Statistical analysis of SAMBAH survey and associated data

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Introduction

SAMBAH (Static Acoustic Monitoring of the Baltic Sea Harbour Porpoise) was an international project involving all EU countries around the Baltic Sea, funded by those countries and by the EU Life program (Project Number LIFE08 NAT/S/000261). It ran from 1/1/2010 to 30/9/2015. One major goal of the project was to estimate the abundance of Baltic Sea harbour porpoise, by designing and implementing a large-scale multi-year passive acoustic survey. CREEM was contracted to collaborate on the survey design, and provide statistical analysis of resulting data. A number of internal reports were produced and circulated to the project team, detailing aspects of the analysis. In this CREEM technical report, we collate the most recent version of each of these internal reports as a means of making them publicly available. Table 1 gives a list of the reports included.

This report can be cited using the suggested citation on the front cover. Alternatively, individual internal reports can be cited using the following suggested format:

[Authors] [Year] [Title] Internal report dated [date]. Centre for Research into Ecological and Environmental Modelling, University of St Andrews.

For example, the first report could be cited as

Thomas L. and M.L. Burt (2015) SAMBAH report 1, version 4.1: encounter rate analysis. Internal report dated 4/4/2015. Centre for Research into Ecological and Environmental Modelling, University of St Andrews.

Table 1. Internal reports collated in this Technical Report.

Report number	Title	Date on document	Description
1 – Version 4.1	Encounter rate analysis	April 4, 2015	Description of spatio-temporal patterns in the amount of survey effort and number of porpoise positive seconds; also examination of patterns in diel phase
2 – Version 1.2	Assessment of C-PODs to detect porpoise using the Kerteminde study	November 18, 2014	EDA and initial detection function analysis on harbour porpoise encounters at Kerteminde. Useful background, but does not contain the final analysis used.
2a – Version 2.1	Kerteminde Free-swimming Porpoise Detection Function Analysis	May 31, 2015	Further analysis of Kerteminde porpoise detection function. Contains the final analysis used.
3 – Version 1.2	Estimating the effective detection area for C-PODs from playback experiments in the Baltic Sea and Kerteminde	December 6, 2014	Initial analysis of playback experiments, both for Kerteminde and (partially) the SAMBAH area. Useful background, but does not contain the final analysis used.
3a – Version 1.1	Further analysis of Kerteminde playback experiments	April 5, 2015	Final analysis of Kerteminde playback data
3b – Version 1.1	Further analysis of SAMBAH playback experiments	June 2, 2015	Final analysis of SAMBAH playback data
3c – Version 1.0	Summary of the environmental covariates used to model playback experiments	December 4, 2014	Exploratory analysis of environmental covariates for SAMBAH playbacks
4 – Version 1.2	Summary of ATag data	October 28, 2014	Initial analyses of ATag data. Useful background, but does not contain the final analysis used.
4a – Version 1.0	2nd ATag data analysis	February 9, 2016	Final analysis of ATag data.
5 – Version 1.1	Sensitivity of C-PODs	October 17, 2014	Background document examining sensitivity data on C-PODs
6	Not included		Analysis of pound net data – not used in density estimation
7 – Version 2.2	Density and abundance estimates	February 8, 2016	Final density and abundance estimates

SAMBAH Report 1 - Version 4.1
Encounter Rate Analysis

Len Thomas & Louise Burt, CREEM

April 4, 2015

1 Preamble

The SAMBAH main survey design consists of 304 sampling positions, in 8 countries. A rough map of positions (labelled by country number) is given in Figure 1.

This report examines the survey effort achieved in the SAMBAH project, and the "encounter rate" (i.e., clicks per unit survey effort) in space and time. It is written for internal consumption by SAMBAH researchers; results given here will form the basis for published outputs. The report is written using `Knitr` package in `R version 3.1.3 (2015-03-09)`; it is therefore a "live" document in the sense that all values, tables and figures given are the direct output from `R` analyses performed as part of document compilation (except where auxiliary `R` scripts were run in advance, as noted in the text).

2 Reading in the data

The raw data to calculate encounter rate is in the files
`detections and environment - validated and cropped - 20140902.txt`
and
`click details - validated and croppped - 20140902.txt`.
We refer to the first as the "effort file" and the second as the "detections file".

2.1 Effort file

The effort file has one line for each minute that each POD was deployed, but is truncated so that days when deployments were made are not in the file – i.e., records for a deployment always start at midnight on the day of deployment and stop one minute before midnight on the day before the deployment ended. The effort file contains 13 columns and is tab delimited. It's a huge file (around 18GB), not amenable to normal text editors; we used the freeware windows software LTF Viewer to look inside it. We wrote R code[1] to read the file.

[1] All R code associated with reading the data is in the file `CalculateEncounterRate_vX.r`, where X is the version number.

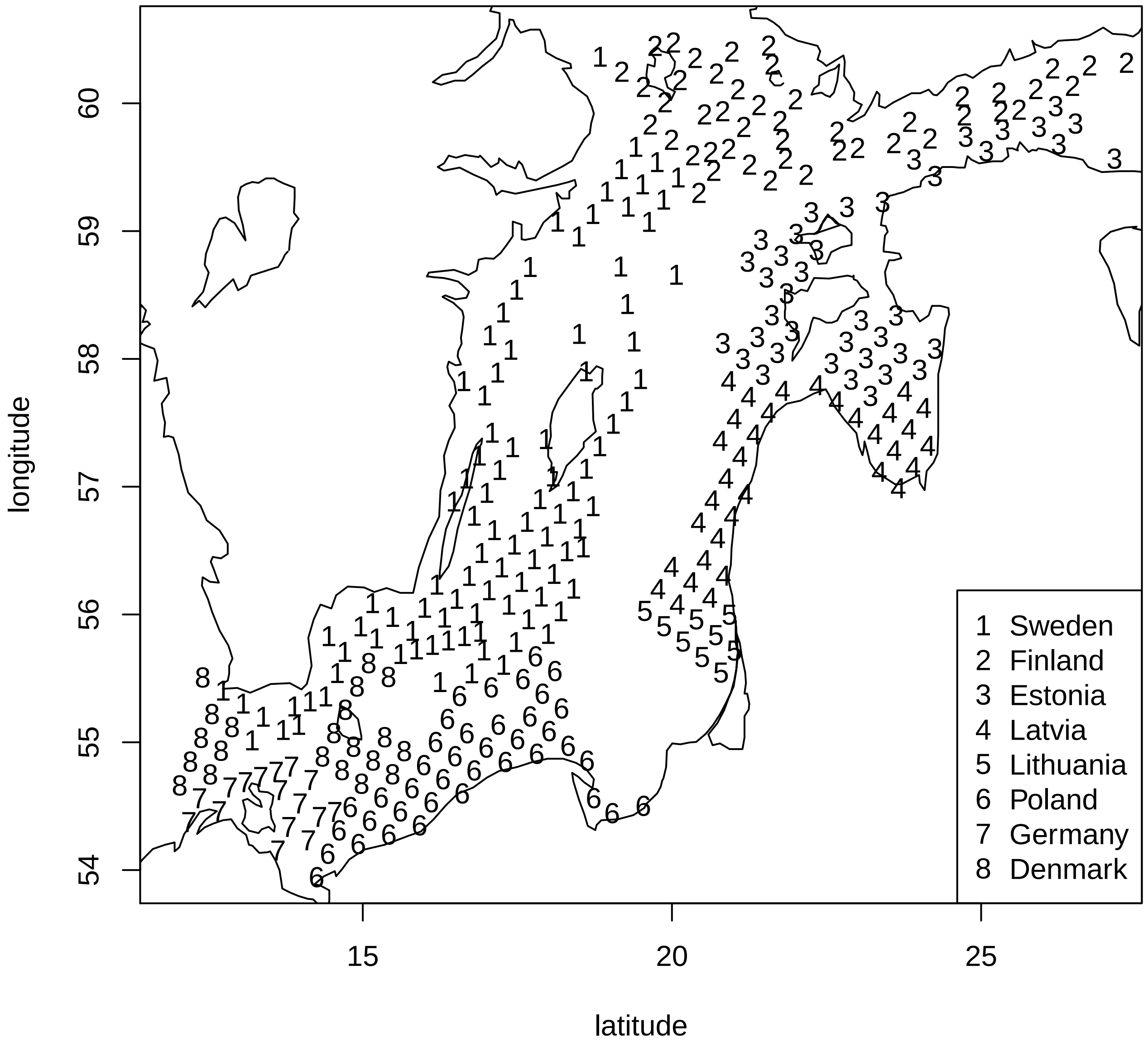

Figure 1: SAMBAH positions, labelled with their country code.

- From the first column ("File") we extract the deployment number (it's the first 6 columns).
- From the second column ("ChunkEnd" we extract) the date and time. From this, we extract the year and month (number: 1-12), as well as the number of minutes after midnight (number: 1-1440).
- From the 6th column ("MinutesON") we extract a zero or 1. If zero, this means the POD was not on for that minute, and we skip to the next record. If 1, then from the 10th column ("%TimeLost") we extract a number between 0 and 100, representing the percentage of that minute that was "lost" – i.e., where the POD was not operating effectively - e.g., it was tipped over, etc.

For each record, we then calculate the number of seconds the POD was operating as 0 (if MinutesON is 0) or 60 times %TimeLost (if MinutesON is 1). Note that this leads to non-integer seconds. For each minute of the day within each month within each deployment, we add the number of seconds together, to make a total `effort.secs` - this is saved to the file `effort.bymonth.bymin.txt` So, we effectively aggregate each minute over days within months within deployments.

Notes:

- All times within this file are local times, with the timezone set at time of deployment. There is a GMT offset column in the master meta data file that will allow us to convert to GMT, if required.
- For stations that are at depths outside our initial criteria, we will keep them for the design-based analysis used here.

The files include data from the Russian supplement to SAMBAH (called "RUMBAH"). We excluded these data from our calculations (by excluding all data with country code of 9.)

We aggregated the results by deployment and month. Here are some summaries.

Once read in, there are 6141 deployment-months containing data, with 1356 deployments at 298 positions. Note, this means there are 6 of the original 304 positions where no data was collected. The total number of seconds of on-effort data is 1.235759e+10, which is equivalent to 391.86 years.

Table 1 and Figure 2 show the number of positions with working CPODs by month.

	1	2	3	4	5	6	7	8	9	10	11	12
2011	0	0	36	169	252	273	272	238	220	205	215	161
2012	193	186	165	135	193	226	228	228	216	216	222	209
2013	208	214	205	190	164	31	4	1	0	0	0	0

Table 1: Number of positions with working CPODs by month

From this point on, we truncate the data, so that we only work with data collected between 1st May 2011 and 30th April 2013, inclusive. This truncation deletes 6.595% of the effort data.

Figure 3 shows the spatial distribution of effort between May 2011 and April 2013.

There are strong spatial patterns in realized effort, with some isolated clusters of low effort, plus a general tendency for lower effort in Estonia, Latvia and Lithuania.

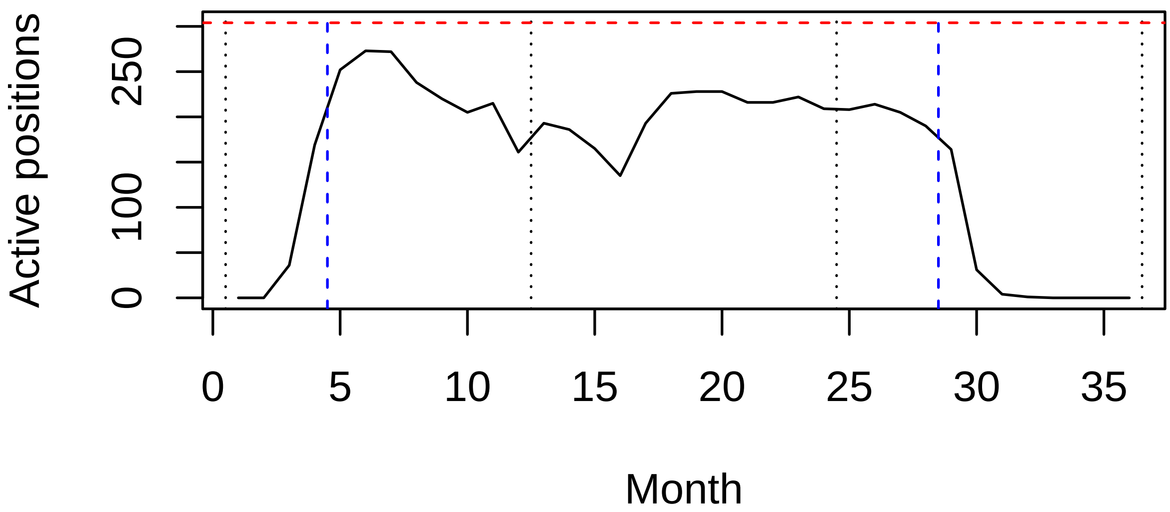

Figure 2: Number of positions with working CPODs by month. The black vertical dotted lines mark the year boundaries, the blue vertical dashed lines mark the April/May 2011 and April/May 2013 boundaries(May 1st 2011 and April 30th 2013 are the agreed start and end points of the project) and the red horizontal dashed line showd the maximum number of positions.

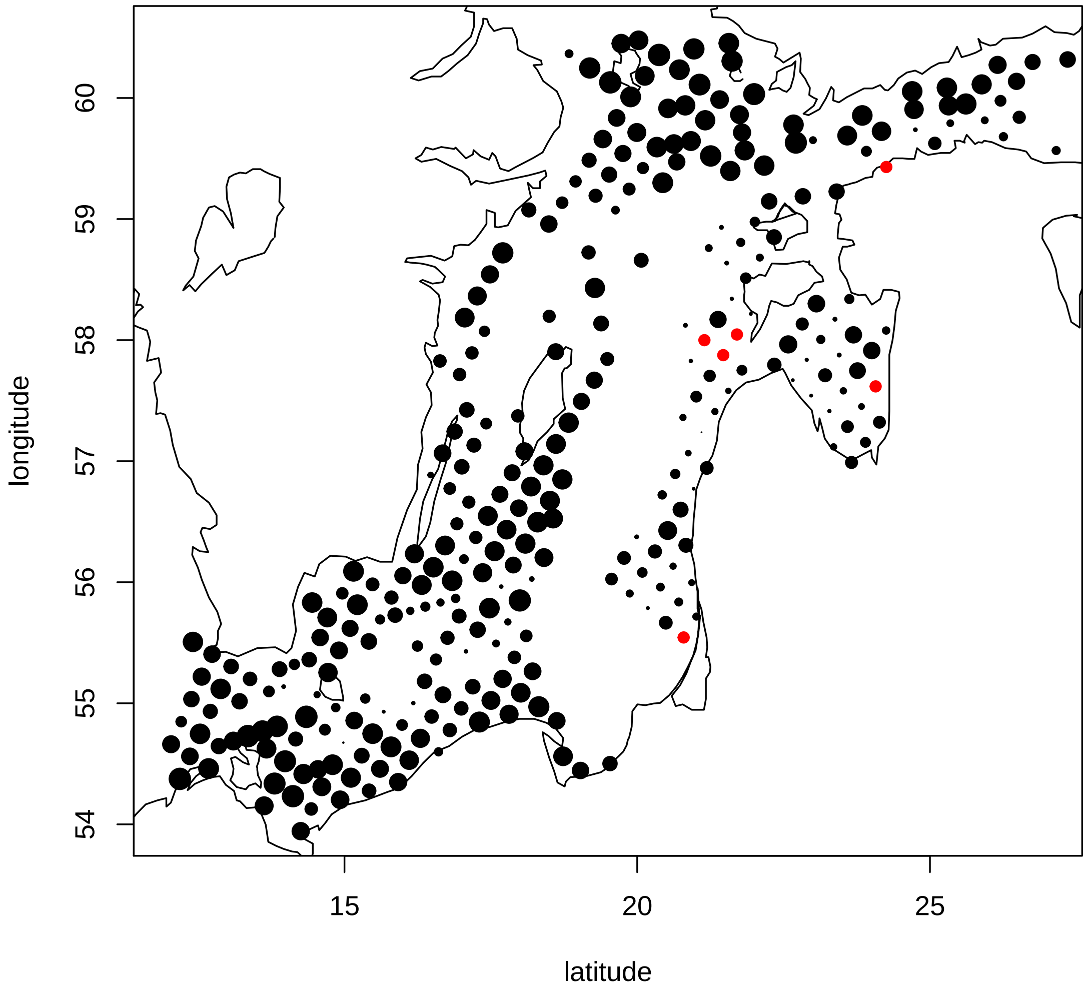

Figure 3: Spatial distribution of effort between May 2011 and April 2013. The size of each point is proportional to the number of days surveyed; red dots are positions with zero days of survey effort.

