possibly bycatch in neighbouring areas. Another aspect of this discussion is where and when to implement the chosen method of mitigation. Whether the mitigation is enforced everywhere, in protected areas (such as Natura 2000 areas) or in identified bycatch hot-spots, and whether it is permanent or limited to certain seasons, will greatly influence the effectiveness of the mitigation and the costs for fisheries. Also mitigation may focus on certain types of fishing gear with high probability for bycatch.

The main problem is that the exact reason for bycatch is not well understood. Previous studies indicate that harbour porpoises are able to detect gill nets at sufficient distance to avoid them (Kastelein et al., 2000; Koschinski et al., 2006; Villadsgaard et al., 2007; Nielsen et al., 2012). Some gear types are also more prone to bycatch e.g. nets with large mesh size used for catching turbot, lumpsucker and cod. Consequently it is assumed, that the porpoises that are bycaught may be distracted (e.g., during prey capture, socialising or flight) from focusing their echolocation on the fishing net. Bjørge et al. (2013) showed that bycatch rates in the Norwegian cod fishery were highest in shallow areas and decreased steeply towards 50 m bottom depth before levelling out, and Kindt-Larsen et al. (2016) showed that the areas with high risk of bycatch may be predicted by combining information on porpoise density and fishing intensity (soak time) in an area.

The large-scale distribution of harbour porpoises is relatively well known in Kattegat, the Belt Seas and Skagerrak from surveys (Hammond et al. 2013, Viquerat et al. 2014), and satellite tracking (Sveegaard et al. 2011). Furthermore, several studies found that distribution and availability of prey as well as abiotic factors such as depth, salinity and distance to coast are important drivers for this large-scale distribution in different seasons (Edrén et al. 2010, Sveegaard et al. 2012a, 2012b). On a smaller spatial (metres) and temporal scale (minutes or hours), however, the drivers are relatively unknown, although the optimization of foraging opportunities is believed to play a major role: Harbour porpoises have to feed every day to satisfy the energy demands of being a small animal living in cold water and recent studies have suggested that they hunt up to 550 small fish prey per hour in inner Danish waters (Wisniewska et al. 2016). However, this fine-scale behaviour may play an important role in bycatch events and knowledge of fine-scale distribution may therefore increase our knowledge about the anatomy of bycatches e.g., are bycatches more likely in areas of specific habitat features like slopes, reefs, certain depths and / or in certain periods of the year.

Based on a high number of porpoise bycatches in April 2014 and April 2015 by a fishing vessel equipped with a remote electronic monitoring video system (REM) in a project run by DTU Aqua, Store Middelgrund has been identified as a potential bycatch hot-spot area (pers. comm. Lotte Kindt-Larsen). The vessel only fished near the Store Middelgrund area in April, so there is no knowledge of bycatches in the remaining months of the year. Since the reef is also designated as Natura 2000 area for harbour porpoises, this area presents an opportunity for studying fine-scale spatial and temporal variability in the distribution of porpoises in a bycatch hot-spot.

By deploying passive acoustic monitoring stations in a regular fine-scale grid and producing monthly habitat-based distribution models, this project aims to illustrate harbour porpoise presence and distribution on and near the Store Middelgrund reef and examine the potential role of different kinds of environmental variables as drivers for this distribution on a small spatial and temporal scale.

The results may later be compared with knowledge on positions of bycatch and set net fisheries (This will be performed by DTU Aqua. It is not part of this report) in order to approach why harbour porpoises are bycaught in certain parts of the Store Middelgrund area.

4 Methods

4.1 Study area

Store Middelgrund is a stone reef situated in Kattegat at the border between Denmark and Sweden. The reef extends into Swedish waters. In 1995, an area on and near the reef were designated as Natura 2000 site ("Store Middelgrund", ID=DK00VA250) and in 2011, harbour porpoises were added as part of the base for the protection of the area (Figure 4-1).

The reef is ranging from 10–20 m depth and the depth of the surrounding water ranges from 20-30 m.

4.2 Passive acoustic monitoring

The locations of the 11 CPODs were determined in collaboration with DTU Aqua prior to deployment and the locations were subsequently approved by Danish Maritime Authority (on December 15th 2015, SFS sag 2015027526).

The CPODs were positioned in a systematic grid design covering the Danish part of Store Middelgrund reef, the main area of harbour porpoise bycatch as identified during the remote electronic monitoring (REM) of fisheries by DTU Aqua (2014-2015), as well as areas with no bycatch (Figure 4-1, Table 4-1). The systematic grid was developed based on the designed in a grid similar to the design used in the SAMBAH project (SAMBAH 2016), and was chosen to obtain a random image of porpoise distribution in the area.

Table 4-1. Station name, positions, depth, CPOD ID and CPOD sensitivity at calibration of the 11 monitoring stations deployed at St. Middelgrund 2016-2017. Deployment A refers to the first deployment period from February-July 2016 and deployment B refers to the second period: July 2016-Jan 2017.

Station	Position (WGS84)		Depth (m)	Deployment period with usable data (day /month /year)	CPOD ID Dep. A / B	CPOD Detection threshold (dB re 1 μPa (pp))
SM01	56° 35,822' N	12° 01,476' E	27	12/2/16-8/7/16 & 16/7/16-5/1/17	1984/1984	112.3
SM02	56° 34,826' N	12° 03,119' E	22	12/2/16-8/7/16 & 16/7/16-25/12/16	908/908	114.3
SM03	56° 33,919' N	12° 01,315' E	26	12/2/16-8/7/16 & 16/7/16-25/12/16	1988/1988	115.8
SM04	56° 33,829' N	12° 04,761' E	14	12/2/16-8/7/16 & 16/7/16-25/12/16	1687/1687	117.3
SM05	56° 32,923' N	12° 02,957' E	25	12/2/16-8/7/16 & 16/7/16-25/12/16	898/898	111.9
SM06	56° 32,016' N	12° 01,154' E	27	12/2/16-8/7/16 & 16/7/16-6/1/17	2117/2117	112.0
SM07	56° 32,833' N	12° 06,402' E	21	12/2/16-8/7/16 & 16/7/16-1/12/16	909/909	113.7[a]
SM08	56° 31,927' N	12° 04,598' E	24	12/2/16-8/7/16 & 16/7/16-25/12/16	1974/1690	114.5/113.3
SM09	56° 31,020' N	12° 02,795' E	29	12/2/16-8/7/16 & 16/7/16-17/1/17	1690/1974	113.3/114.5
SM10	56° 30,930' N	12° 06,237' E	30	12/2/16-8/7/16 & Lost	1693/1693	113.7[b]
SM11	56° 30,024' N	12° 04,435' E	30	12/2/16-27/5/16 & 16/7/16-17/1/17	1986/1776	113.7[a] /112.0

a) CPOD not calibrated due to redeployment. In the analysis this CPOD were given the average sensitivity of the calibrated CPODs.

b) CPOD lost at sea and thus not calibrated. In the analysis this CPOD were given the average sensitivity of the calibrated CPODs.

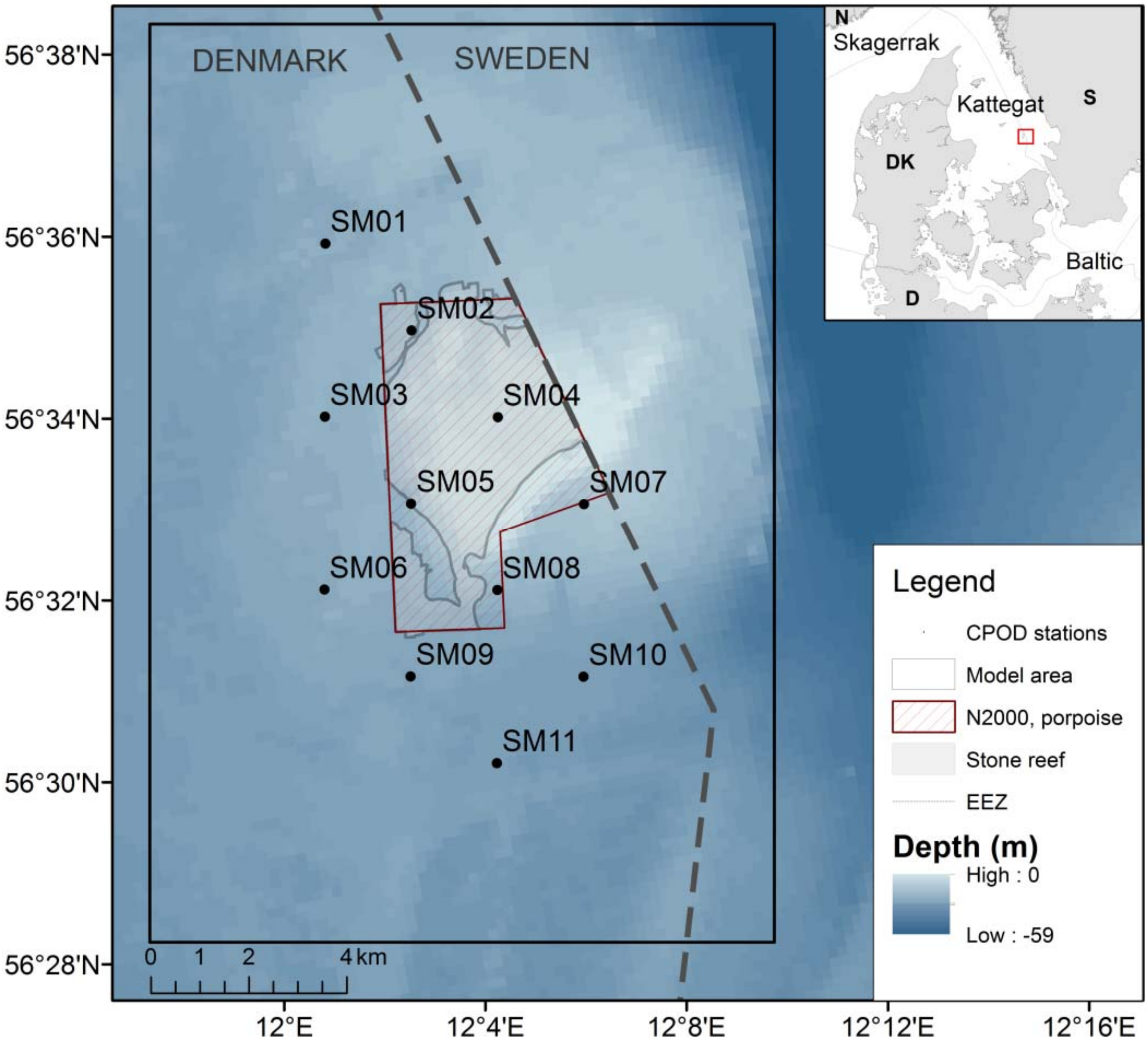


Figure 4-1. Locations of the 11 CPODs deployed at and near St. Middelgrund from February 2016 to January 2017.

The 11 CPODs were deployed 2 m above the sea bed on February 11th 2016 and serviced on July 9th 2016. They were anchored by the use of acoustic releasers (type AR-60-E by SubSeaSonic) and two sandbags each weighing 25 kg. During service the station was recovered, batteries were changed and data downloaded. During the July service 10 of the 11 CPODs were recovered, while one CPOD (SM11) was lost. The loss of stations is not uncommon as CPODS are sometimes caught in trawls or hit by anchor chains. The missing CPOD was, however, later found on the beach and handed over to the DCE. Thus data from 10 stations were usable from February to July 2016 and for SM11 the date was usable from February to May 2016. The 11 stations were re-deployed on July 15th 2016 and recovered once more on January 17th 2017. At this time, only 4 (SM01, SM06, SM08, SM11) of the 11 CPODs were retrieved. Subsequently, however, six more stations (SM02, SM03, SM04, SM05, SM07, SM09) were found on beaches and handed in, but station SM10 is at present still missing and are thus not included in the second recording period.