Effort can be lost for many reasons. A non-exhaustive list is: PODs not deployed; PODs failing early; PODs not serviced promptly; PODs moving from original position (e.g., being caught in trawl nets) and either lost or found later; PODs being temporarily tilted beyond tolerence (in which case any collected data is not used in those seconds); too many detections in a minute (in which case the POD stops recording for those seconds). Over two years, at each site, the total number of potential seconds of monitoring is $60 \times 60 \times 24 \times 365 = 31,536,000$. Table 2 shows give the potential and total monitoring time for each country.

	name	positions	potential.years	years	perc.effort
1	Sweden	99	198.00	130.75	66.03
2	Finland	46	92.00	78.64	85.48
3	Estonia	40	80.00	30.20	37.74
4	Latvia	34	68.00	25.10	36.91
5	Lithuania	9	18.00	5.49	30.53
6	Poland	39	78.00	52.26	67.00
7	Germany	16	32.00	27.86	87.05
8	Denmark	21	42.00	26.77	63.75

Table 2: Number of positions by country, together with potential total monitoring time (in years) and the actual and percentage monitoring time (calculated by summing all seconds where a C-POD was operational per position).

Overall, there are 377.07 years of data out of a possible 608, representing 62.018% of the total possible survey effort.

2.2 Click file

This file contains one record for each click.

- The first column ("abbreviated file name") is the deployment number.
- From the second column ("Minute" we extract) the year, month and minute.
- From the forth column ("cycles") we extract the second the click took place in, by dividing by 1E6 and taking the quotient.

Given the above, we add up the number of click-positive seconds in each deployment-month-minute, to make the number of `click.secs` and this is saved to the file `click.seconds.bymonth.bymin.txt`.
These have been aggregated over minutes to give deplyment-months in what follows.

The data presented here have been truncated so that only data from 1st May 2011 - 30th April 2013 are presented.

Once read in, we have a total of 5.835674e+06 click positive seconds.

Interpreting patterns in the click positive seconds without correcting for effort and detectability is not particularly enlightening, but a few summary statistics are perhaps informative. Here, we give a text and graphical summary of the distribution – both show how right skewed it is. A quarter of the records are of 62 clicks or fewer, while is maximum number of clicks per month is very high, and the mean is much higher than the median (see Table 3 and Figure 4).

	location	value
1	Min.	1.00
2	1st Qu.	62.00
3	Median	344.00
4	Mean	6228.00
5	3rd Qu.	3158.00
6	Max.	179100.00

Table 3: Summary of click positive seconds.

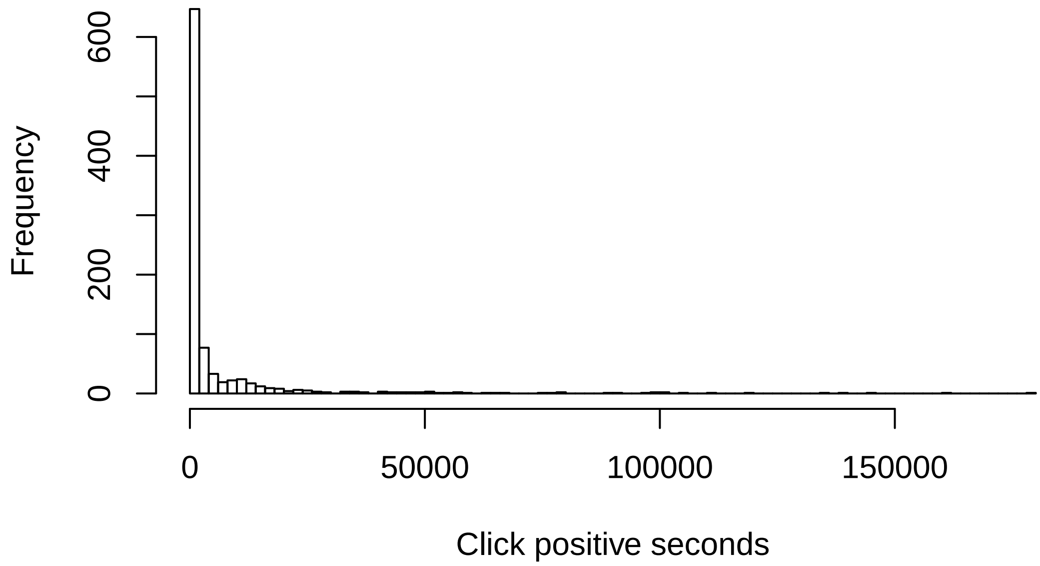

Figure 4: Histogram of click positive seconds.

2.3 Merging the effort and click files

The two datasets were merged, truncated to the period 1st May 2011 - 30th April 2013, and saved into `n.bymonth.trunc.txt`. Given this, the proportion of click-positive seconds of monitoring can be calculated. On average, over the whole dataset, given 5.835674×10^6 click positive seconds in 1.1891231×10^{10} seconds of monitoring, the proportion of click positive seconds is 0.00049075, or 0.049075%.

Dividing it by position, we have 6 positions with no effort, 154 that have 0 clicks counted, and 144 with at least 1 click counted. Summaries of the encounter rate where > 0 clicks counted are given in Table 4 and Figures 5 and 6.

Figures 7, 8 and 9 show how encounter rate varies over space – Figure 7 is for all data, Figure 8 is for November - April ("Winter") and 9 is for May - October ("Summer").

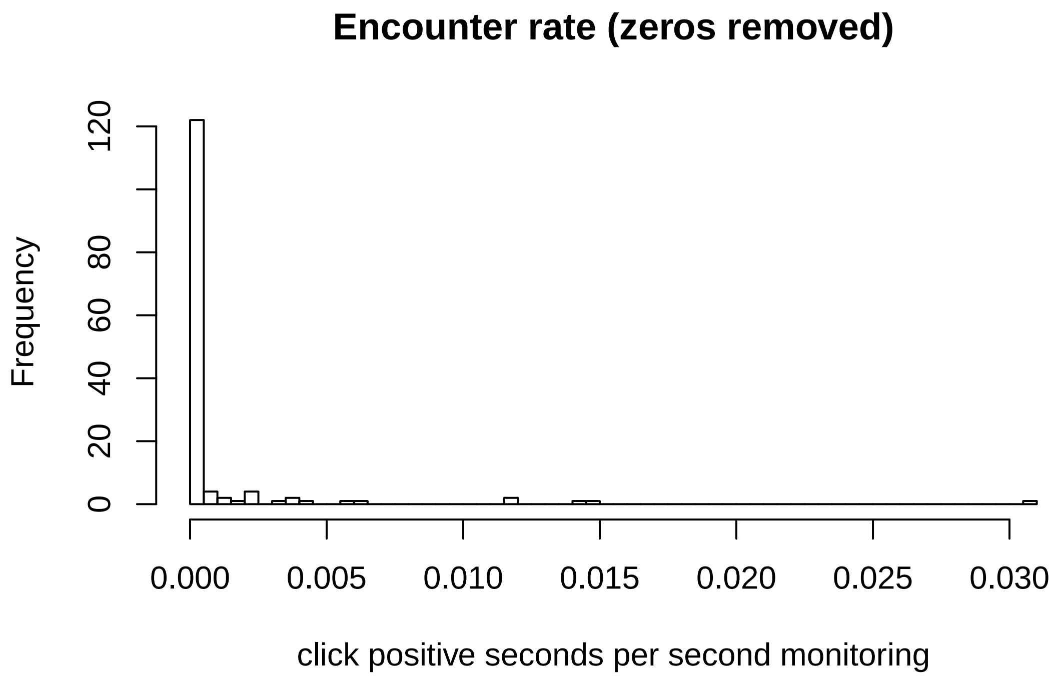

Figure 5: Histogram of encounter rate (i.e., click seconds over effort seconds) for positions with > 0 clicks.

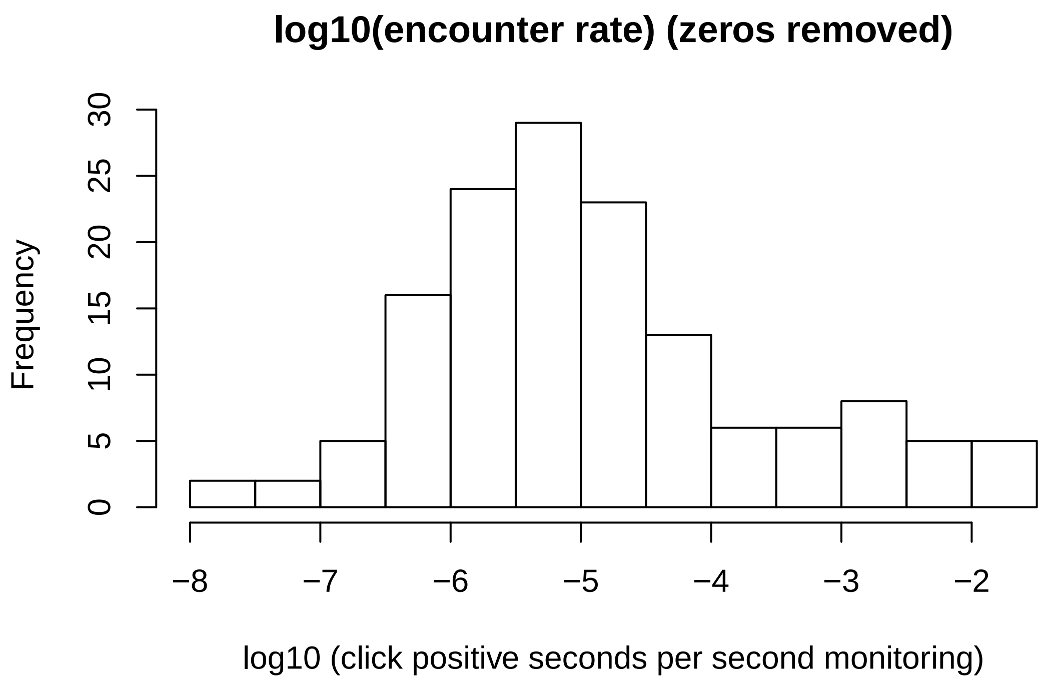

Figure 6: Histogram of log10 encounter rate (i.e., click seconds over effort seconds) for positions with > 0 clicks.

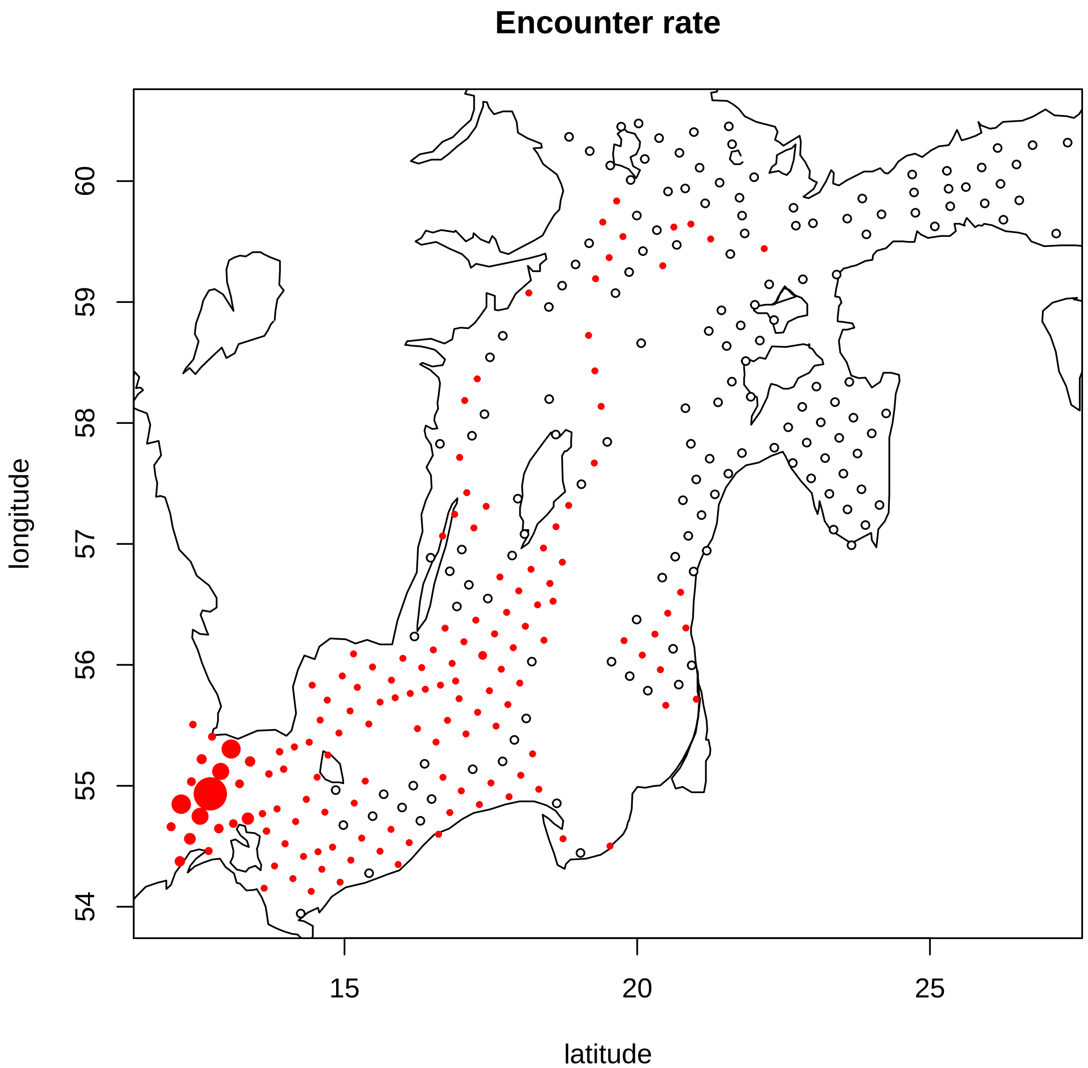

Figure 7: Map showing encounter rate (proportion of click positive seconds per second monitoring) by position. Point size is proportional to the encounter rate for the red dots (plus some offset, so that locations with almost zero encounter rate are visible); the black open circles indicate positions that were surveyed but where the encounter rate is zero.