During examination of the data from the 6 CPODs, that had been missing, it turned out that five of them (SM02, SM03, SM04, SM05, SM09) had released on December 26th 2016. On this date, a storm "Urd" hit Denmark and the strong current and turbulence may be the reason behind the releases. DCE has never experienced such a massive loss of stations before nor previously contributed loss of stations to weather conditions, although more than 100 stations have been deployed over the last decade. Nevertheless, data recorded after December 26th on these 5 CPODs should not be used. Station SM07 released on December 2nd 2016, and data should only be used up till this date. Due to an internal error in the CPOD programming, data from station SM01 and SM06 are only usable until January 5 and 6, respectively. Information on usable dates for all stations is included in Table 4-1.

After recovery the CPODs were calibrated to examine whether the sensitivity of the individual CPODs were comparable. The calibration was performed in a tank by transmitting artificial porpoise clicks at the CPOD. The received level at the position of the CPOD was measured with a hydrophone. The source level of the artificial clicks was lowered in 1 dB steps. The sensitivity is measured as 50% detection threshold, i.e. the received level in dB re 1 µPa (pp) at which 50% of the emitted clicks were recorded by the CPOD. The average 50% detection threshold was 113.7 dB re 1 µPa peak-peak (min: 111.9, max: 117.3). The difference in detection threshold will affect the detection range of the CPOD and therefore possibly the number of detected clicks. In this study, however, the unit used for analysis is number of hours with porpoise clicks, so called 'porpoise positive hours – a unit that is not very sensitive to minor changes in detection threshold.

The raw CPOD detections were imported into CPOD.exe v.2.044 (Chelonia Limited) and harbour porpoise clicks were identified by running the build in "Hel1"-algoritm." Hel1" was developed during the SAMBAH project (http://www.sambah.org/) during a meeting in the Polish city, Hel, to minimize the number of false detections and is as such a rather restrictive method of detecting porpoises. Following identification of porpoise clicks, data were exported as detection positive minutes (DPM) and detection positive hours (DPH).

4.3 Analysis (Model and variables)

We tested whether the presence of porpoises by the 11 CPOD stations in the Store Middelgrund area was related to variations in salinity (salt), temperature (temp), East-West current velocity (uvel), North-South current velocity (vvel), chlorophyll A (chla) and bathymetry (bathy) (continuous variables). These variables were obtained from the 3D hydrodynamic model HBM (Dick et al. 2001) that has been running operationally at the Danish Meteorological Institute (DMI) since 2009 (Berg & Poulsen 2012). Chla data is produced by the biogeochemical model ERGOM (Neumann 2000), one way coupled to the HBM model. Environmental data were extracted via the CMEMS (Copernicus Marine Environmental Monitoring Service) online data portal. The HBM-ERGOM model provides information for the physical and biogeochemical conditions in the Baltic Sea on a grid with horizontal resolution of 1 nautical mile and with up to 25 vertical depth levels. The area covers the Baltic Sea including the transition area towards the North Sea (i.e. the Danish Belts, the Kattegat and Skagerrak). The environmental data include hourly instantaneous values of all variables for the period 1-2-2016 to 31-1-2017. Maps illustrating the average predictor variables for each month used in the GLM are shown in

Appendix 1. The variables of current and chlorophyll a are presumably a proxy for prey density.

All data were aggregated on an hourly basis, corresponding to the temporal resolution of the hydrographical data, so hourly values for each environmental variable were extracted from the maps of the environmental variables every hour for each station. All environmental predictor variables were expected to influence the distribution of porpoise or their prey, and were therefore expected to be of relevance to porpoise presence. In addition to the environmental variables we included a variable representing differences in CPOD detection threshold (called mean.sensitivity).

In order to evaluate whether the relationship between presence of porpoises and each of the predictor variables varied among months, we included month as a variable (factor) as well as the interactions between month and each of the six environmental predictor variables.

We used AIC to determine whether the number of porpoise detections per hour were most adequately modelled using a Poisson model (i.e. with number of detection positive minutes per hour as dependent variable; GLM models with log link function) or using a logistic model (with pres-ence-absence of porpoises per hour (dpm.bin) as the binary dependent variable; GLM models with logit link function). Both models were based on filtered CPOD data. As the binary model was far more parsimonious (AIC= 91997) than the Poisson model (AIC=6819501), the binary models were used in following analyses. The Poisson models also showed signs of severe over dispersion, so only binary models were considered. In order to find the set of predictor variables that best explained variations in presence / absence of porpoises per station and month, we compared the full model:

glm(dpm.bin ~ salt + temp + uvel + vvel + chla + bathy + month + dpm.prev.hr.bin + mean.sensitivity + salt:month + temp:month + uvel:month + vvel:month + chla:month + bathy:month, family= binomial, link = "logit")

with all models using all possible subsets of the predictor variables using AIC. Here dpm.prev.hr.bin is an autoregressive variable accounting for the presence of porpoises in the previous hour (Hamel et al. 2012).

5 Results and discussion

5.1 Harbour porpoise detections

Of the 22 deployments (two times 11 stations), only one was permanently lost (SM10, second deployment). Six stations were released prematurely in December 2016 and two stations had corrupted data in January 2017. Consequently, only two stations recorded porpoises as planned in January 2017. This was insufficient data to create a sensible and robust model, and thus January data were excluded from further analysis and only 11 month of harbour porpoise data were analysed (February – December 2016).

Average daily detection positive hours (DPH) per month and average daily detection positive minutes (DPM) are illustrated in Figure 5-1. The results show that porpoise detections are not distributed evenly across the year: On average, the period from May to August had the most detections with June being peak month (with detections almost every hour of the day) while the period from September to December had the fewest detections. Station SM08 at the southern end of the reef had almost twice as many porpoise positive minutes as the other stations (Figure 5-1, upper panel). Why this position is particularly interesting for porpoise, will need further examination.

The variation across the year was similar at all stations except station SM04, which had significantly less detections throughout the year, and especially from February to July. Station SM04 was positioned on the shallowest part of the reef, which could indicate that this area is not as interesting to the porpoises as the deeper areas along the edge of the reef. However, during calibration it was found that CPOD 1687 located on station SM04 was the least sensitive of all the deployed CPODs. The difference from the average detection threshold is however merely 3.7 dB and the difference to CPOD 1988 at station SM03 with the second highest detection threshold (= 15.8 dB) was only 1.5 dB. SM03 showed no apparent decrease in detections compared to the other stations and thus it seems unlikely that the high detection threshold should be the sole driver for such a large difference in porpoise positive hours and minutes.

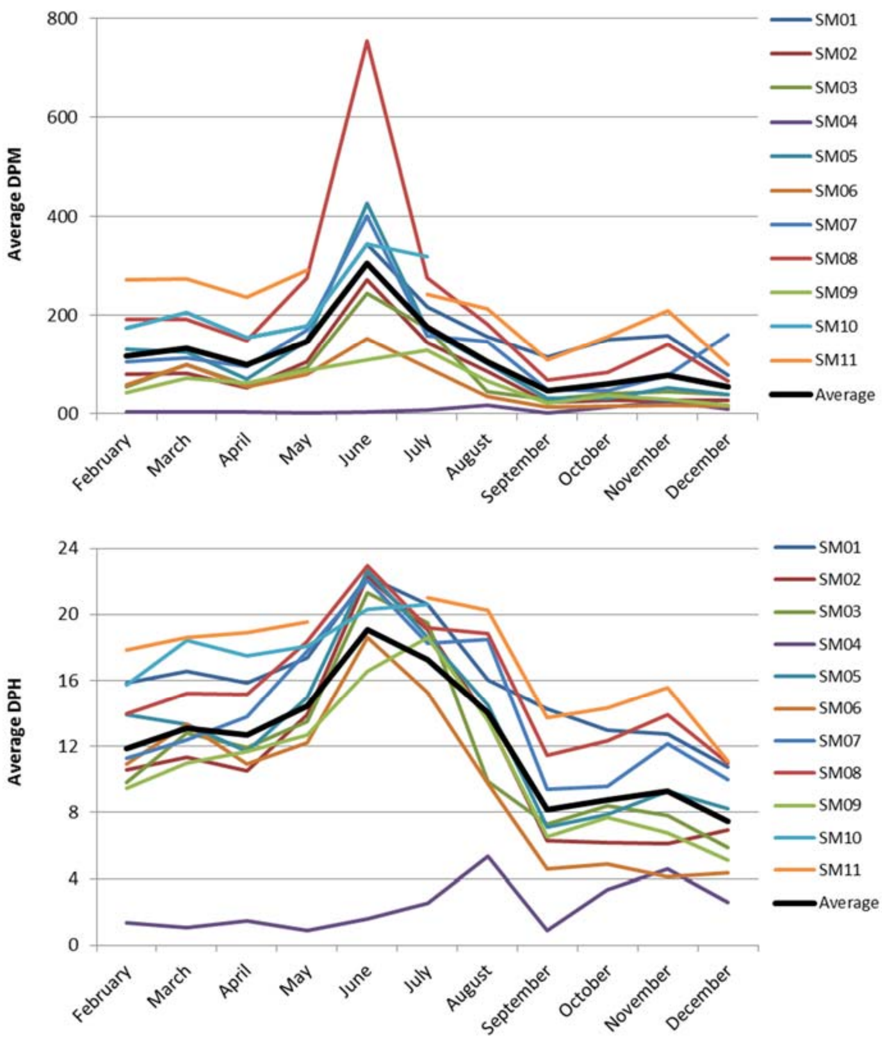


Figure 5-1. Average daily detection positive minutes (DPM, top panel) and average daily detection positive hours (DPH, lower panel) per month from February to December 2016 at the 11 CPODs deployed at and near St. Middelgrund.

5.2 Model results

The model that best explained presence / absence of porpoises per station and month included all the predictor variables (Akaike weight=0.999; McFadden pseudo-R^2=0.23), suggesting that all variables in the full model were important for predicting the presence of porpoises at Store Middelgrund. The second best model (i.e. the model with second lowest AIC score) was not well supported by data (ΔAIC_c=18.9). As the autoregressive variable could not be used for predictions (since this variable requires knowledge of number of porpoises the previous hour, which we only have at the CPOD stations), we excluded this variable from the analysis (ΔAICc= 9814) before producing a map of the likelihood of encountering porpoises (Figure 5-2; Appendix 2). The model that was used for producing the maps therefore only included the six environmental variables, CPOD sensitivity, month, and the interactions between month and each of the environmental variables (to account for differences in their effects in different months). This model explained less of the variation in porpoise presence (pseudo-R^2=0.145) than the model that included and accounted for temporal autocorrelation.

Relative importance of each variable (described as Δ pseudo-R^2, i.e. the change in pseudo-R^2 when removing the variable from the full model) is provided in Table 5-1. The higher the Δ pseudo-R^2, the higher importance of the variable for the model. This shows that month and bathymetry were the most important variables, followed by chlorophyll A and CPOD detection threshold (mean.sensitivity). That month comes out as important reflects the observed variations in porpoise detections among months (Figure 5-1). The relatively low pseudo-R^2 for the full model indicates that the model only explains a modest part of the observed variation in presence of porpoises. The part of the variation that is not explained can be attributed to chance events and to variables that were not included in the model. Bathymetry has previously been shown to have a high influence on porpoise presence in several studies with other important factors being slope, Chlorophyll A, tidal phase, current and distance to coast (Booth et al. 2013, Edrén et al. 2010, Gilles et al. 2011, Sveegaard et al. 2012b). Here, we find that porpoises are more likely to occur in the deeper part of the study area surrounding the reef than on the shallower central part of the reef, and furthermore, that from May to July, when the highest densities are observed, the probability of porpoise detections are higher closer to or on the slopes of reef compared to the rest of the year (Figure 5-2).

Chlorophyll A is often regarded as proxy for primary production and prey distribution in porpoise habitat models (Edrén et al. 2010, Gilles et al. 2011). Thus the observed variation in distribution may be attributed to changes in prey availability near the reef. Sveegaard (2011) reviewed all available studies on porpoise prey (based on analysis of stomach content) in Kattegat, the Belt seas, the Sound and the Western Baltic and found that cod, whiting, herring and goby were the most important prey items both in terms of prey weight ingested and in terms of prey species occurrence i.e. 15-45% of the porpoise stomachs examined had ingested these species. Thus the distribution of porpoises in this area is likely affected by availability of these species. However, since the fine-scale movement of these species at Store Middelgrund has not been studied, we cannot extrapolate on this subject.

Table 5-1. Relative importance of variables. The full model was run once for each explanatory variable excluding them one by one, to calculate the Δ pseudo-R^2 for each variable i.e. the importance of each variable. The higher the Δ pseudo-R^2, the higher importance for the model.

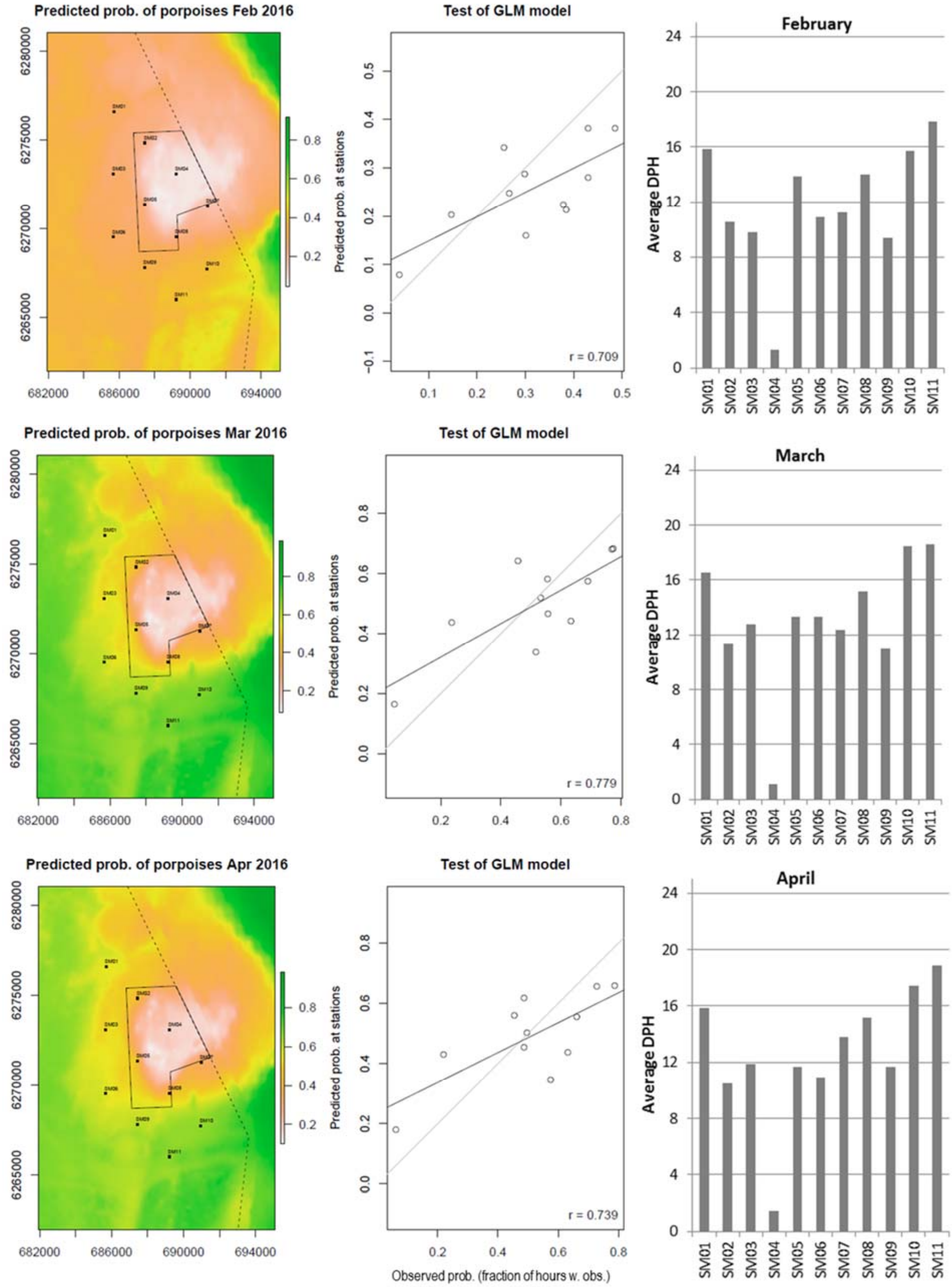
Model	**Pseudo-R^2**	**Δ pseudo-R^2**
Full	0.1450	0.0000
No month	0.0645	0.0806
No bathy	0.1253	0.0198
No chla	0.1352	0.0098
No mean.sensitivity	0.1373	0.0078
No salt	0.1394	0.0057
No temp	0.1417	0.0033
No vvel	0.1430	0.0021
No uvel	0.1443	0.0007

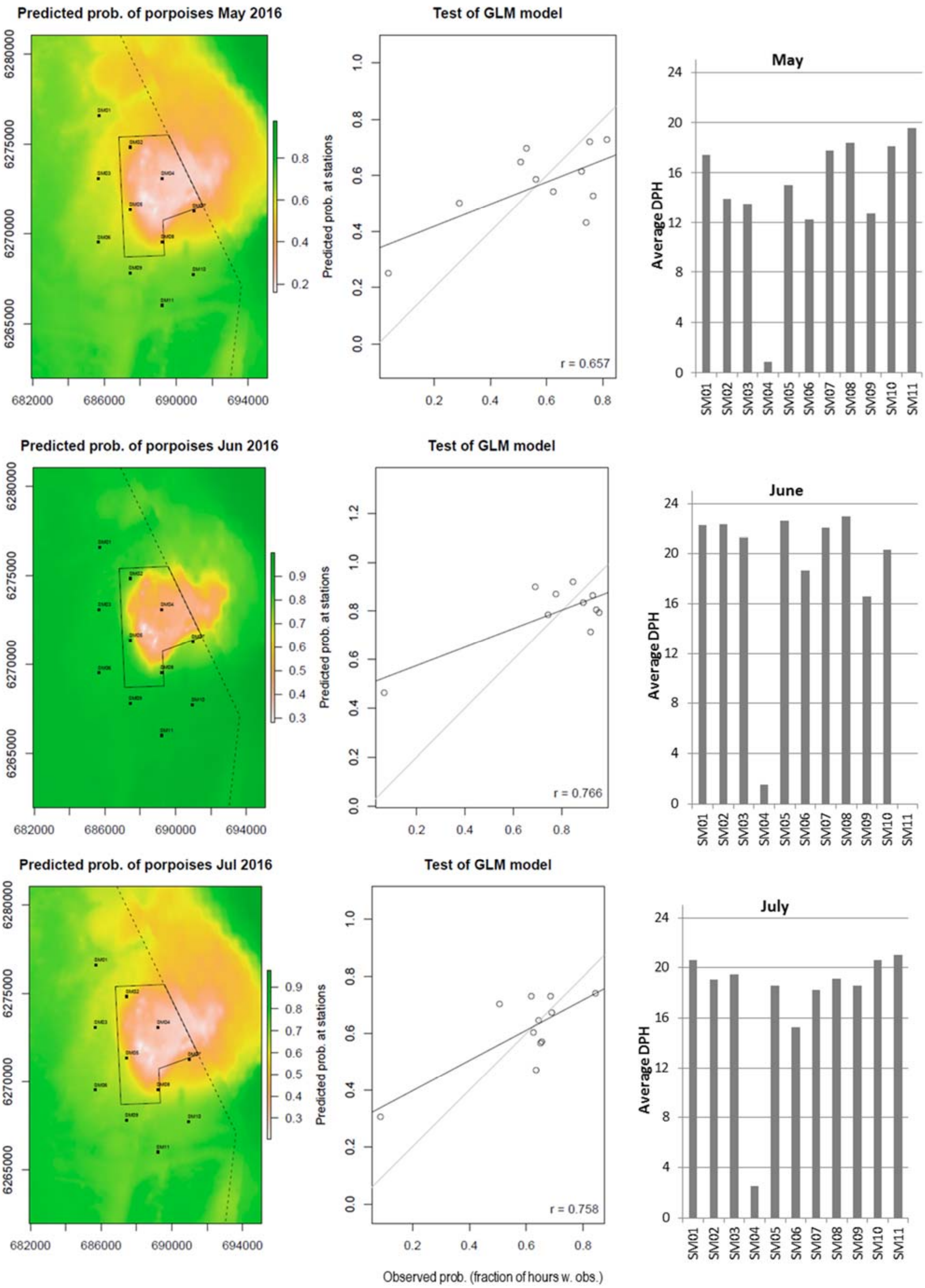
CPOD detection threshold (mean.sensitivity) was included as a model variable to reduce the impact of CPOD sensitivity on the probability of detecting porpoises. This was a valid concern due to the before mentioned low detection threshold of station SM04 (17.3 dB). SM04 was the only CPOD found in water depth < 20 m and had at the same time the lowest number of detections year round. In our model, bathymetry is an important descriptor of porpoise presence, and thus the model is highly sensitive to the values measured at station SM04, as this is the only station on shallow water. The relative importance (Δ pseudo-R^2) of the detection thresholds were, however, minor, and thus we advocate that the low density in the shallow part of the reef is representative of the actual densities on the reef.