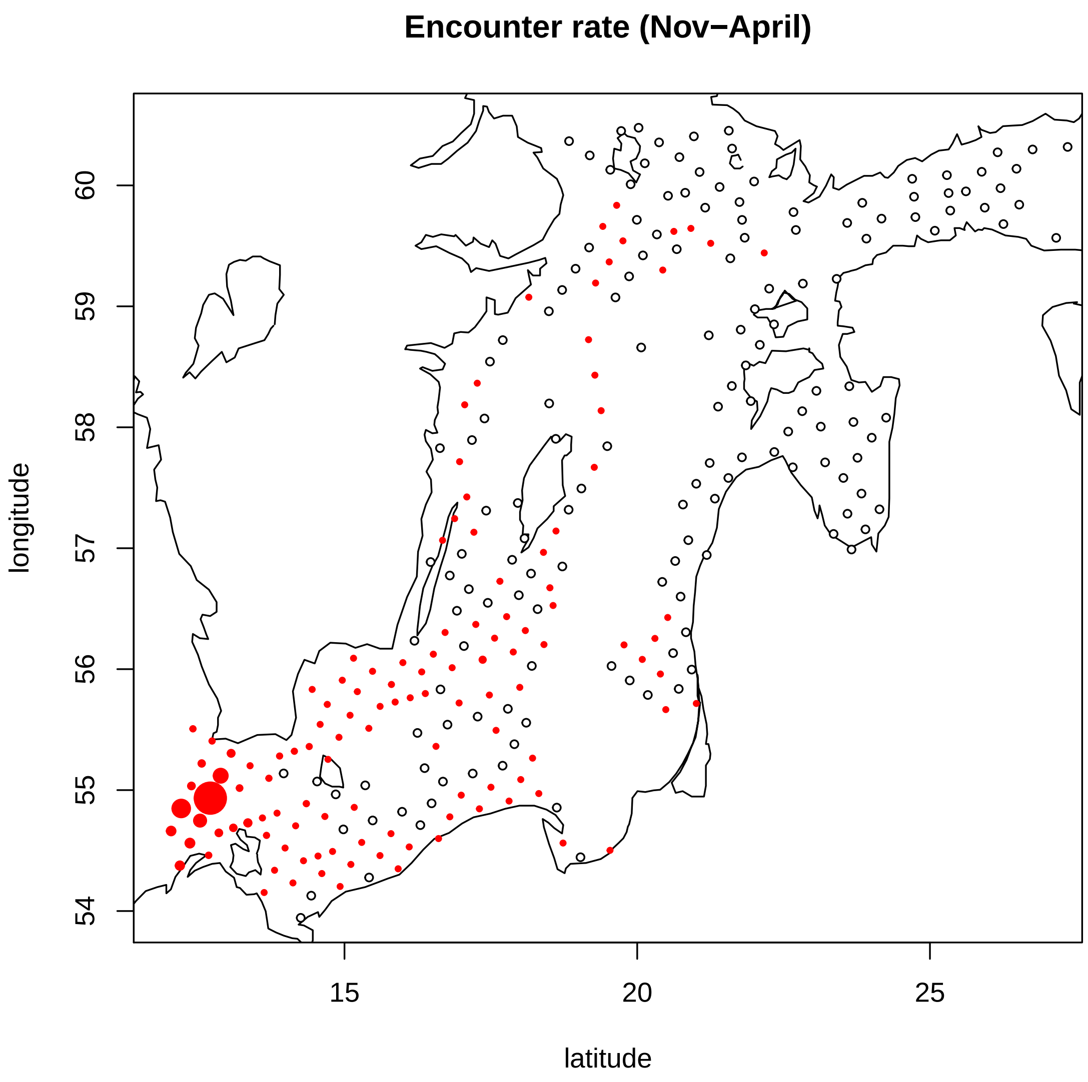

Figure 8: Map showing encounter rate by position for November - April.

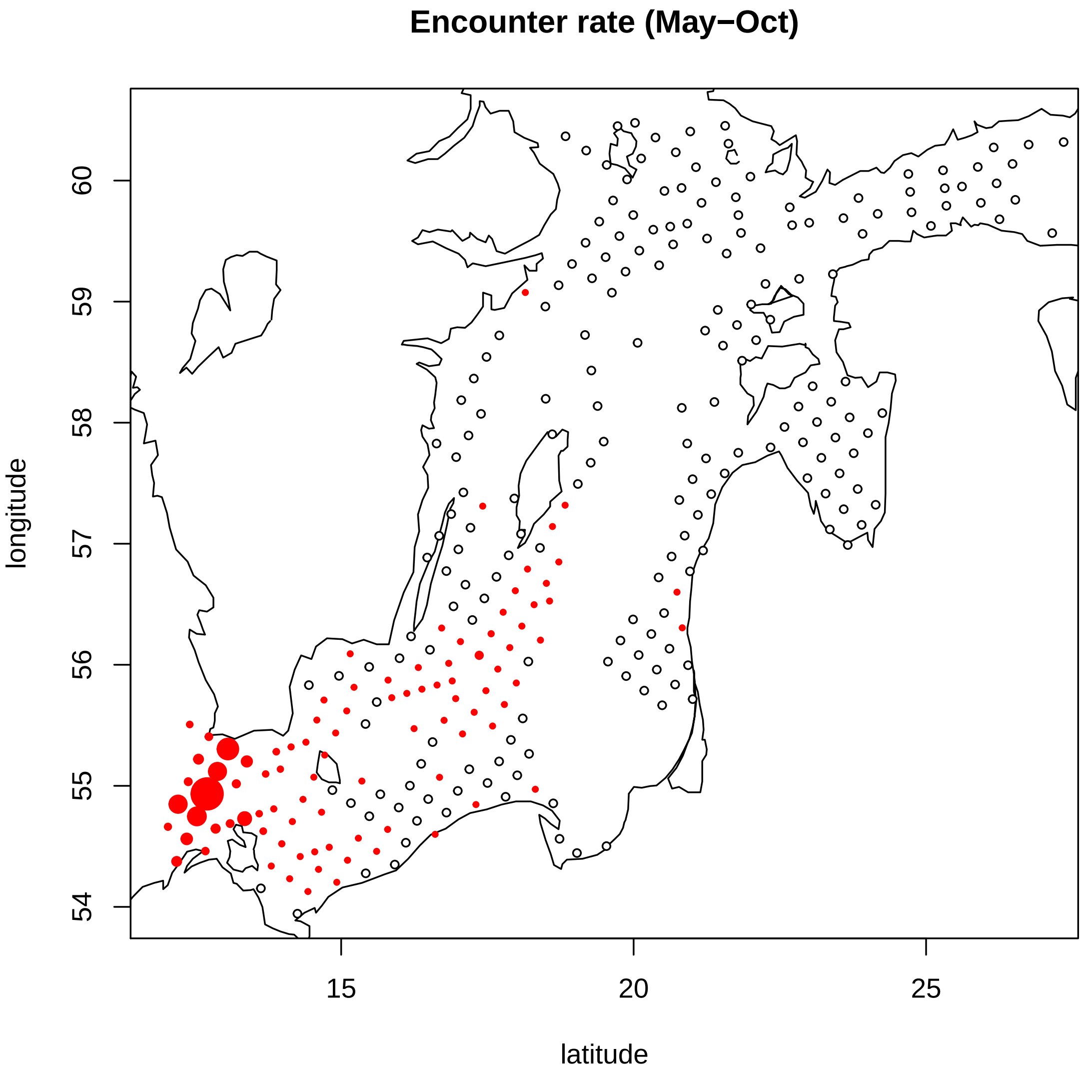

Figure 9: Map showing encounter rate by position for May - October.

	location	value
1	Min.	0.0000000
2	1st Qu.	0.0000017
3	Median	0.0000073
4	Mean	0.0008896
5	3rd Qu.	0.0000445
6	Max.	0.0308600

Table 4: Summary of encounter rate, truncated to include only positions with > 0 encounters.

3 Merging in the meta file

Now to read in in the meta data spreadsheet. We use the file `Megametadata SAMBAH v6.csv`, which is a .csv version of the original .xlsx file (.csv's are easier to read into 64-bit R). We use it for two things:

1. Check the deployment numbers and dates match what we have in the effort data file
2. Retrieve the GMT correction - we'll use the GMT correction at the start of the deployment. We need this so we can look at diurnal patterns.

Note, for this we are using the untruncated data (i.e., including all deployments, not just those in the May 2011 - April 2013 time frame). This is because we want to check all the deployments against the meta file. We go back to using truncated data later on in this report.

Regarding the first item, all we check for is missing records in the meta or effort files.

There are 0 records in the effort file that do not have any records in the meta file. (This number should be zero.)

There are 431 records in the meta file that do not have any records in the effort file. Information about these is saved into the file `NoEffort.csv`, available on request.

1 of these has a position record in the meta file but no deployments – we suppose these represent positions never surveyed. Here are the position numbers:

```
## [1] 1006
```

The rest have deployments, but one or more of these deployments have no effort records – we suppose these are deployments that failed for one reason or another (lost C-PODS, corrupted SDs, etc.). The file `NoEffort.csv` should be checked to make sure these are all correct.[2]

4 Merging in the diel phase file

Now we read in the file of diel times, `Diel phase start times.csv`, and merge it with the previous data tables.

Note, we are using the date-truncated dataset for this merge.

Table 5 gives a summary of the encounter rate data by phase.

[2]It is our understanding that Daniel has checked all of these.

	phase	effort.secs	click.secs	er	relative.er
1	day	5731044415.20	2002554	0.0003494	1.000
2	eve	832462931.40	311642	0.0003744	1.071
3	morn	838949194.80	356616	0.0004251	1.217
4	night	4955131548.60	3188435	0.0006435	1.842

Table 5: Summary of encounter rate data by phase. First column is the total number of seconds of effort in the data, second is the total number of clicks, third is the encounter rate (i.e., number of click seconds/number of effot seconds), forth is encounter rate standardized so the smallest encounter rate has a value of 1 (just to make comparison easier).

However, any patterns seen in the above could be biased, because encounter rate varies over space and time and so does the amount of daylight and night. So, it would be better to view/analyze by country/position (space) and month (time).

Here, we fit a set of models where encounter rate (per hour) is modelled as a Tweedie random variable, as a function of country, month and phase, with up to three-way interactions.

AIC for the fitted models is shown in Table 6. The AIC-best model (model 3) has a two-way interaction between country and month, plus a main effect of phase. In other words, in the most parsimonious model, encounter rate varies over large scale space and time (as we'd expect), but there is an effect of diel phase on ecounter rate that is constant over space and time. Table 7 gives the coefficients for the phase terms (day is not included as it is absorbed into the intercept term), on the log link scale (column "Estimate") and back-transformed (column "Exp(Estimate)"). Reassuringly, the results are not enormously different from those in Table 5.

	rhs	df	AIC	DeltaAIC
3	phase+country*fmonth	101	475.22	0.00
1	phase*country+fmonth	45	518.56	43.35
7	country*fmonth	98	528.96	53.74
4	phase+country+fmonth	24	553.54	78.32
2	phase*fmonth+country	57	584.11	108.90
10	country+fmonth	21	585.50	110.28
5	phase*country	34	740.22	265.01
8	phase+country	13	756.07	280.85
9	phase+fmonth	17	1179.69	704.47
6	phase*fmonth	50	1242.66	767.44

Table 6: Encounter rate model selection statistics.

	Estimate	Std. Error	t value	Pr(>|t|)	Exp(Estimate)	95 perc LCL	95 perc UCL
phaseeve	0.181	0.126	1.442	0.150	1.199	0.937	1.534
phasemorn	0.353	0.124	2.859	0.005	1.424	1.117	1.814
phasenight	0.729	0.119	6.121	0.000	2.073	1.641	2.618

Table 7: Phase coefficients from the best fitting model.

SAMBAH Report 2 Version 1.2

Assessment of C-PODs to detect porpoise using the Kerteminde study

ML Burt and L Thomas, CREEM, University of St Andrews

SUMMARY

For the SAMBAH project an assessment of fixed acoustic devices (C-PODs) to detect harbour porpoise in their natural environment was required. To address this issue an experiment was conducted in the Great Belt, near Kerteminde, Denmark, in June 2013. This report describes the analysis of data collected during the experiment to determine the effective detection area of the C-PODs for detecting porpoise. The C-PODs were moored to the sea floor while observers on a ship visually searched for animals swimming around the devices. For every device, each second of an encounter with a single porpoise was considered to be a trial and classified as either a success, if a porpoise click was detected, or a failure, if the porpoise was not detected. This formed the response variable in a logistic regression framework to estimate the probability of detection and hence estimate the effective detection area. The majority of clicks were detected at night and so time of day, included as diel phase with four levels based on light levels, was an important factor in the model. To account for differences between devices and repeated measurements, random effect terms were also considered. The widest effective detection radius (EDR) was predicted for the night and narrowest EDR predicted for the morning or day, depending on the model. An average daily EDA was calculated by weighting the estimated effective detection areas for each diel phase by the proportion of time in each phase; this resulted in an average effective detection area of 6,443m^2 (CV=**). If diel phase was ignored in the model, then the estimated EDA was 1524m^2 (CV=**)

INTRODUCTION

In June 2013 an experiment was conducted in the Great Belt near Kerteminde, Denmark, to assess the performance of acoustic click detection devices (C-PODs) to detect harbour porpoises in their natural setting. Acoustic detectors were moored to the seabed and observers on a boat, anchored close to the detectors, searched visually for harbour porpoise swimming near to the detectors. The boat was fitted with a hydrophone array and this was used to localize every click and hence obtain a track of the animal. By geo-referencing the swim path of the animal, the distance of the animal at each second during an encounter to each of the detectors could be determined. Encounters were defined based on the timing of clicks and the location of the animal. Data recorded on the C-POD devices were then processed to determine which devices had detected a porpoise click. From this information, the probability of detection can be modelled as a function of the distance of the porpoise to the device and other explanatory variable. This document summarises the data collected and describes the analyses.

SURVEY METHOD

Devices were placed in either a 4x4 grid moored to the seabed or, on some days, placed in small clusters of 3 or 4 devices near to the boat (Table 1; Figure 1). Two different types of detector were used; 16 C-PODs and one T-POD (but note that the data from the T-POD was not used in this analysis). The distance between detectors in the grid was 50m and the hydrophones of the detectors were deployed 2m above the seafloor. Water depth was 19.5m over the whole site. On five days in June 2013 (5^{th}, 9^{th}, 11^{th}, 17^{th} and 18^{th}) a boat was anchored at different positions each day and observers on the boat searched visually for animals to assess group size; this was to ensure that data where only one animal was present during an encounter was used in the analysis.

Through the hydrophone array, animals were recorded with a program called MALTA (Microphone Array Localization Tool for Animals) and the position of the animal was calculated using PAMGUARD and MATLAB. Positions of the animal were calculated from the emitted clicks recorded by the hydrophone array and the other data (GPS, inclinometer, heading of the boat). A smoothing function was used to determine the swim paths of the porpoises from these single positions. From the swim paths, the positions of the animals were determined for every second of the encounter and the horizontal distances between the animal and all deployed devices were calculated.

For the C-POD data, the HEL1 classifier was used to identify clicks during an encounter. At every deployment, each second of an encounter was classified as either containing a porpoise click (or clicks) or not containing a click. For seconds identified as containing at least one click, the numbers of clicks made during the second were counted.

Independently, the individual C-POD devices were tested in a tank under standard conditions and the detection threshold at which the device registered 50% of clicks was determined; a device with a low detection threshold was more sensitive than a device with a high detection threshold. Where devices were tested more than once, the average RLs were obtained.