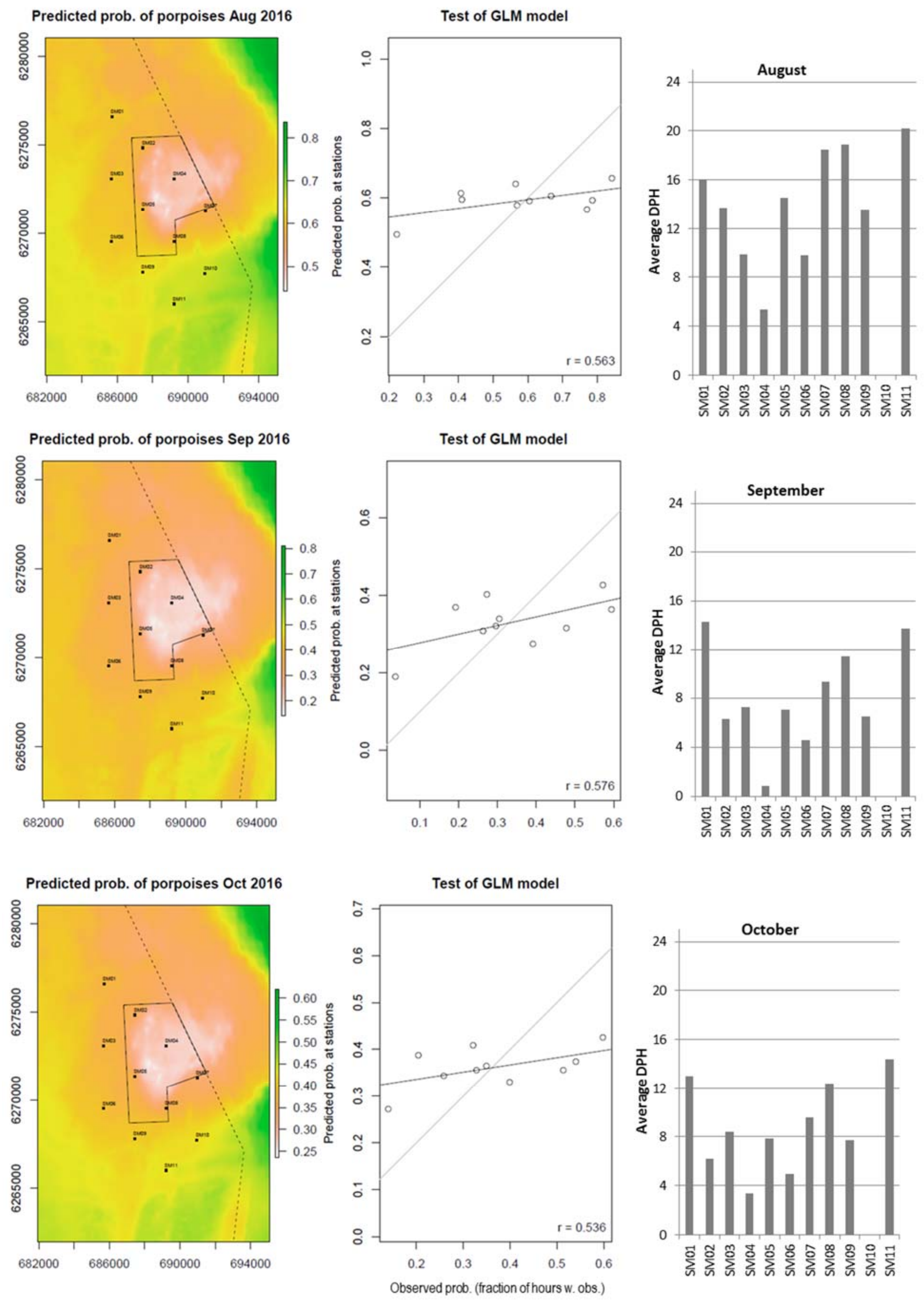
For most months, the predicted and the observed hourly probability of detecting porpoises (Center panel, Figure 5-2) were highly correlated. The model was, however, poor at predicting observed probability in November and December, and in some months (May–July) the model fit appeared to be strongly influenced by observations from a single station with low detection rates (SM04).

For all month, a high probability of porpoise detections is predicted in the northeastern corner of the study area. Here, it should be emphasized that model predictions were based on stations in the center of the mapped area where there was a high degree of agreement between observed and predicted values. Model predictions are likely to become increasingly unreliable further away from the area where the data used for parameterizing the model were collected, i.e. at the edge of the study area.

The waters within the designated NATURA 2000 area “Store Middelgrund” holds relatively low probabilities of harbour porpoise detection (<0.4 during most months) throughout the year. This indicates that the geographical extent of the designated area is too small to cover the areas important to harbour porpoises.


Predicted prob. of porpoises Feb 2016
Test of GLM model
Predicted prob. at stations
r = 0.709
February
Average DPH
Predicted prob. of porpoises Mar 2016
Test of GLM model
Predicted prob. at stations
r = 0.779
March
Average DPH
Predicted prob. of porpoises Apr 2016
Test of GLM model
Predicted prob. at stations
r = 0.739
Observed prob. (fraction of hours w. obs.)
April
Average DPH
SM01 SM02 SM03 SM04 SM05 SM06 SM07 SM08 SM09 SM10 SM11


Predicted prob. of porpoises May 2016
Test of GLM model
May
Predicted prob. of porpoises Jun 2016
Test of GLM model
June
Predicted prob. of porpoises Jul 2016
Test of GLM model
July
Predicted prob. at stations
Observed prob. (fraction of hours w. obs.)
Average DPH
r = 0.657
r = 0.766
r = 0.758
682000
686000
690000
694000
6265000
6270000
6275000
6280000
SM01
SM02
SM03
SM04
SM05
SM06
SM07
SM08
SM09
SM10
SM11



Predicted prob. of porpoises Aug 2016
Test of GLM model
Predicted prob. at stations
r = 0.563
August
Average DPH
SM01
SM02
SM03
SM04
SM05
SM06
SM07
SM08
SM09
SM10
SM11
Predicted prob. of porpoises Sep 2016
Test of GLM model
Predicted prob. at stations
r = 0.576
September
Average DPH
Predicted prob. of porpoises Oct 2016
Test of GLM model
Predicted prob. at stations
r = 0.536
Observed prob. (fraction of hours w. obs.)
October
Average DPH

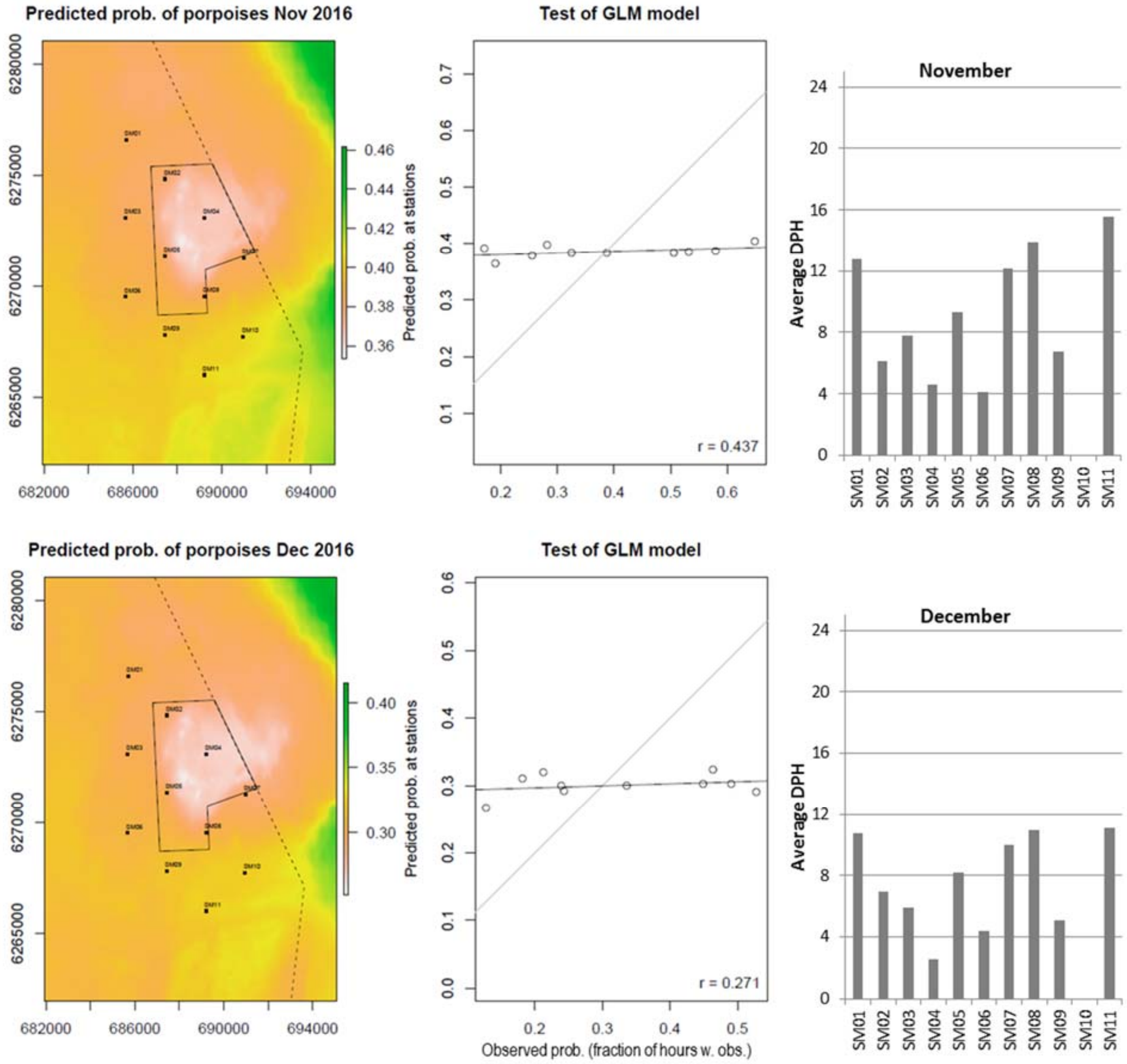


Figure 5-2. Map illustrating the modelled porpoise distribution (left panel, Green is the highest probality, red is medium and white is lowest), the observed probability plotted against the predicted probability of detecting a porpoise (center) and the average daily detection positive hours (right panel) for each month.

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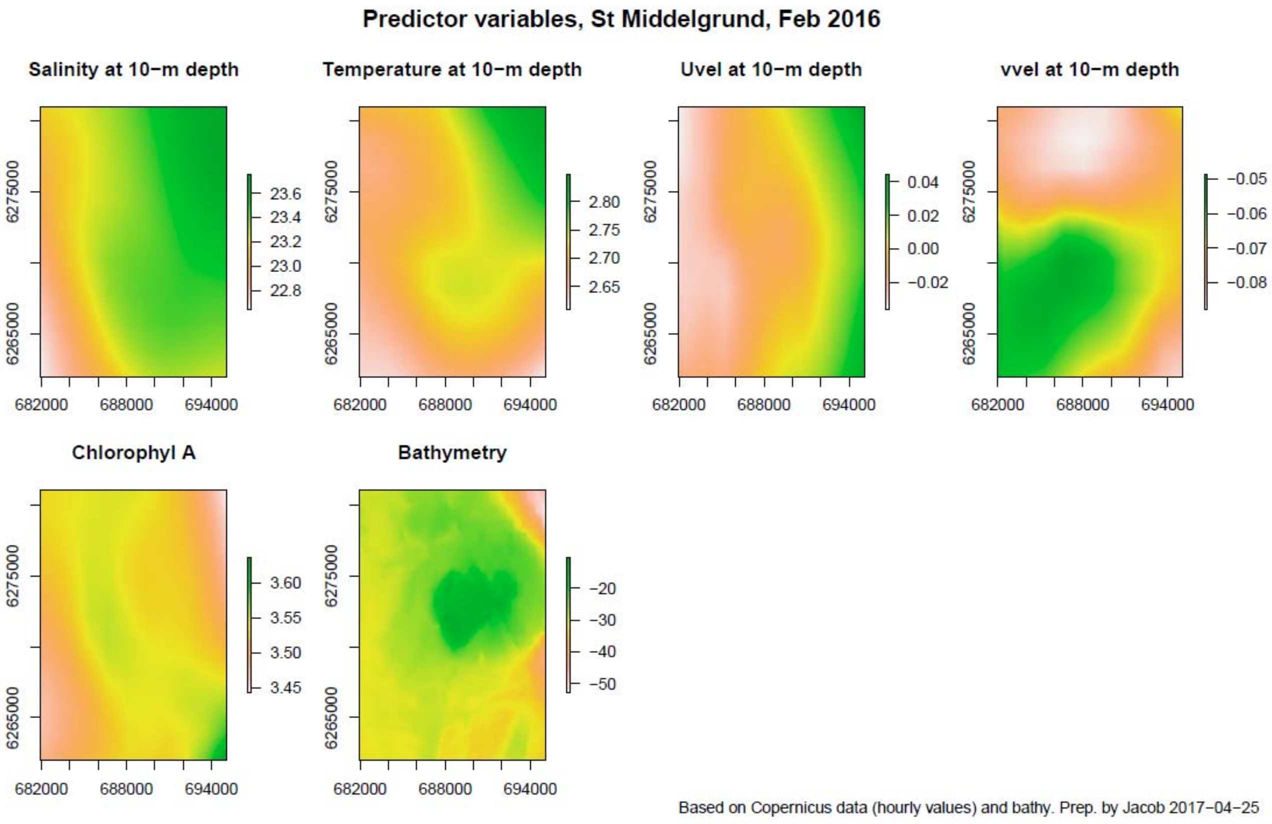
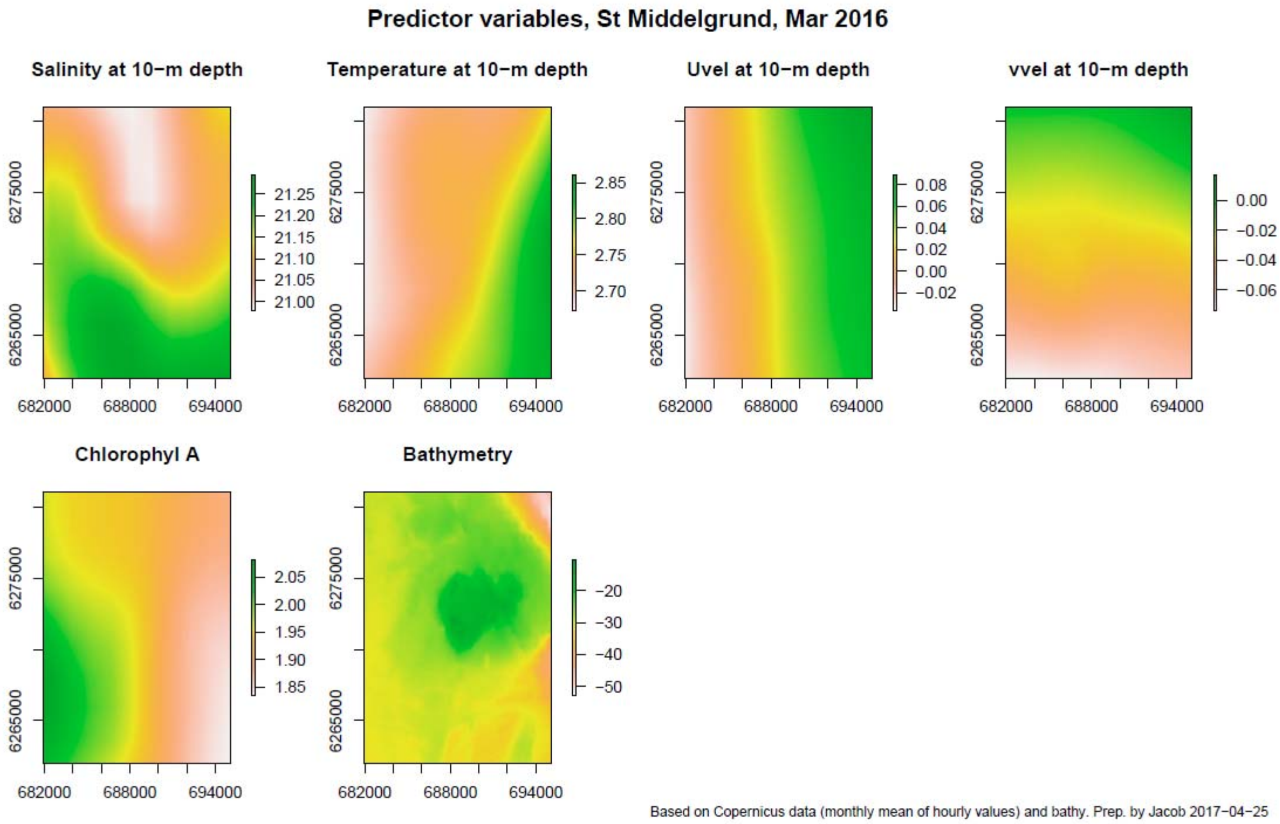
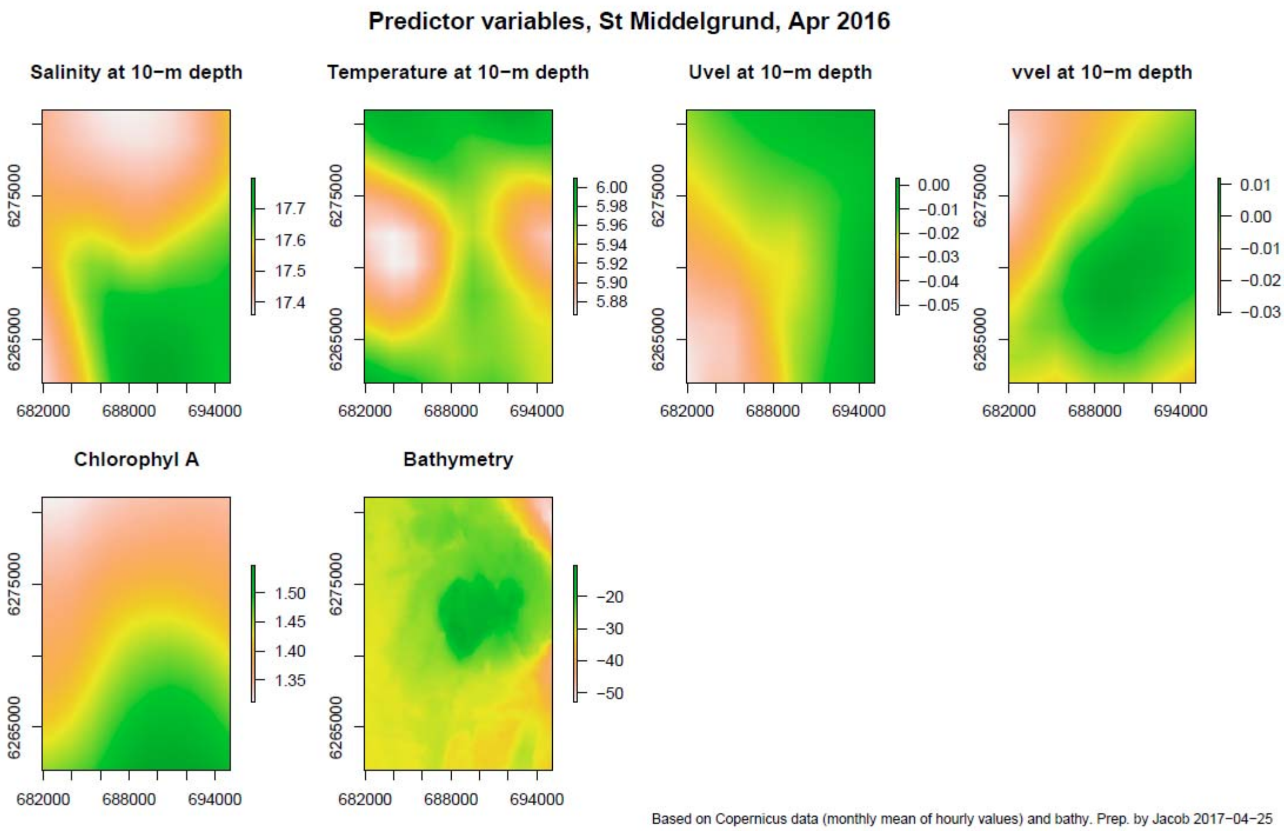
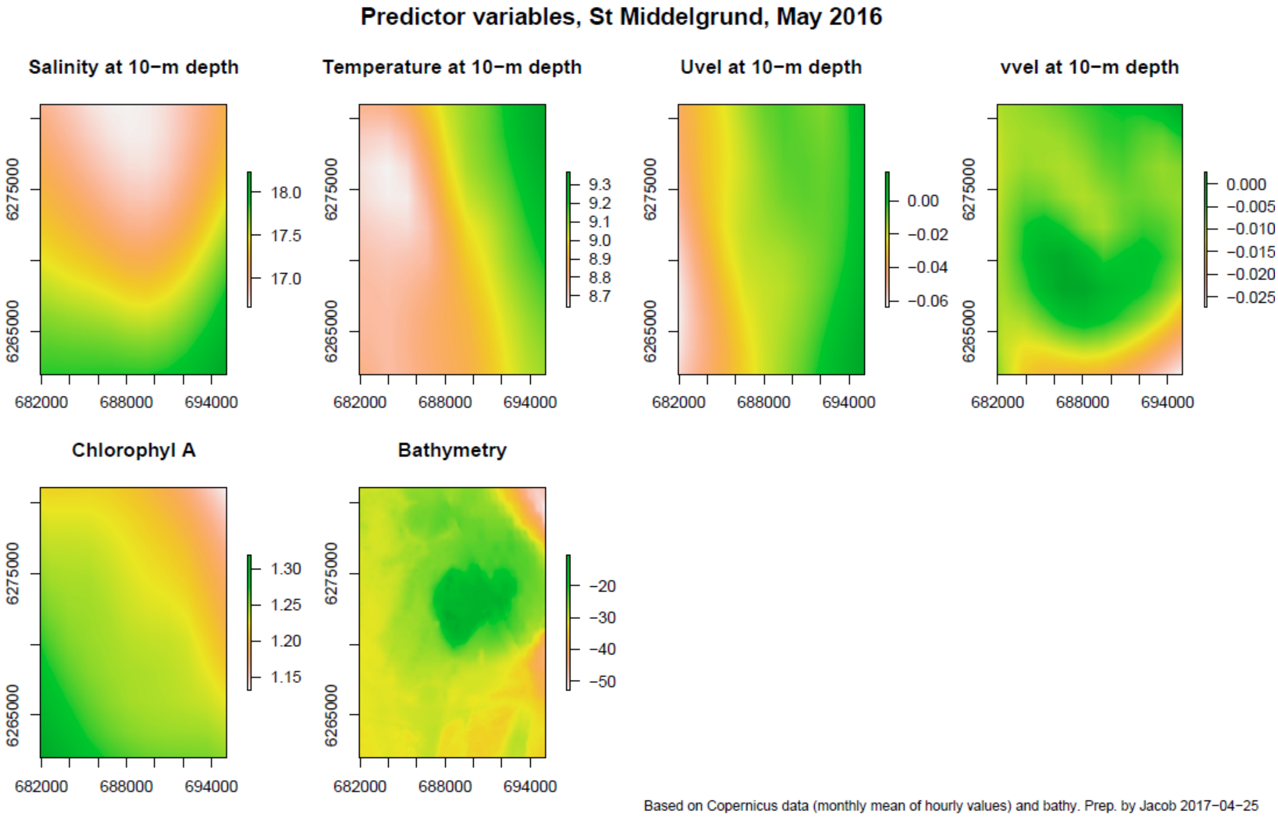
Appendix 1