ANALYSIS METHOD

Each device was treated as a point transect (Buckland *et al*. 2001) and the aim of the analysis was to estimate the effective detection radius (EDR;ρ) and hence estimate the effective detection area (EDA; $\upsilon = \pi\rho^2$) of the detectors for porpoise in a natural environment. The detectability of the devices was considered here as two dimensional, whereas in reality it is three dimensional – variables to incorporate the 3D nature of the problem are discussed later. The EDR is obtained from the detection function, $g(r)$, the probability that a click at distance r from the detector can be detected. The detection function was estimated by modelling the probability of a porpoise being detected during each second of the encounter as the response variable and distance of the porpoise to the detector and other covariates as explanatory variables.

Estimating the effective detection radius and effective detection area

Point transects are considered to be circular (Buckland *et al*. 2001) and so the area of any incremental ring at distance r from the central point of the transect, is given by $2\pi r\ dr$, proportional to r. Therefore, the EDA covered by the detector can be estimated from

$$\nu = 2\pi \int_0^w rg(r)dr \qquad (1)$$

The total area (a) covered by a detector, assuming certain detection out to distance w, is given by $a = \pi w^2$. The overall probability of detection within the covered area (P_a) is given by

$$P_a = \frac{\nu}{a} = \frac{\pi\rho^2}{\pi w^2} \qquad (2)$$

where ρ is the effective detection radius, the distance at which as many calls are heard outside that distance as are missed within it. Rearranging (2) provides an estimate of the EDR;

$$\rho = \sqrt{P_a w^2}.$$

The parameter P_a is estimated by substituting (1) into (2) to give

$$P_a = \frac{2}{w^2}\int_0^w rg(r)dr.$$

Estimation of $g(r)$ is described below.

Estimating the detection function

For every detector, each second of an encounter was treated as a trial with two outcomes; either a porpoise was detected during that second (**porpoise positive second; PPS**) or a porpoise was not detected. The detection function, $g(r)$, was estimated by treating the probability of a porpoise being detected during each second of an encounter as the response variable in a model framework, and distance from the porpoise to the detector and other covariates as explanatory variables. Note that this probability of detection incorporated the probability of clicks being produced by a porpoise, being recorded on a C-POD and then being classified as a porpoise click. To complete the model specification the probability of detection was assumed to be a binomial random variable and a logit link function was specified. A generalized additive mixed model (GAMM; Wood, 2006) framework was used and the potential explanatory variables were:

- Distance – horizontal distance (m) of the porpoise to the detector fitted as a smooth function,
- Encounter – unique id allocated to each encounter (36 levels) fitted as a random effect,
- id – unique identification allocated to each C-POD (16 devices) fitted as a random effect.

The random effect terms were included to account for differences between individual encounters and devices but these differences are not of specific interest – devices and encounters in the study are assumed to be a subset of a larger population (which is normally distributed with a mean equal to zero and variance to be estimated from the data). These terms included an interaction with an indicator variable which was set to 1 during the model fitting and set to 0 during prediction (see below). A possible alternative way to account for differences between C-PODs would have been to use the detection threshold of each device as an explanatory variable instead of including a term for C-POD id. This is a less appealing option, however, as the results obtained from this study are to be applied to a larger study of C-PODs (see SAMBAH Report 7) and the RL has not been obtained for all those devices.

Three additional variables were also considered; angle from the animal to the pod and, to take into account the three-dimensional nature of the problem, depth of the animal and the vertical direction the animal was pointing (in terms of the difference in the angle from the horizontal) (see Appendix D).

There was evidence to suggest that click rates did not change substantially through the data, however, during this study there were more PPSs recorded at night (Table 2) than at other times of day which suggested that for these data, at least, time (in some form) may be an important explanatory variable. To gauge the effect this may have two models were considered; one ignoring time of day and one taking time of day (in some form) into account. Rather than use the, somewhat artificial, time of day, two measures of light levels were considered;

- Dielp - diel phase fitted as a factor with four levels (see Appendix A),
- SunAlt – altitude of sun (in degrees) fitted as a smooth function,

Diel phase divided the day into four phases (morning, day, evening and night) based on the movement of the sun. See Appendix A for more information.

The analysis was performed in R (version 3.0.2; R core team, 2013) using the mgcv library (version 1.7-27; Wood, 2004) and gam function. The random effect terms were fitted by treating them as penalized regression terms. To avoid fitting unrealistic smooth functions, the degree of smoothness was reduced to a maximum of 6 knots (5 degrees of freedom). Including distance as a linear term, rather than as a smooth term, was also considered.

Prediction

Using the selected model, the probability of detection at each distance (up to w=2,000m) was estimated by setting the dummy variable to zero for the random effect terms provided an estimate ignoring any effects due to these terms to obtain, essentially, an average value. Confidence limits were estimated using a parametric bootstrap: 1000 realizations of the parameters in the selected model were generated using a multivariate random normal distribution and for each realization, a new EDR and EDA were obtained (possible ref. Kyhn *et al*. 2012). The 2.5% and 97.5% quantiles of the bootstrap distributions provided the lower and upper 95% confidence limits, respectively.

RESULTS

Thirty-six encounters of individual harbour porpoises were recorded lasting for a total of 38 minutes and 28 seconds; the shortest encounter lasted 5 seconds and the longest, over 4 minutes. The average encounter length was 64.1 seconds (SD=49). Either 11, 12 or 13 detectors were deployed each day and so, taking into account the length of time of each encounter, the total number of seconds of recording time on the C-PODs was 26,207 (7 hours 16 minutes 47 seconds). Eleven C-PODs detected clicks and five C-PODs did not detect any porpoise clicks. Clicks were detected on four of the five days of the study and 137 seconds were identified as containing one, or more, clicks. A total of 1,406 individual clicks were identified, the majority occurring late in the day on the 17th June. Table 2 summarises the data collected during each encounter. Most encounters occurred during the day, however, most PPS occurred at night and so the proportion of PPS was highest for the night and lowest for the day (Table 3).

The swim paths of the porpoises encountered during each day are shown in Figure 2. See Appendix B for separate plots of each encounter. The distribution of distances between the devices and the animals are shown in Figure 3. The shortest (horizontal) distance from a detector to a porpoise was 21m and the longest distance was 390m with the mean distance being 148m. For PPS, the shortest distance was 26m and the longest distance was 260m (Table 4). The distances of the porpoises from each detector at each second of the encounters are shown in Appendix C.

Detection function

Preliminary analysis indicated that diel phase was a better explanatory variable than sun altitude and so diel phase was only considered here. Four different models were fitted; a model containing a term for distance only, a model with distance and time of day and then both these models were refitted including random effect terms.

The first selected model contained a linear term for distance and random effect terms for encounter and pod id (model 2 in Table 5). Replacing the term of C-POD id with a smooth term of RL did not improve the model fit and so was not considered further (model 3). In the model with diel phase, distance was fitted as a linear term (model 5).

Estimated EDR and EDA

The estimated probabilities of detection for models 2, 5, 6 and 7 are shown in Figure 5 and the estimated EDRs and EDAs are given in Table 6. Ignoring diel phase, EDAs for models with and without random effect terms were similar; 1,523m^2 (95% CI 801m^2 – 0.25km^2) and 1,178m^2 (95% CI 129m^2 – 1.16km^2), respectively. Taking into account diel phase, the night has the longest EDR and the morning or day had the shortest depending on whether random effect terms had been included. The EDAs for each phase are also given in Table 6.

To obtain an EDR and EDA over a whole day, a weighted average was calculated where the EDRs and EDAs for each phase were weighted by the length of each diel phase. The average length of the daytime phase (for the 5 days of the encounters) was 15 hours 24 minutes with morning and evening lasting nearly 2 hours and night lasting 4 hours 40 minutes. The average EDA including diel phase and random effect terms was 6,443m^2 () and including diel phase only was 2182m^2 () (Table 6).

DISCUSSION

GAMMs were fitted to the data recorded on C-PODs during encounters with wild harbour porpoise to assess the performance of C-PODs in terms of their effective detection area. More PPS were recorded during encounters of single animals that occurred at night indicating that time of day was an important indicator for the probability of detection. However, given that this may be due to the small number of encounters in this study, two basic models were considered; one model excluded time of day and a second model included a term for time of day and diel phase was chosen. These two basic models were also fitted with and without random effect terms to account for differences in devices and repeated measurements for each encounter. The shapes of the detections functions were dependent on whether random effect terms were included; when random effect terms were included the distance term was not significant (at the 5% significance level) and the detection function decreased more slowly with increasing distance. Despite the differences in detection function shape, the models without diel phase, resulted in similar EDAs for models with and without random effect terms. Taking into account diel phase, the EDAs for the morning and day phases were similar with and without random effects. The largest differences occurred in the evening and night phases with the random effect model resulting in larger EDAs. There were only positive detections at a very narrow range of distances and times and the number of PPS was small compared to the total number of seconds that the detectors were recording during the encounters. Each encounter was assumed to be independent, however, some encounters may have been the same animal (and unlikely to be independent) and so this would further reduce the sample size.

In this analysis, the time of day, in terms of the diurnal phase, was found to be an important explanatory variable. However, the numbers of encounters in the morning, evening and night phases were small compared to the number of encounters in the day phase. If some encounters are the same animal, then these apparent differences in diurnal phase may be due to differences between animals. Other data within the SAMBAH project have been used to investigate diurnal patterns (see SAMBAH Report 1; SAMBAH Report 4) and so these data can be used to refine this analysis.

ACKNOWLEDGEMENTS

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REFERENCES

Buckland ST, Anderson DR, Burnham KP, Laake JL, Borchers DL and Thomas L (2001) *Introduction to Distance Sampling: Estimating abundance of Biological Populations*. Oxford University Press, Oxford, UK

Kyhn *et al.* (2012)

R Core Team (2013) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/

SAMBAH Report 1: Encounter rates of C-POD data

SAMBAH Report 4: Summary of A-tag data

SAMBAH Report 7: Summary of porpoise densities in the Baltic Sea

Wood SN (2006) *Generalized Additive Models: An Introduction with R*. Chapman and Hall/CRC

Wood SN (2004) Stable and efficient multiple smoothing parameter estimation for generalized additive models. *Journal of the American Statistical Association*. 99: 673-686.

Table 1 Summary of detectors and deployment location and date (indicated by •).

Position	Location	Type	Pod id	Received level (dB)	Date deployed in June				
					5	9	11	17	18
Grid	01	C-POD	466	116.9	•	•	•	•	•
	02	C-POD	804	114.7	•	•	•		
	03	C-POD	806	112.3	•	•	•		
	04	C-POD	819	114.4	•	•	•	•	•
	05	C-POD	822	113.1	•	•	•	•	•
	06	C-POD	1465	120.3	•	•	•	•	•
	07	C-POD	1470	124.6	•	•	•	•	•
	08	C-POD	1472	127.6	•	•	•	•	•
	09	C-POD	1480	116.6	•	•	•	•	•
	10	C-POD	1829	114.2	•	•	•	•	•
	11	C-POD	1830	114.0	•	•	•		
Cluster	16	C-POD	809	115.6				•	•
	17	C-POD	815	113.6				•	•
	18	C-POD	824	110.6		•	•		
	20	C-POD	1466	122.0	•				
	21	C-POD	1474	117.0				•	•
Total					12	12	12	11	11

Table 2 Summary of the encounters (recorded on the C-PODs). Times are in UT. The encounters in italics were additional encounters.

Date	Number of detectors deployed	Encounter					Total possible detector seconds[1]	Number of click seconds	Number of individual clicks	Average number of clicks per second
		No.	Start time	End time	Diel phase	Length (secs)				
5 June	12	1	11:12:17	11:13:12	Day	56	672	0		
		2	11:13:20	11:15:18	Day	119	1428	0		
		3	11:15:36	11:16:52	Day	77	924	2	7	3.5
		7[2]	*12:35:47*	*12:36:49*	*Day*	*63*	*756*	*0*		
		8[2]	*12:37:07*	*12:38:35*	*Day*	*89*	*1068*	*0*		
		4	12:38:43	12:40:01	Day	79	948	0		
		5	12:40:26	12:41:24	Day	59	708	0		
		6	12:41:45	12:42:19	Day	35	420	0		
9 June	12	1	12:14:49	12:15:22	Day	34	408	0		
11 June	12	*7*	*06:16:00*	*06:16:45*	*Day*	*46*	*552*	*1*	*7*	*7.0*
		1	08:35:35	08:36:59	Day	85	1020	0		
		2	08:37:26	08:37:44	Day	19	228	0		
		3	09:22:12	09:22:58	Day	47	564	1	5	5.0
		4	10:45:16	10:46:08	Day	53	636	2	10	5.0
		5	11:18:03	11:18:12	Day	10	120	0		
		6	12:49:15	12:50:54	Day	100	1200	2	11	5.5
17 June	11	1	12:52:42	12:53:23	Day	42	462	0		
		2	15:25:58	15:27:39	Day	102	1122	0		
		3	15:29:20	15:29:44	Day	25	275	4	34	8.5
		4	16:15:01	16:15:13	Day	13	143	0		
		15	*18:13:03*	*18:14:37*	*Day*	*95*	*1045*	*0*		
		5	19:31:17	19:33:05	Evening	109	1199	6	24	4.0
		6	20:12:22	20:13:05	Evening	44	484	2	9	4.5
		7	20:35:33	20:36:03	Evening	31	341	4	18	4.5
		8	20:44:46	20:45:39	Evening	54	594	4	27	6.8
		9	20:54:49	20:54:55	Evening	7	77	0		
		10	21:37:55	21:40:45	Night	171	1881	4	5	1.3
		11	22:18:03	22:18:08	Night	6	66	3	39	13.0
		16	*22:49:04*	*22:49:59*	*Night*	*56*	*616*	*13*	*238*	*18.3*
		12	22:51:08	22:51:51	Night	44	484	21	210	10.0
		13	22:53:02	22:53:06	Night	5	55	14	246	17.6
		14	23:02:21	23:03:26	Night	66	726	46	478	10.2
18 June	11	1	02:10:14	02:11:31	Morning	78	858	0		
		2	02:11:48	02:16:10	Morning	263	2893	8	38	4.8
		3	02:22:29	02:23:30	Morning	62	682	0		
		4	02:50:55	02:51:58	Morning	64	704	0		
Total						2308	26207	137	1406	10.3

[1]Total possible encounter seconds = number of detectors deployed X total seconds of encounter

[2] 11 PODs used

Table 3 Proportion of PPS by diel phase.

Diel phase	Number of PPS	Total number of seconds	Proportion of PPS
Morning	8	5137	0.0016
Day	12	14547	0.0001
Evening	16	2695	0.0059
Night	101	3828	0.0264
All	137	26207	0.0052

Table 4 Summary of the distribution of distances (m) between the animal and the detectors for each second of the encounters (C-PODs only).