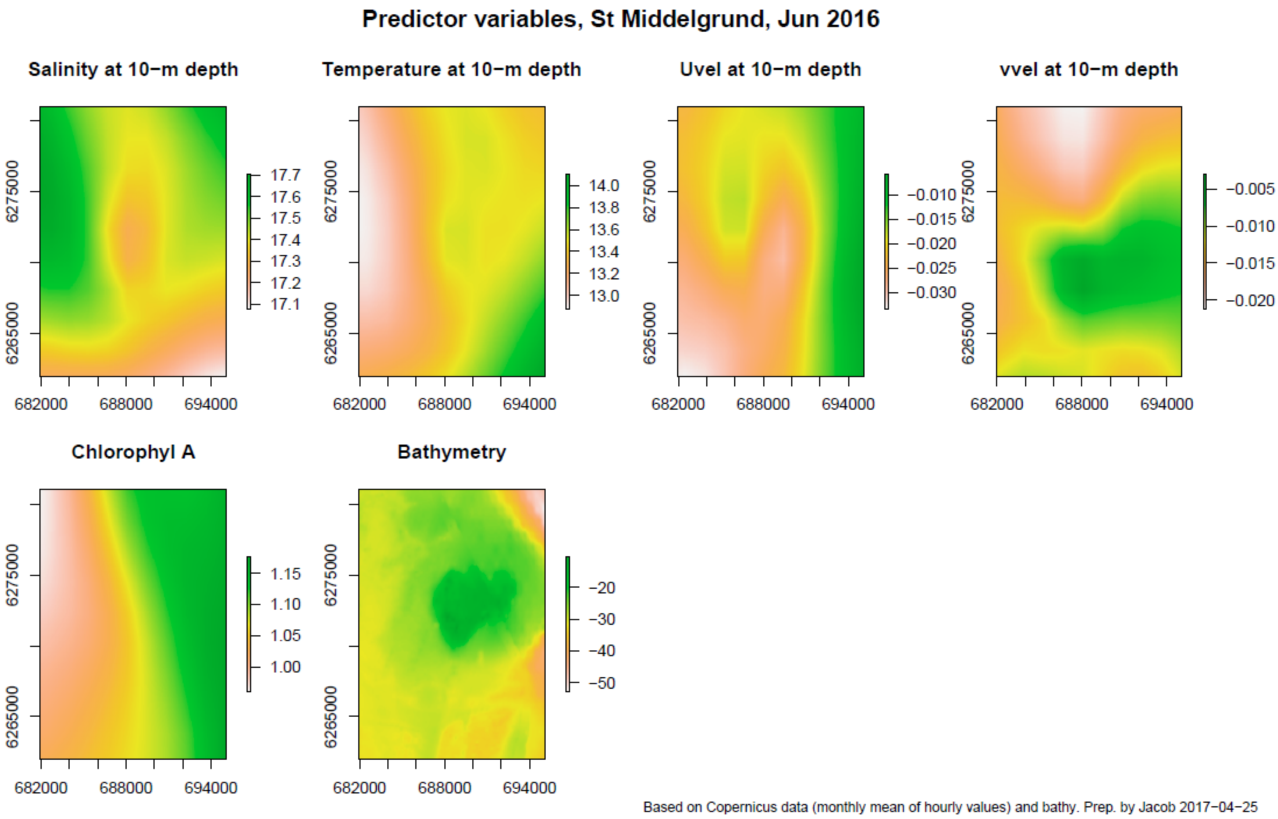
Maps illustrating the average predictor variables for each month used in the GLM. Green is high , red is medium and white is the lowest.The units are arbitrary.

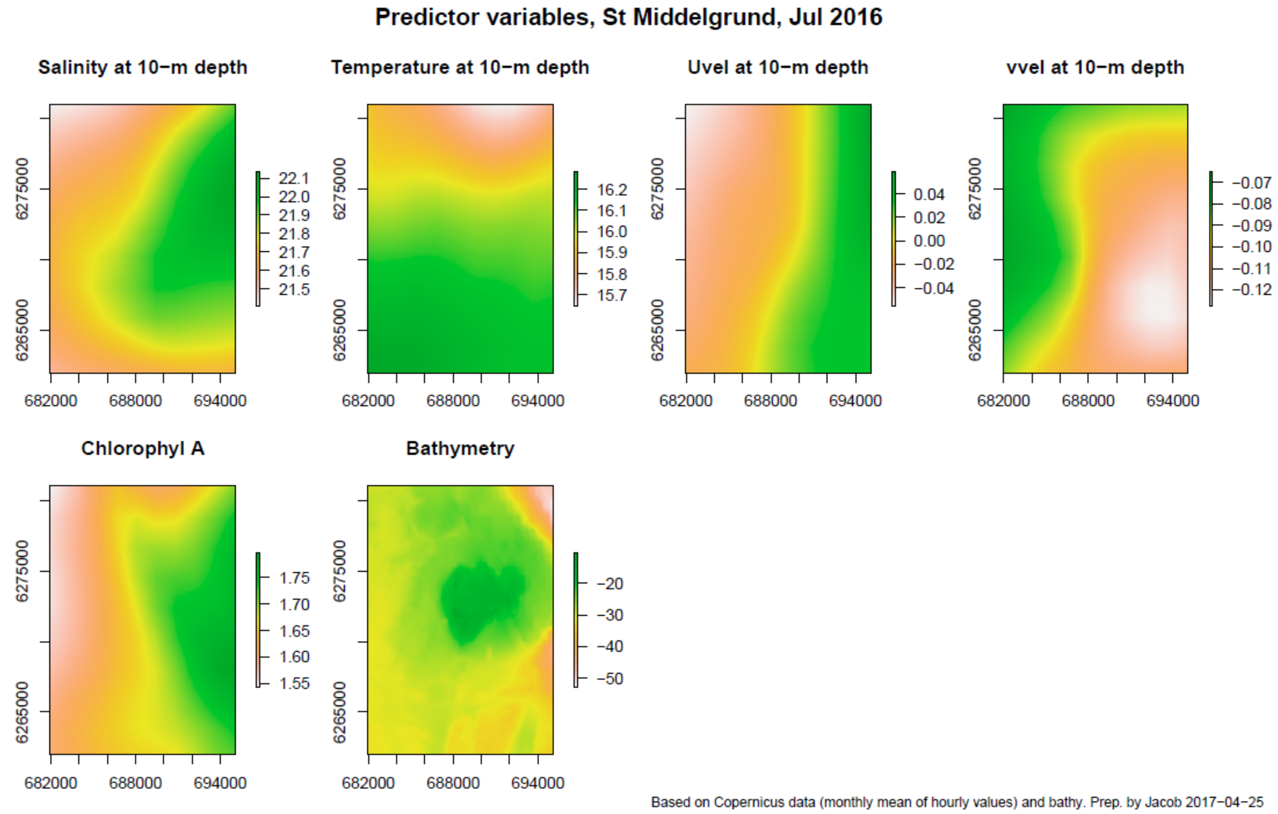


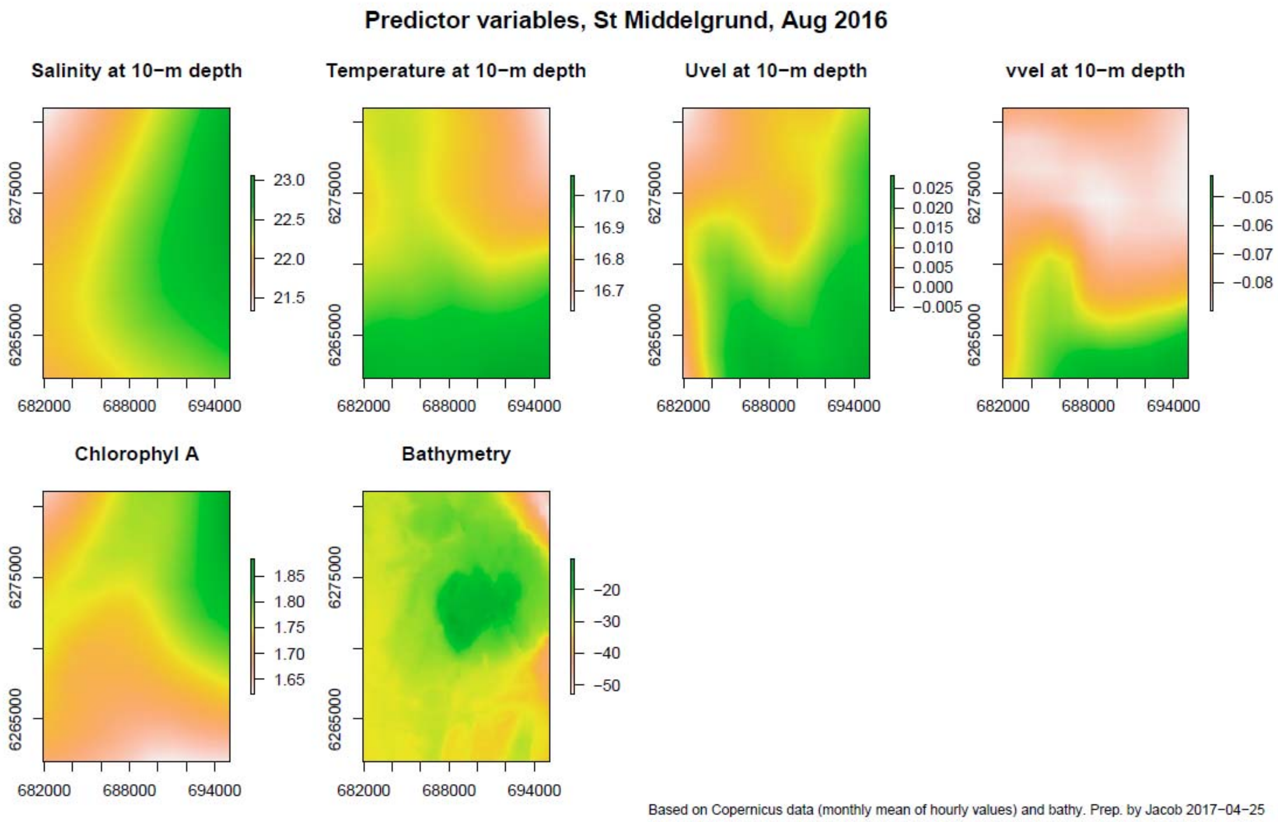

Predictor variables, St Middelgrund, Mar 2016
Salinity at 10−m depth
Temperature at 10−m depth
Uvel at 10−m depth
vvel at 10−m depth
Chlorophyl A
Bathymetry
6275000
6265000
682000
688000
694000
21.25
21.20
21.15
21.10
21.05
21.00
2.85
2.80
2.75
2.70
0.08
0.06
0.04
0.02
0.00
−0.02
0.00
−0.02
−0.04
−0.06
2.05
2.00
1.95
1.90
1.85
−20
−30
−40
−50
Based on Copernicus data (monthly mean of hourly values) and bathy. Prep. by Jacob 2017−04−25