Variable	Porpoise detected	Minimum	Mean	Maximum
Distances (m)	No	20.5	148.4	389.3
	Yes	26.1	119.8	260.1
	Total	20.5	148.3	389.3

Table 5 Summary of the fitted models, degrees of freedom (df), AIC values and adjusted R^2 values. The selected models are shown in bold and 's' indicates a smooth term and 're' indicates a term fitted as a random effect.

a) Random effects included

Number	Model	df	AIC	Adjusted R^2
1	s(distance) + re(id, by=ind) + re(encounter,by=ind)	40.1	1242	0.082
2	**distance + re(id, by=ind) + re(encounter,by=ind)**	**40.1**	**1242**	**0.082**
3	distance + s(RL, by=ind) + re(encounter,by=ind)	31.2	1246	0.069
4	s(distance) + dielp + re(id, by=ind) + re(encounter,by=ind)	30.4	1235	0.081
5	**distance + dielp + re(id, by=ind) + re(encounter,by=ind)**	**30.4**	**1235**	**0.081**

b) No random effects included

Number	Model	df	AIC	Adjusted R^2
6	s(distance)	3.4	1673	0.001
7	s(distance) + dielp	5.7	1449	0.016

Table 6 Estimated effective detection radii and effective detection areas and 95% confidence intervals (in parentheses) were obtained for the selected models.

a) Ignoring diel phase

Model	EDR (m)	EDA (m^2)
Model 2	22.0 (6 – 608)	1524 (129 - 1162517)
Model 6	17.5 (16 – 281)	1178 (801 – 248309)

b) Including diel phase. The numbers of minutes spent in each diel phase are the averages of the times spent in each phase over the 5 days of the study.

Diel phase	Minutes in diel phase	Proportion of time in phase	Model 7		Model 5	
			EDR (m)	EDA (m^2)	EDR (m)	EDA (m^2)
Morning	118	0.082	13.9 (9 - 1724)	604 ()	13.8 (4 - 212)	601 (58 - 141549)
Day	924	0.642	10.1 (9 - 1698)	323 ()	14.3 (6 - 239)	647 (95 - 180935)
Evening	118	0.082	25.6 (17 - 1792)	2057 ()	37.2 (13 - 563)	4340 (514 - 995523)
Night	280	0.194	53.6 (38 - 1857)	9037 ()	95.9 (37 - 1209)	28919 (4399 - 4593312)
Total	1440	1.000	20.2 ()	2182 ()	32.0 ()	6443 ()

Figure 1 Location of all detectors placed in either a grid (filled circles) or in clusters (open triangles). Colours indicate the type of the detector.

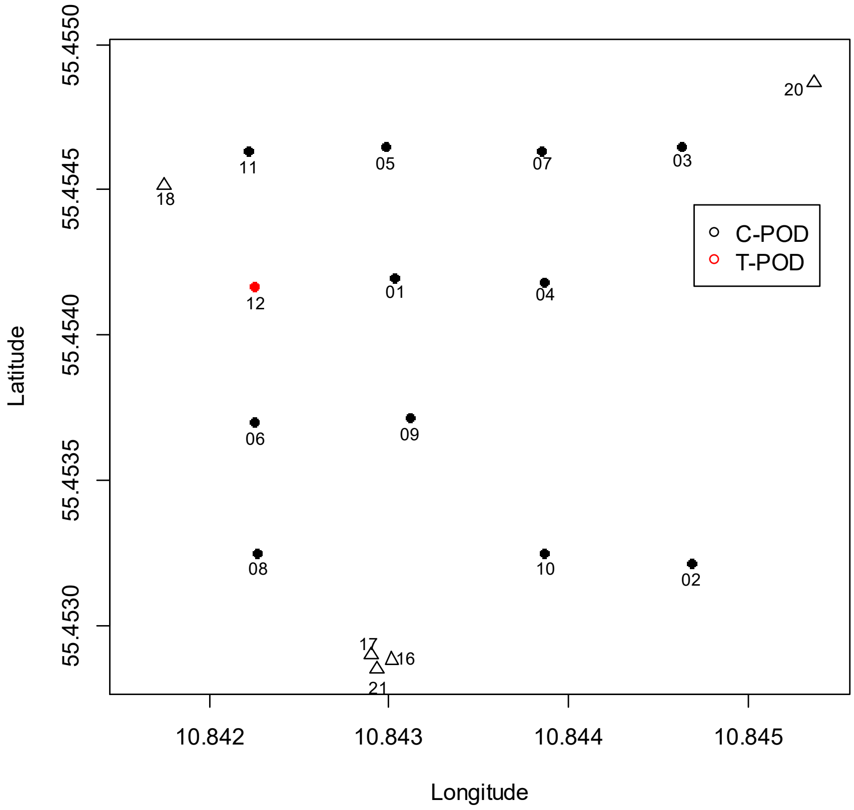


Figure 2 Plot of HP swim paths for each encounter (indicated by a number). Filled circles indicate the positions of the detectors deployed with red filled circles indicating detectors where clicks were detected. Triangles indicate the position of the boat during each encounter and the colours of the boat match the colours of the encounter.

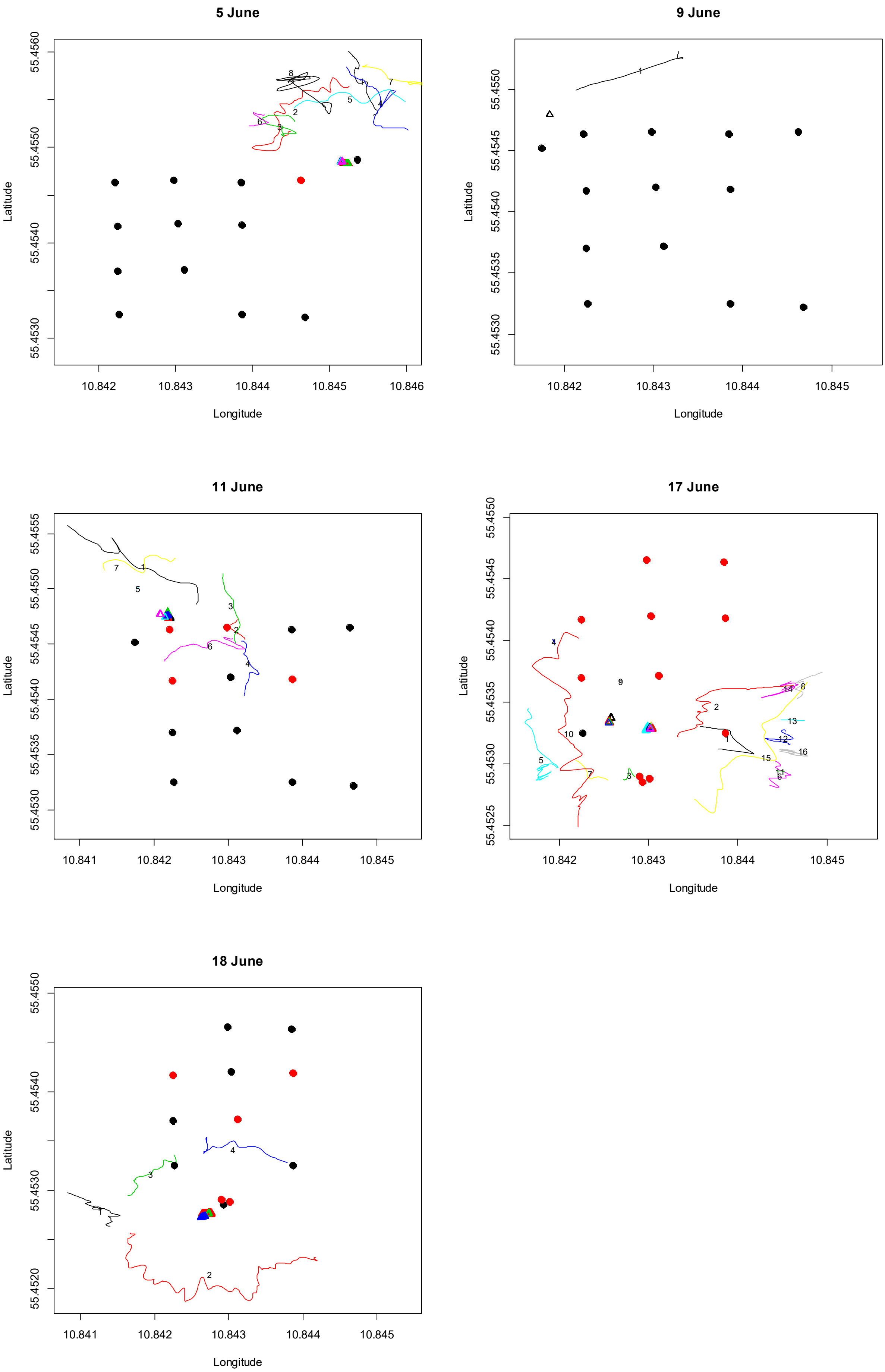


Figure 3 Histograms of the distances between the animal and the detectors deployed at each second during the encounter (top) and time of day (bottom). The left plot indicates all distances (red bars indicate where clicks were detected) and the middle and right plots show records where clicks were not detected (white bars) and where clicks were detected (red bars), respectively. Note that the right plot has a different scale on y-axis.

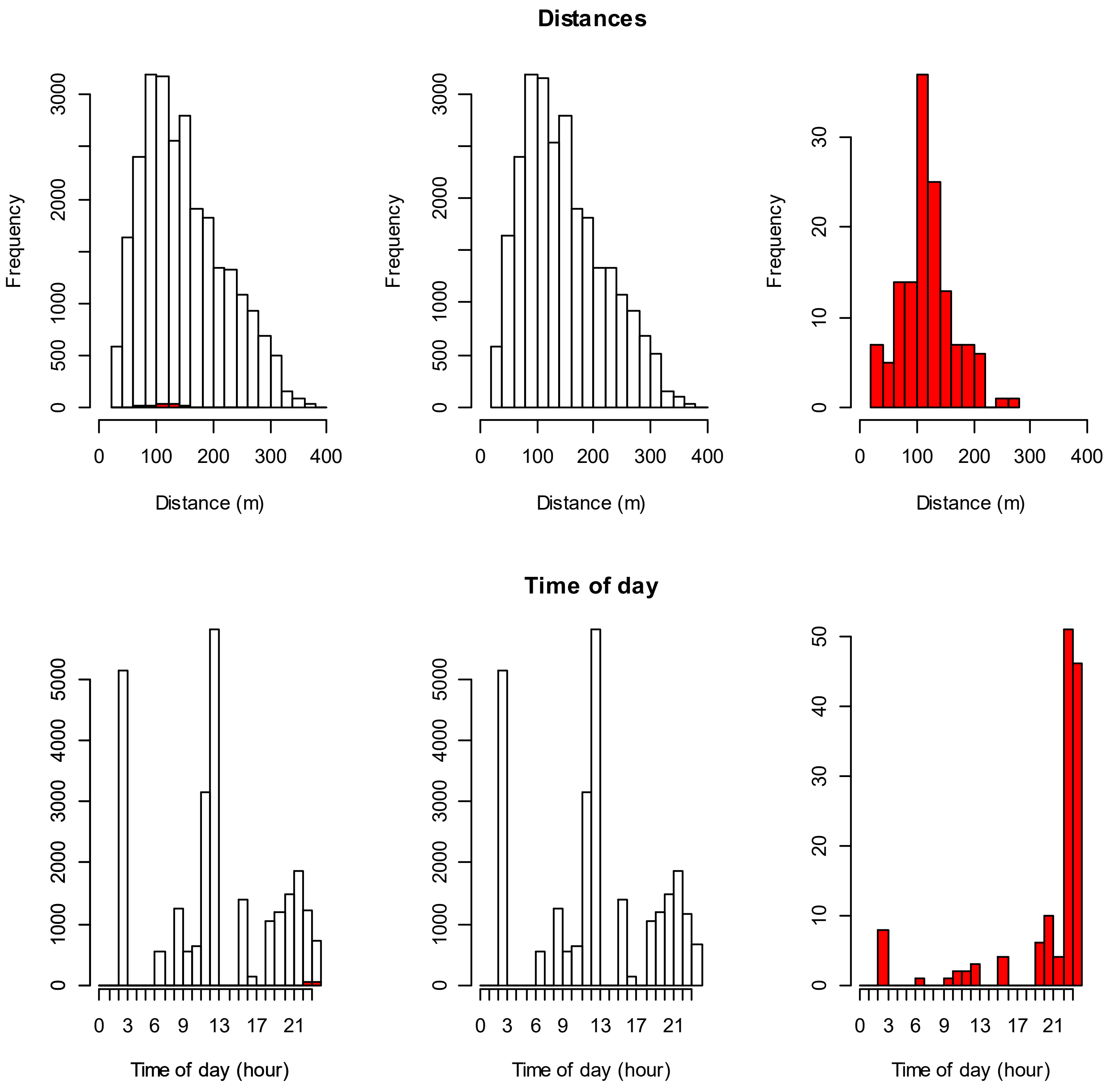
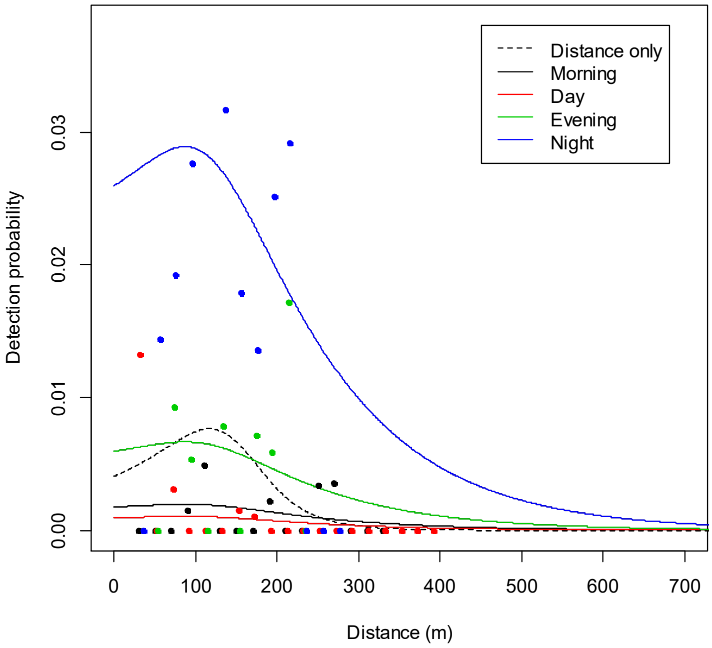
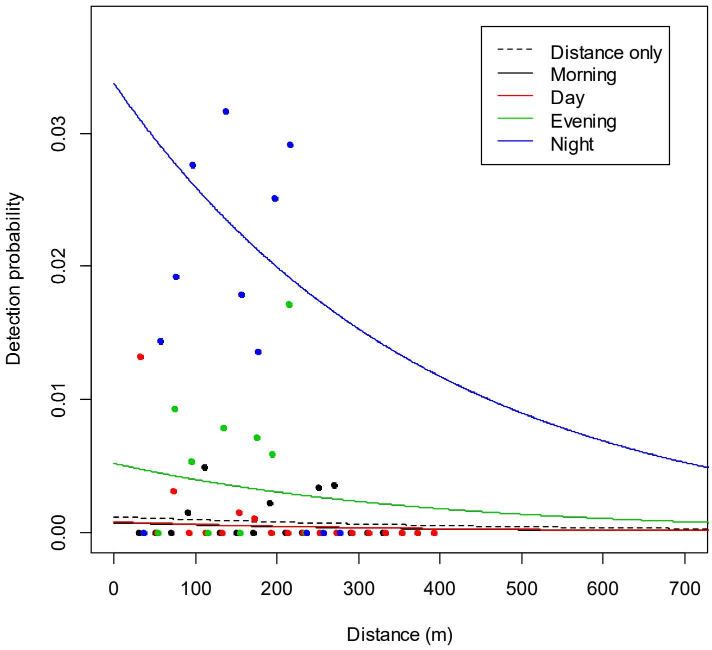


Figure 4 Estimated probability of detection for a C-POD during each diel phase (morning, day, evening and night) and ignoring diel phase (Distance only model). The points are the observed proportions of PPS within 20m distance bins.

a) No random effect terms



b) Random effect terms included



Appendix A Time of day measurements

Time of day, in terms of light levels, was measured in two different ways; as diel phase and altitude of the sun.