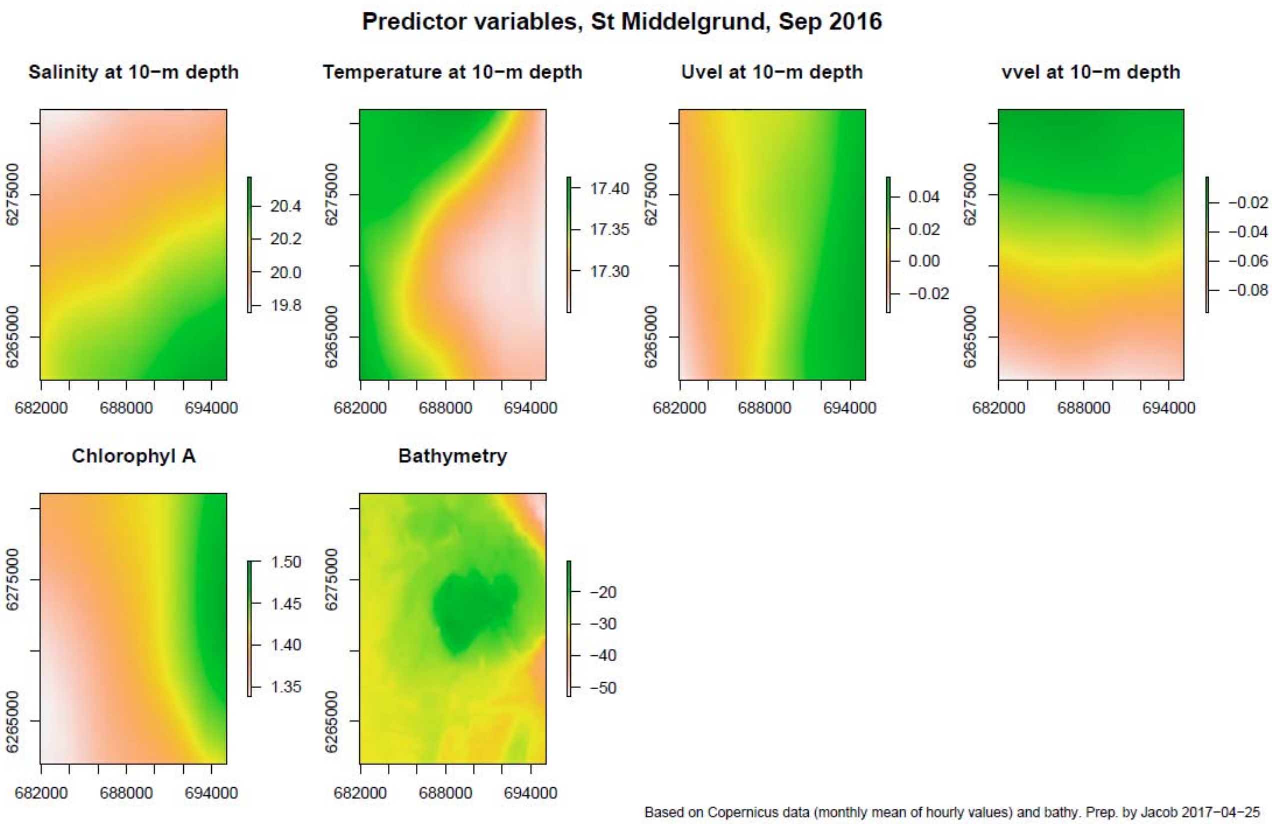

Predictor variables, St Middelgrund, Apr 2016
Salinity at 10−m depth
Temperature at 10−m depth
Uvel at 10−m depth
vvel at 10−m depth
Chlorophyl A
Bathymetry
6275000
6265000
682000
688000
694000
17.7
17.6
17.5
17.4
6.00
5.98
5.96
5.94
5.92
5.90
5.88
0.00
−0.01
−0.02
−0.03
−0.04
−0.05
0.01
0.00
−0.01
−0.02
−0.03
1.50
1.45
1.40
1.35
−20
−30
−40
−50
Based on Copernicus data (monthly mean of hourly values) and bathy. Prep. by Jacob 2017−04−25

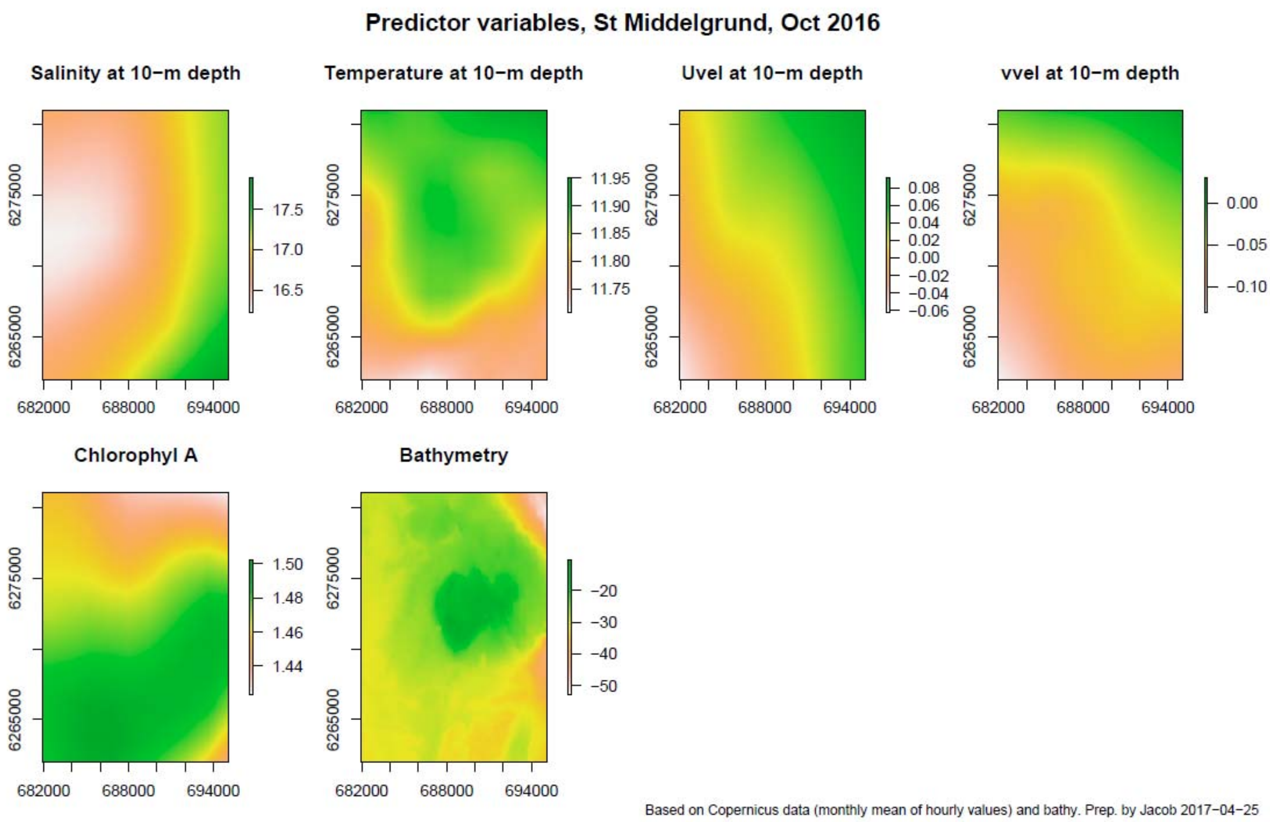

Predictor variables, St Middelgrund, May 2016
Salinity at 10−m depth
Temperature at 10−m depth
Uvel at 10−m depth
vvel at 10−m depth
Chlorophyl A
Bathymetry
6275000
6265000
682000
688000
694000
18.0
17.5
17.0
9.3
9.2
9.1
9.0
8.9
8.8
8.7
0.00
−0.02
−0.04
−0.06
0.000
−0.005
−0.010
−0.015
−0.020
−0.025
1.30
1.25
1.20
1.15
−20
−30
−40
−50
Based on Copernicus data (monthly mean of hourly values) and bathy. Prep. by Jacob 2017−04−25

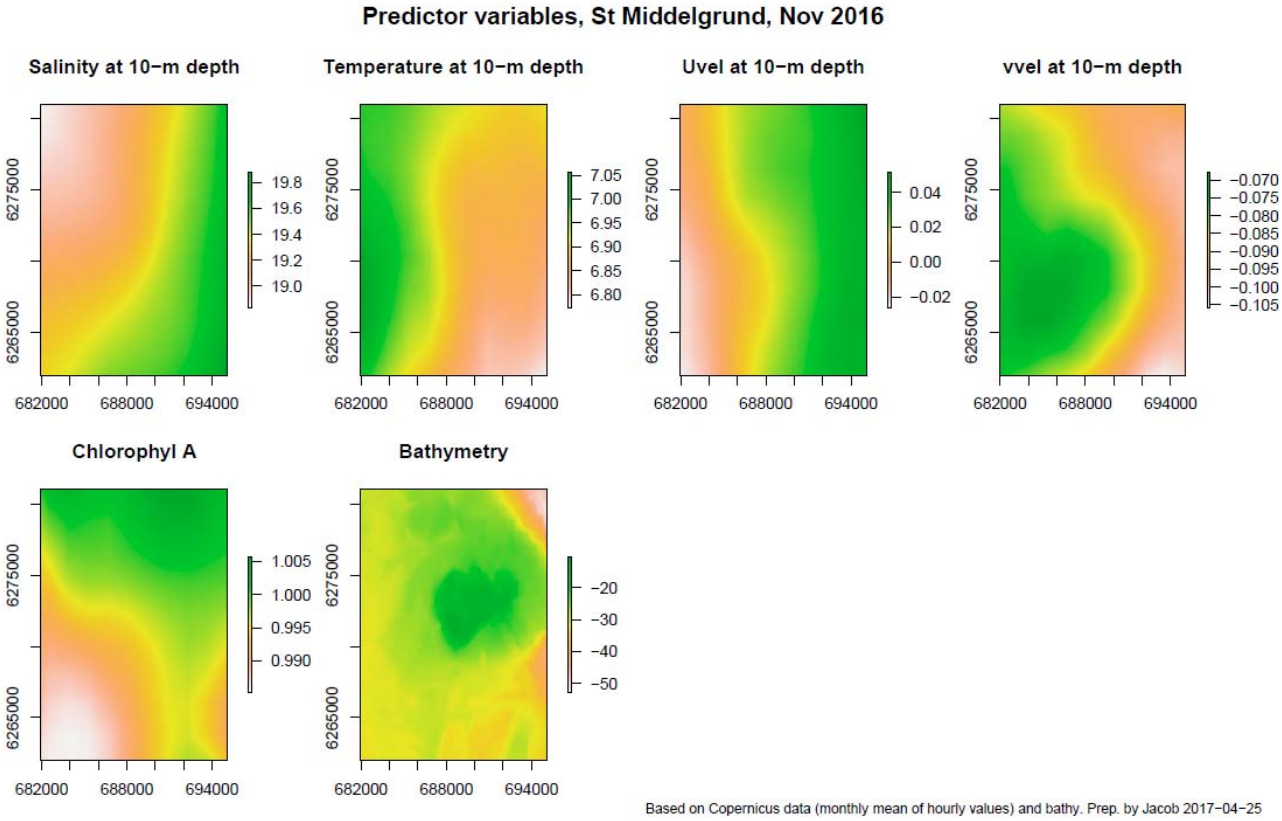

Predictor variables, St Middelgrund, Jun 2016
Salinity at 10−m depth
Temperature at 10−m depth
Uvel at 10−m depth
vvel at 10−m depth
Chlorophyl A
Bathymetry
6275000
6265000
682000
688000
694000
17.7
17.6
17.5
17.4
17.3
17.2
17.1
14.0
13.8
13.6
13.4
13.2
13.0
−0.010
−0.015
−0.020
−0.025
−0.030
−0.005
−0.010
−0.015
−0.020
1.15
1.10
1.05
1.00
−20
−30
−40
−50
Based on Copernicus data (monthly mean of hourly values) and bathy. Prep. by Jacob 2017−04−25

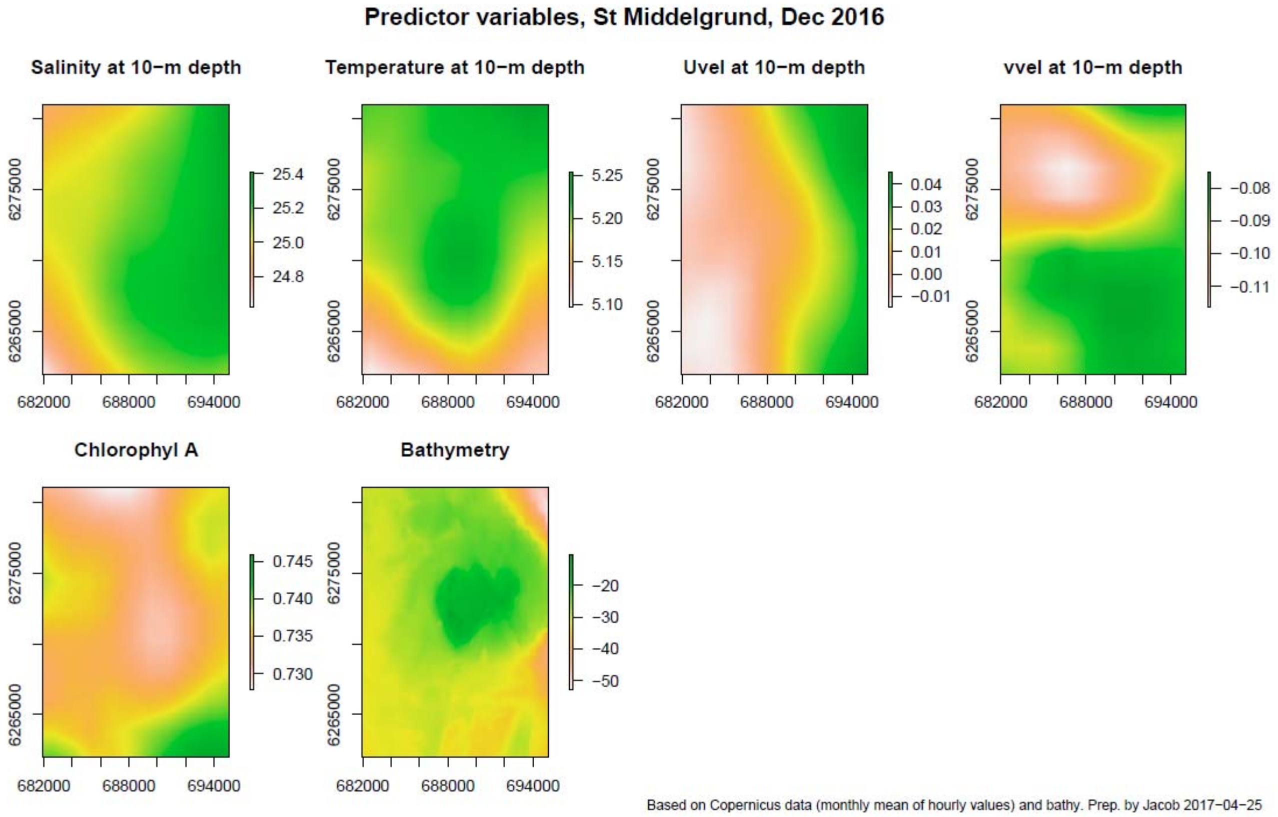

Predictor variables, St Middelgrund, Jul 2016
Salinity at 10−m depth
Temperature at 10−m depth
Uvel at 10−m depth
vvel at 10−m depth
Chlorophyl A
Bathymetry
Based on Copernicus data (monthly mean of hourly values) and bathy. Prep. by Jacob 2017−04−25


Predictor variables, St Middelgrund, Aug 2016
Salinity at 10−m depth
Temperature at 10−m depth
Uvel at 10−m depth
vvel at 10−m depth
Chlorophyl A
Bathymetry
Based on Copernicus data (monthly mean of hourly values) and bathy. Prep. by Jacob 2017−04−25


Predictor variables, St Middelgrund, Sep 2016
Salinity at 10−m depth
Temperature at 10−m depth
Uvel at 10−m depth
vvel at 10−m depth
Chlorophyl A
Bathymetry
6275000
6265000
682000 688000 694000
20.4 20.2 20.0 19.8
17.40 17.35 17.30
0.04 0.02 0.00 −0.02
−0.02 −0.04 −0.06 −0.08
1.50 1.45 1.40 1.35
−20 −30 −40 −50
Based on Copernicus data (monthly mean of hourly values) and bathy. Prep. by Jacob 2017−04−25


Predictor variables, St Middelgrund, Oct 2016
Salinity at 10−m depth
Temperature at 10−m depth
Uvel at 10−m depth
vvel at 10−m depth
Chlorophyl A
Bathymetry
6275000
6265000
682000 688000 694000
17.5 17.0 16.5
11.95 11.90 11.85 11.80 11.75
0.08 0.06 0.04 0.02 0.00 −0.02 −0.04 −0.06
0.00 −0.05 −0.10
1.50 1.48 1.46 1.44
−20 −30 −40 −50
Based on Copernicus data (monthly mean of hourly values) and bathy. Prep. by Jacob 2017−04−25


Predictor variables, St Middelgrund, Nov 2016
Salinity at 10−m depth
Temperature at 10−m depth
Uvel at 10−m depth
vvel at 10−m depth
Chlorophyl A
Bathymetry
Based on Copernicus data (monthly mean of hourly values) and bathy. Prep. by Jacob 2017−04−25


Predictor variables, St Middelgrund, Dec 2016
Salinity at 10−m depth
Temperature at 10−m depth
Uvel at 10−m depth
vvel at 10−m depth
Chlorophyl A
Bathymetry
Based on Copernicus data (monthly mean of hourly values) and bathy. Prep. by Jacob 2017−04−25

Appendix 2

Summary and details of the model used for producing the spatial maps.

Call:
glm(formula = dpm.bin ~ salt + temp + uvel + vvel + chla + bathy + month + mean.sensitivity + salt:month + temp:month + uvel:month + vvel:month + chla:month + bathy:month, family = binomial, data = ll.data2)

Deviance Residuals:

Min	1Q	Median	3Q	Max
-2.5694	-0.9920	-0.4119	1.0152	2.7732

	Estimate	Std. Error
(Intercept)	9.203329	1.41717
salt	0.21913	0.05814
temp	-0.178851	0.114802
uvel	1.17781	0.301283
vvel	0.60409	0.266928
chla	0.792049	0.02807
bathy	-0.127425	0.008152
month3	11.281816	1.633035
month4	4.534049	1.386969
month5	6.619702	1.327204
month6	0.217271	2.201714
month7	2.015096	1.489255
month8	4.292464	1.861784
month9	9.776988	1.765899
month10	8.384397	1.270534
month11	7.714137	1.320906
month12	8.783702	1.411631
mean.sensitivity	-0.184475	0.00612
salt:month3	-0.376755	0.071708
salt:month4	-0.047092	0.067982
salt:month5	-0.011626	0.061744
salt:month6	0.074056	0.093834
salt:month7	-0.443437	0.059269
salt:month8	-0.068714	0.064163
salt:month9	-0.320763	0.062584
salt:month10	-0.14533	0.062793
salt:month11	-0.095216	0.063626
salt:month12	-0.165031	0.061875
temp:month3	0.108158	0.145255
temp:month4	0.382632	0.117369
temp:month5	0.041363	0.120499
temp:month6	0.447965	0.125147
temp:month7	0.869432	0.123878

temp:month8	0.382372	0.130839
temp:month9	0.175545	0.13269
temp:month10	0.13029	0.116239
temp:month11	0.262367	0.120089
temp:month12	0.446716	0.128249
uvel:month3	-1.764882	0.43736
uvel:month4	-0.341082	0.41232
uvel:month5	-1.903724	0.375993
uvel:month6	-0.849717	0.481536
uvel:month7	-3.181485	0.423251
uvel:month8	-0.986278	0.4171
uvel:month9	-1.251046	0.426183
uvel:month10	-1.544472	0.387942
uvel:month11	-1.117915	0.392654
uvel:month12	-1.016309	0.403382
vvel:month3	-0.820702	0.417432
vvel:month4	-0.96105	0.357659
vvel:month5	0.30827	0.339473
vvel:month6	-0.907792	0.455643
vvel:month7	2.86055	0.416388
vvel:month8	-1.94965	0.339296
vvel:month9	-1.804574	0.385798
vvel:month10	-1.51292	0.354144
vvel:month11	-0.27923	0.319803
vvel:month12	0.234684	0.329474
chla:month3	-0.787275	0.041981
chla:month4	-1.216629	0.107302
chla:month5	-0.887507	0.141322
chla:month6	-0.635334	0.19266
chla:month7	-0.050213	0.077609
chla:month8	-0.860573	0.100034
chla:month9	0.256016	0.203379
chla:month10	-0.044929	0.124232
chla:month11	-0.357909	0.20929
chla:month12	-2.108426	0.542731
bathy:month3	-0.030116	0.010506
bathy:month4	-0.013155	0.010481
bathy:month5	0.001684	0.010265
bathy:month6	-0.039829	0.010918
bathy:month7	0.004506	0.010784
bathy:month8	0.084561	0.010095
bathy:month9	0.052623	0.010908
bathy:month10	0.086727	0.010445
bathy:month11	0.118354	0.010259
bathy:month12	0.11033	0.010851

Null deviance: 118900 on 85922 degrees of freedom
Residual deviance: 101654 on 85845 degrees of freedom
AIC: 101810

Number of Fisher Scoring iterations: 5

MONTHLY VARIATION IN FINE-SCALE DISTRIBUTION OF HARBOUR PORPOISES AT ST. MIDDELGRUND REEF

Store Middelgrund reef in Kattegat has been identified as harbour porpoise bycatch hot-spot. This study aims to examine the fine-scale harbour porpoise distribution at the Store Middelgrund reef by deploying passive acoustic monitoring stations (CPODS) in the area for one year (February 2016 – January 2017). The distribution was analysed and presented by monthly habitat-based distribution models (GLM), and the potential role of different kinds of environmental variables (e.g. water current strength, temperature, and salinity) as drivers for this distribution on a small spatial and temporal scale was examined. The study found that porpoises are present around the reef all year, but that the densities are higher in May to August with a peak in June on most stations while the period from September to December had the fewest detections. The most important drivers for harbour porpoise distribution as identified in the model was month, bathymetry and chlorophyll A. Porpoises occur mainly in the deeper part of the study area and not as frequent within the shallowest part of the reef that is designated as Natura 2000 for harbour porpoises.

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