Diel cycle

The diel cycle was divided into four phases; morning, day, evening and night. The definitions were based on the vertical angle of the sun:

- Sunrise and sunset occurs when the upper edge of the disk is on the horizon
- Morning started at the onset of civil twilight (i.e. when the sun was geometrically 6° below the horizon)
- Morning lasted for twice the time between the beginning of civil twilight and sunrise
- Evening ended at the end of civil twilight
- Evening lasted for twice the time between sunset and the end of civil twilight.

The times the start and end of civil twilight and sunrise and sunset (Table A1) were obtained from http://aa.usno.navy.mil/. Using the above definitions and the times in Table A1, the diel phases for each day of the experiment were obtained (Table A2). The location of the experiment was at (10.84°E, 55.45°N) and times were recorded in Universal Time (UT).

Altitude of sun

Light levels were defined by the altitude of the sun (0° indicates sunrise and sunset). These were obtained (for every minute throughout the days of the study) from the website http://aa.usno.navy.mil/. The days were very close in time (5th to 18th) and so the distributions for each day of the study were similar (Figure A2).

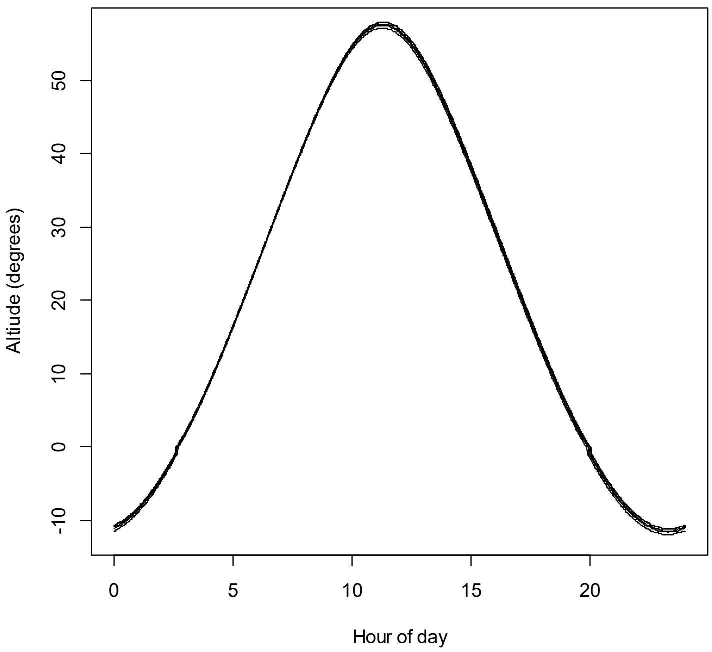
Table A1 Times (UT) of the phases of the sun for each day of the experiment in 2013.

Phase of the sun	Times (HH:MM)			
	5 June	9 June	11 June	17/18 June
Begin civil twilight	01:42	01:38	01:36	01:34
Sunrise	02:39	02:36	02:35	02:34
Sunset	19:52	19:56	19:58	20:02
End civil twilight	20:50	20:55	20:57	21:02

Table A2 Start times (UT) of each diel phase and the number of minutes in each phase.

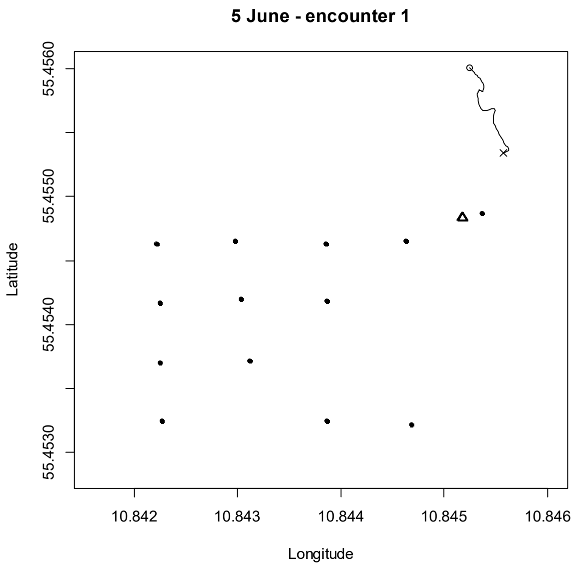
Diel phase	Start times (HH:MM)				Minutes in each phase				
	5 June	9 June	11 June	17/18 June	5 June	9 June	11 June	17/18 June	Average (SD)
Morning	01:42	01:38	01:36	01:34	114	116	118	120	118 (2.6)
Day	03:36	03:34	03:34	03:34	918	923	925	928	924 (4.2)
Evening	18:54	18:57	18:59	19:02	116	118	118	120	118 (1.7)
Night	20:50	20:55	20:57	21:02	292	283	279	272	280 (8.4)

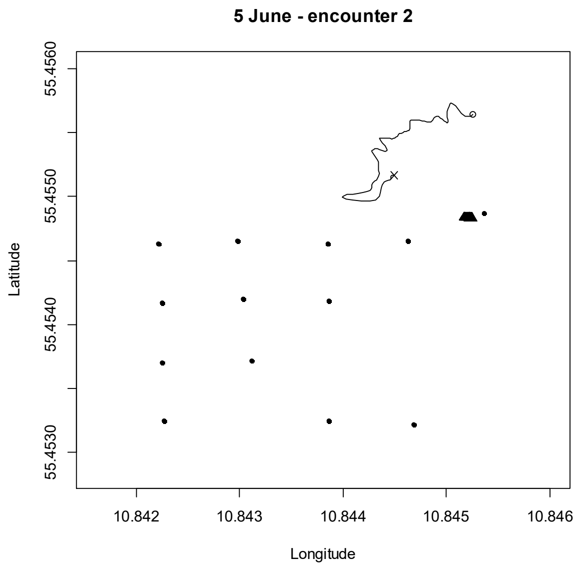
Figure A2 Altitude of the sun for each day of the Kerteminde study.

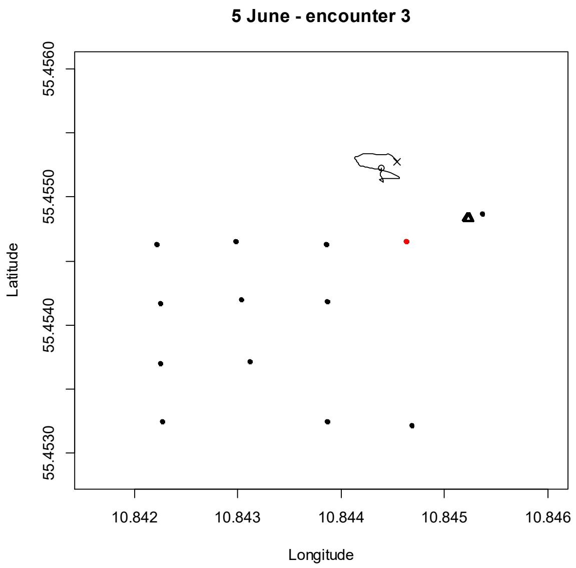


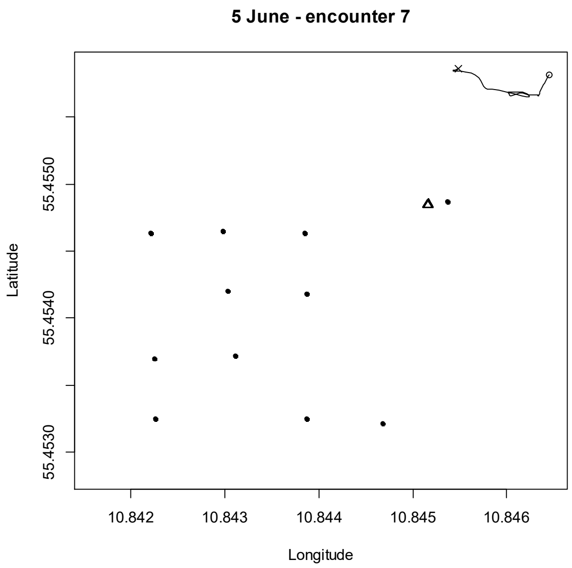
Appendix B Swim paths for each encounter

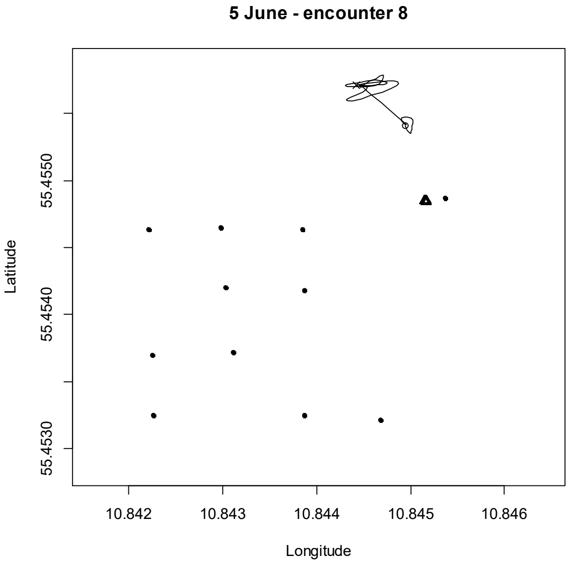
Plots of HP swim paths for each encounter: the start of the path is indicated by an open circle and 'x' indicates the end; filled circles indicate the locations of the detectors deployed and red filled circles represent detectors where clicks were detected; triangles indicate the position of the boat. Note that the T-POD is included on some figures.

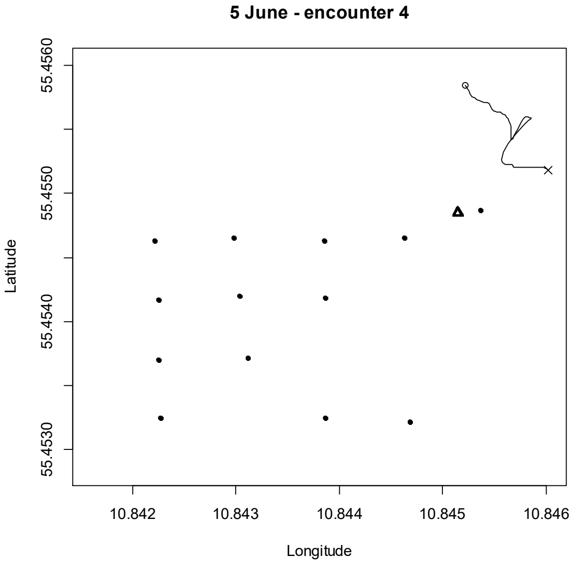


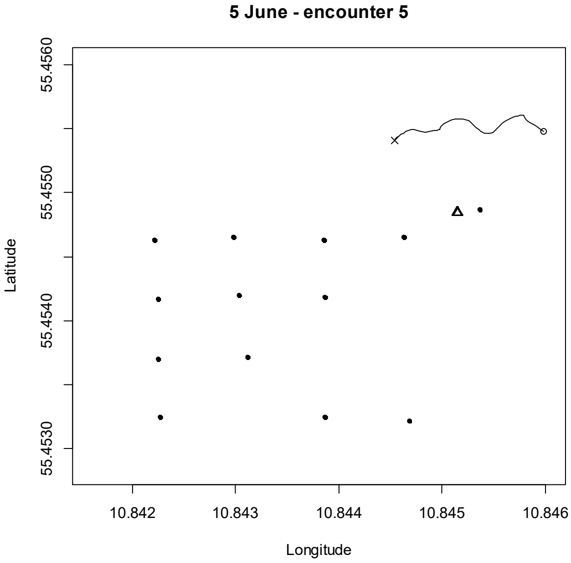







5 June - encounter 8
Latitude
55.4530
55.4540
55.4550
10.842
10.843
10.844
10.845
10.846
Longitude


5 June - encounter 4
Latitude
55.4530
55.4540
55.4550
55.4560
10.842
10.843
10.844
10.845
10.846
Longitude


5 June - encounter 5
Latitude
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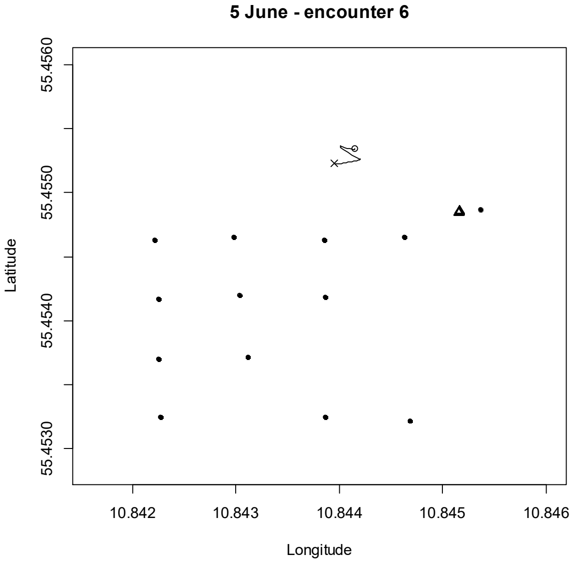
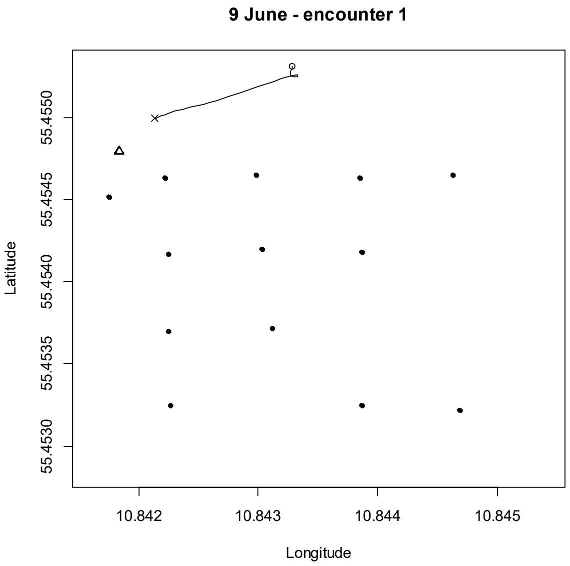
55.4550
55.4560
10.842
10.843
10.844
10.845
10.846
Longitude


5 June - encounter 6
Latitude
55.4530
55.4540
55.4550
55.4560
10.842
10.843
10.844
10.845
10.846
Longitude


9 June - encounter 1
Latitude
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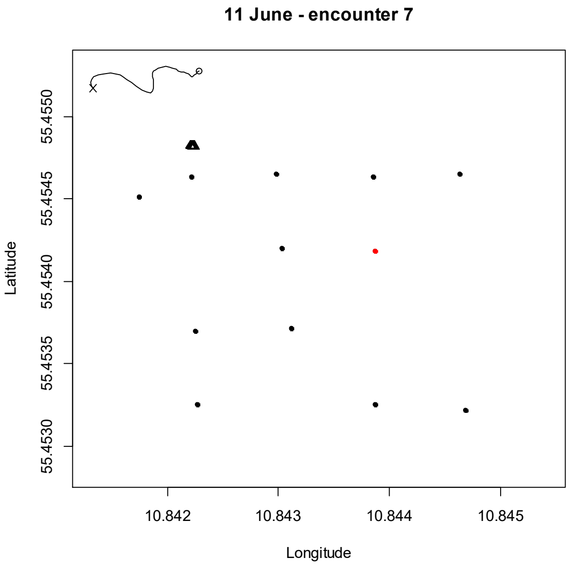
55.4535
55.4540
55.4545
55.4550
10.842
10.843
10.844
10.845
Longitude


11 June - encounter 7
Latitude
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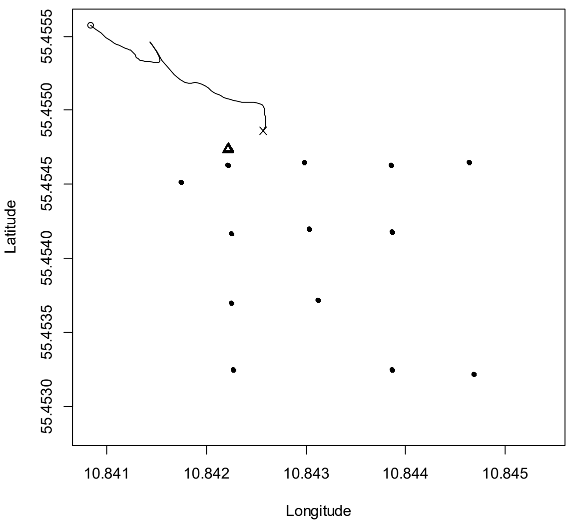
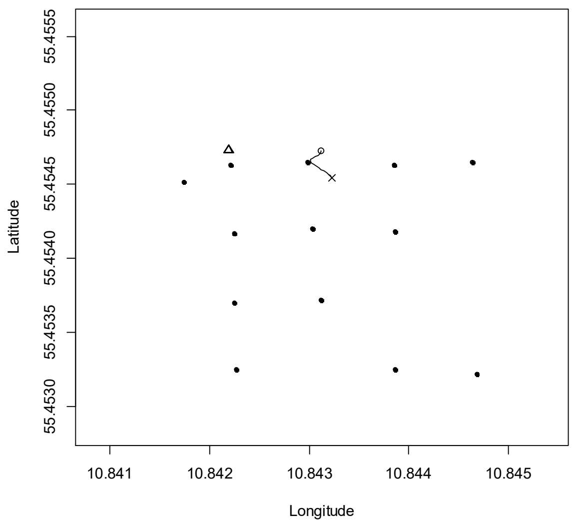
55.4540
55.4545
55.4550
10.842
10.843
10.844
10.845
Longitude

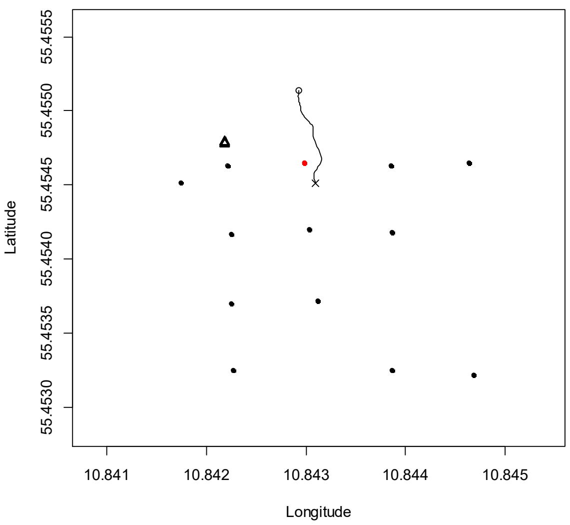
11 June - encounter 1



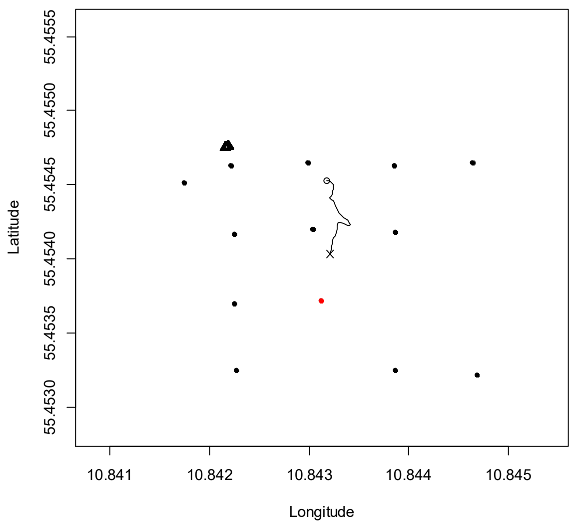
11 June - encounter 2



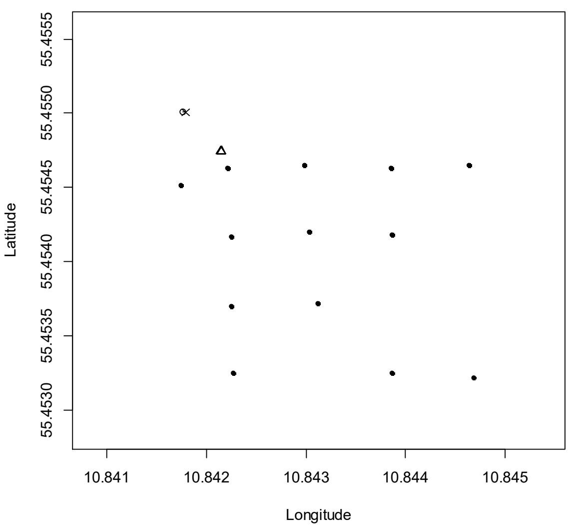
11 June - encounter 3



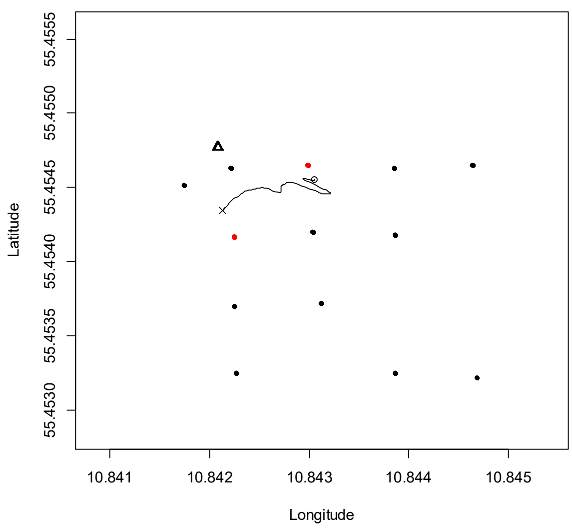
11 June - encounter 4

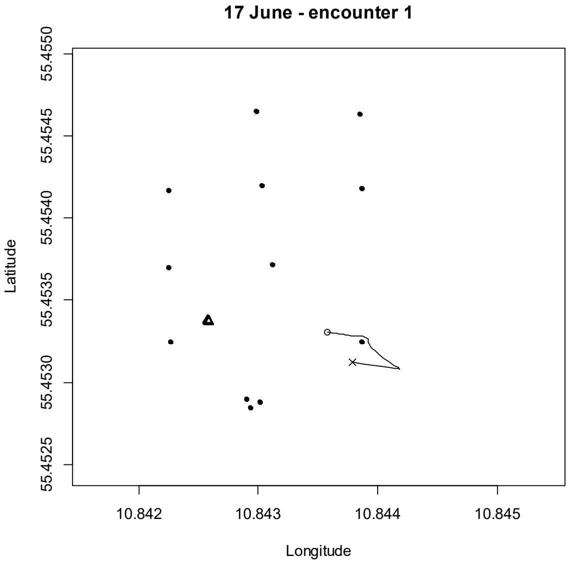


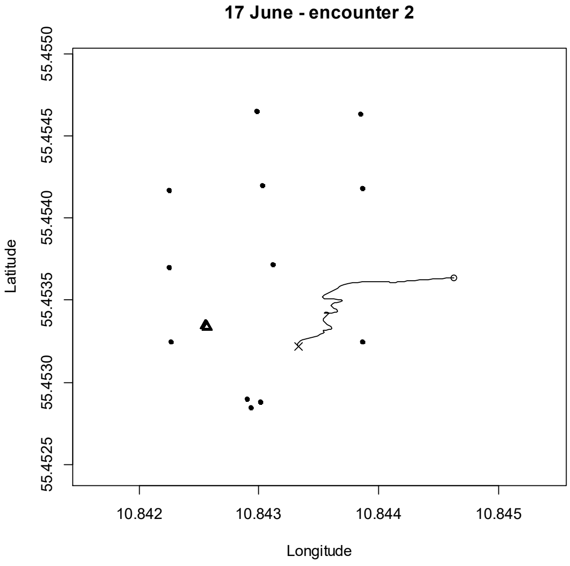
11 June - encounter 5



11 June - encounter 6




17 June - encounter 1
Latitude
55.4525
55.4530
55.4535
55.4540
55.4545
55.4550
Longitude
10.842
10.843
10.844
10.845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55.4540
55.4545
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Longitude
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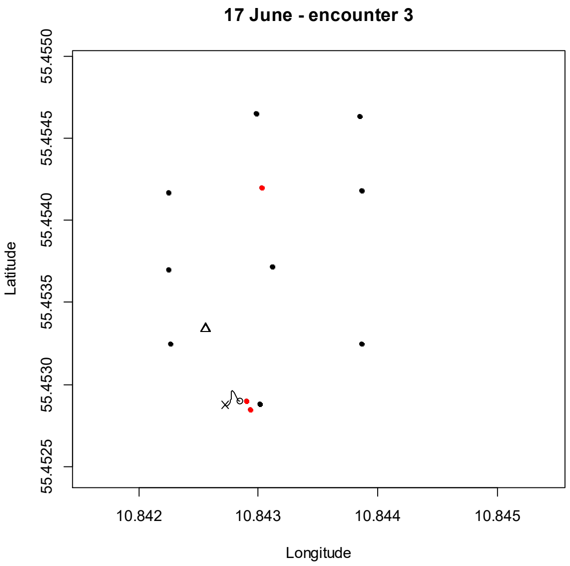
10.844
10.845


17 June - encounter 3
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55.4545
55.4550
Longitude
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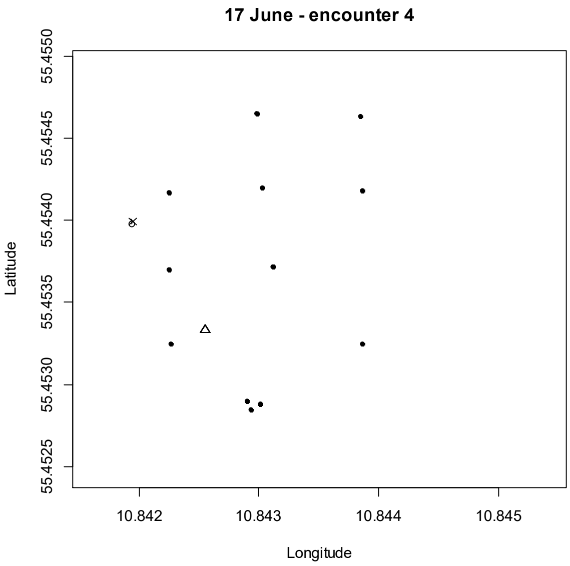
10.843
10.844
10.845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Latitude
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55.4550
Longitude
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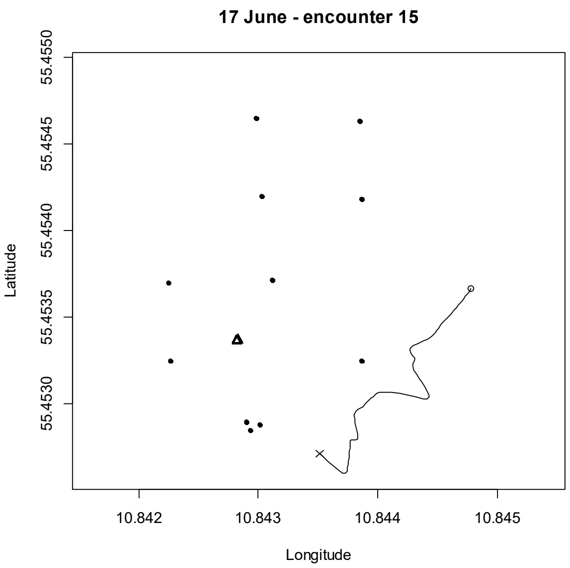
10.844
10.845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55.4550
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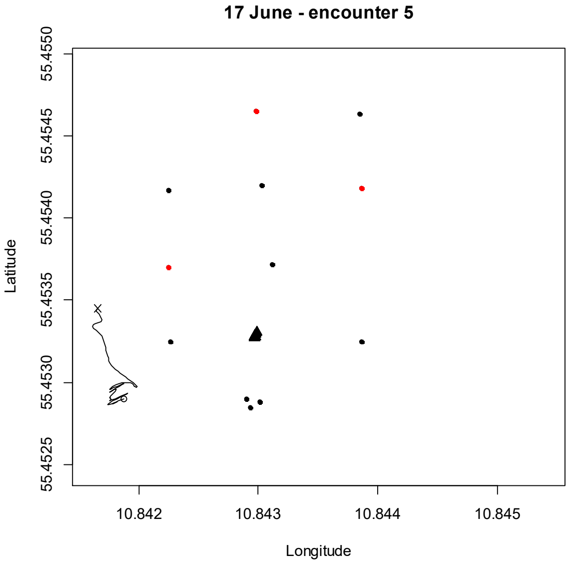
10.845


17 June - encounter 5
Latitude
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55.4535
55.4540
55.4545
55.4550
Longitude
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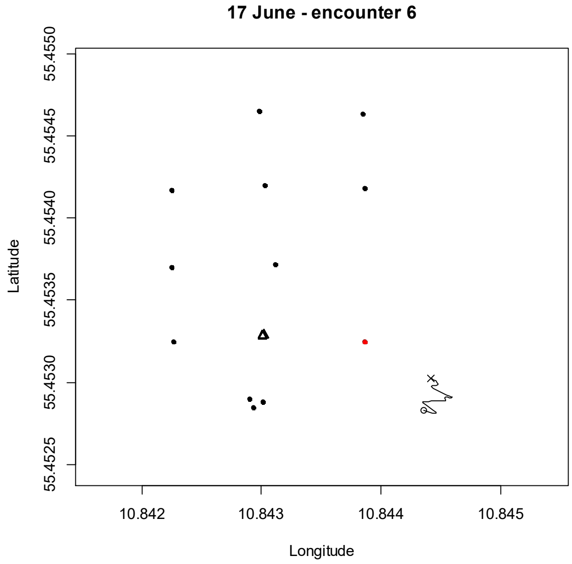
10.844
10.845


17 June - encounter 6
Latitude
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55.4530
55.4535
55.4540
55.4545
55.4550
Longitude
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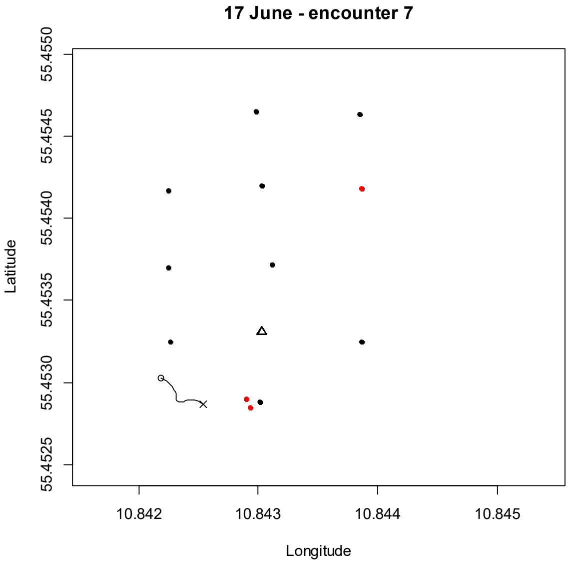
10.843
10.844
10.845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Latitude
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55.4540
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Longitude
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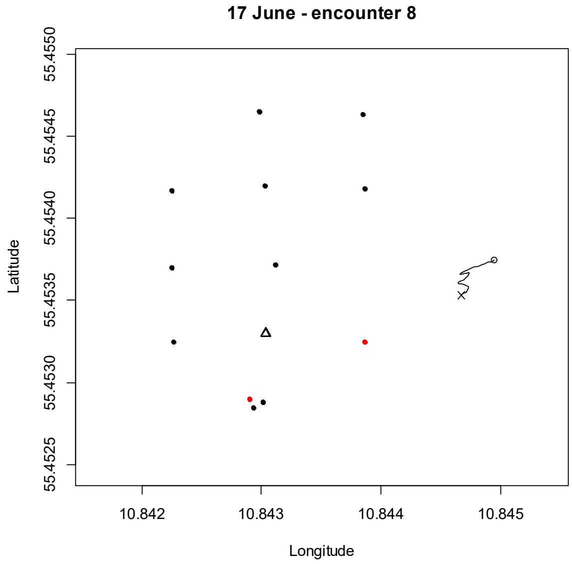
10.843
10.844
10.845


17 June - encounter 8
Latitude
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Longitude
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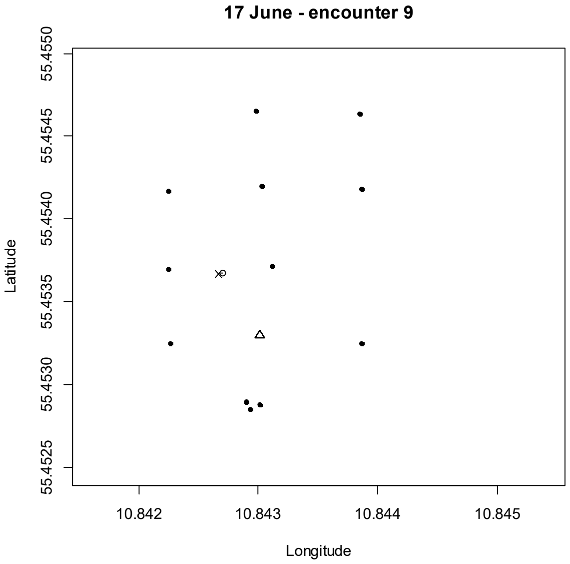
10.844
10.845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Latitude
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55.4545
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Longitude
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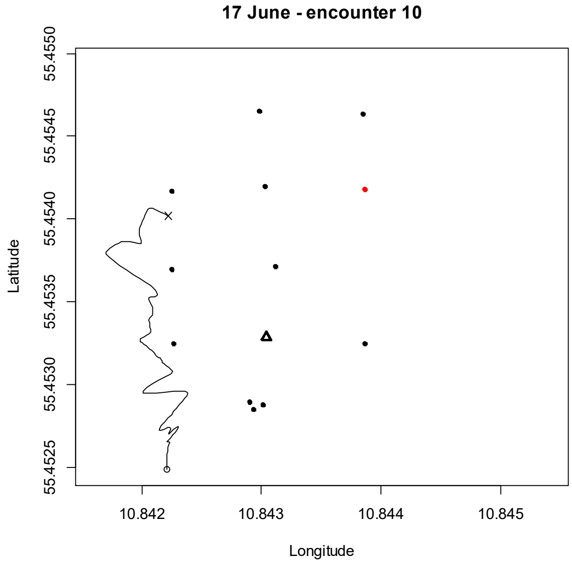
10.844
10.845


17 June - encounter 10
Latitude
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55.4530
55.4535
55.4540
55.4545
55.4550
Longitude
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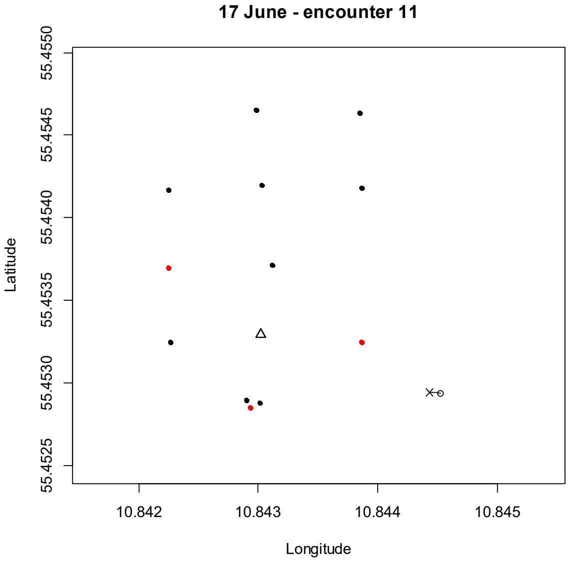
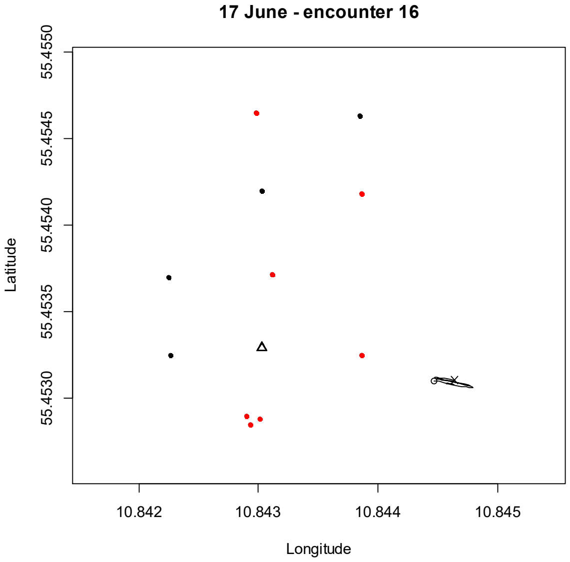
10.843
10.844
10.845


17 June - encounter 11
Latitude
55.4525
55.4530
55.4535
55.4540
55.4545
55.4550
10.842
10.843
10.844
10.845
Longitude


17 June - encounter 16
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55.4550
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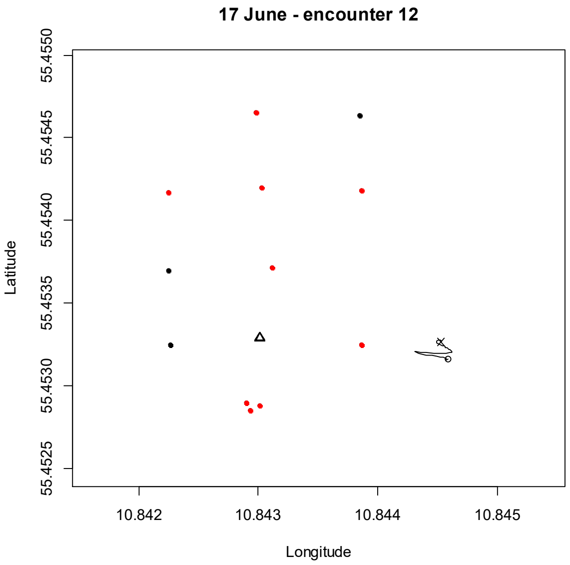
10.843
10.844
10.845
Longitude


17 June - encounter 12
Latitude
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55.4540
55.4545
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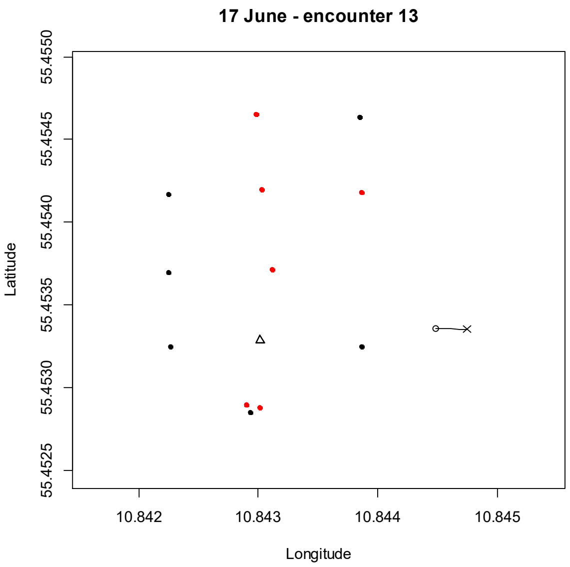
10.844
10.845
Longitude


17 June - encounter 13
Latitude
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55.4540
55.4545
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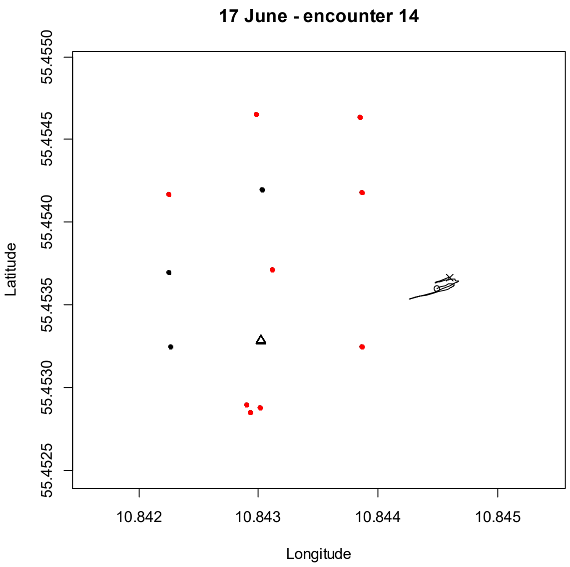
10.842
10.843
10.844
10.845
Longitude


17 June - encounter 14
Latitude
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55.4545
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10.842
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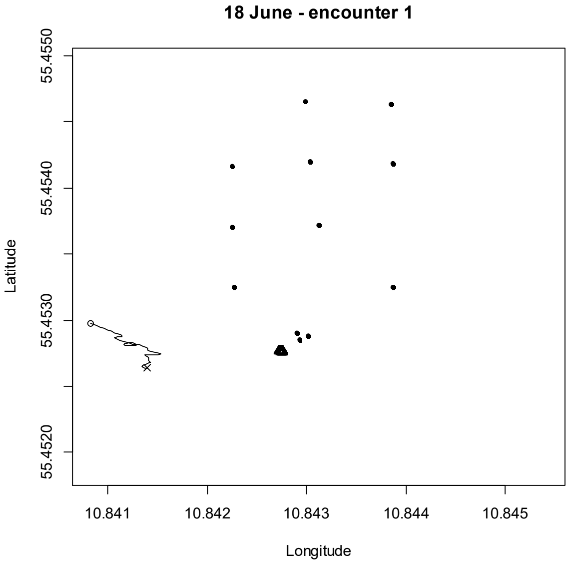
10.844
10.845
Longitude


18 June - encounter 1
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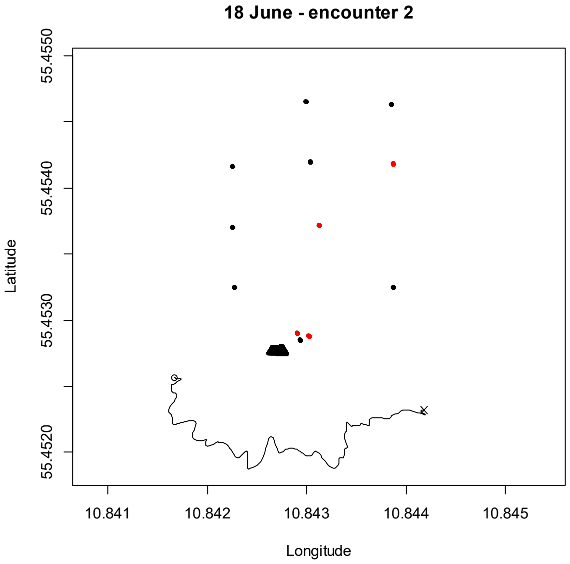
55.4530
55.4540
55.4550
Longitude
10.841
10.842
10.843
10.844
10.845


18 June - encounter 2
Latitude
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55.4530
55.4540
55.4550
Longitude
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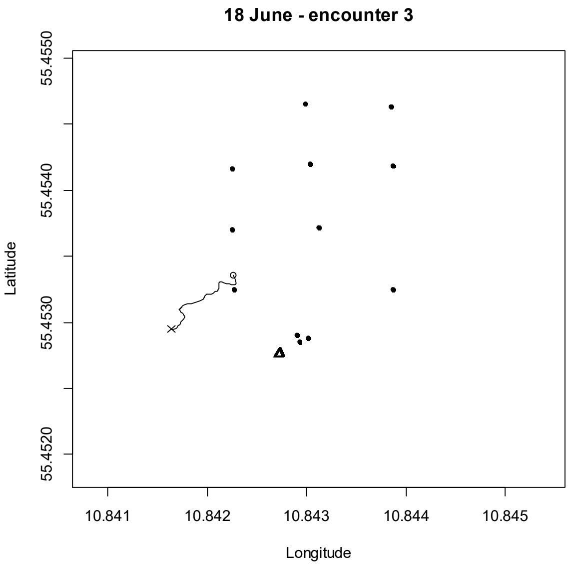
10.842
10.843
10.844
10.845


18 June - encounter 3
Latitude
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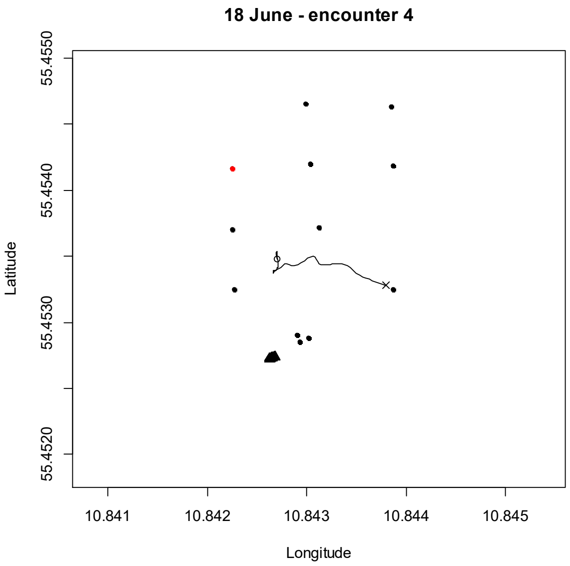
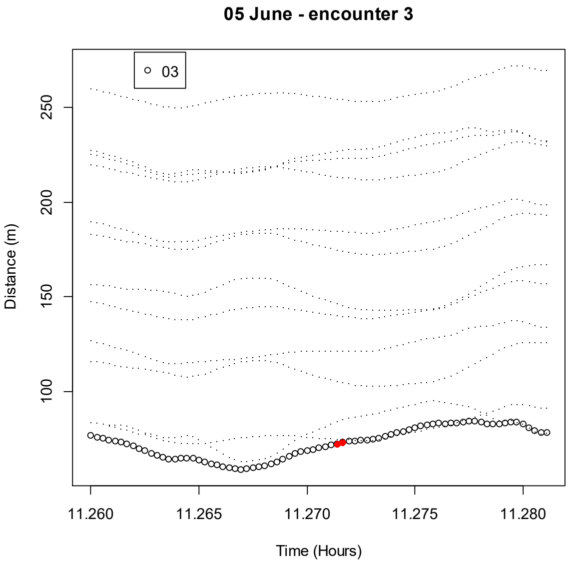
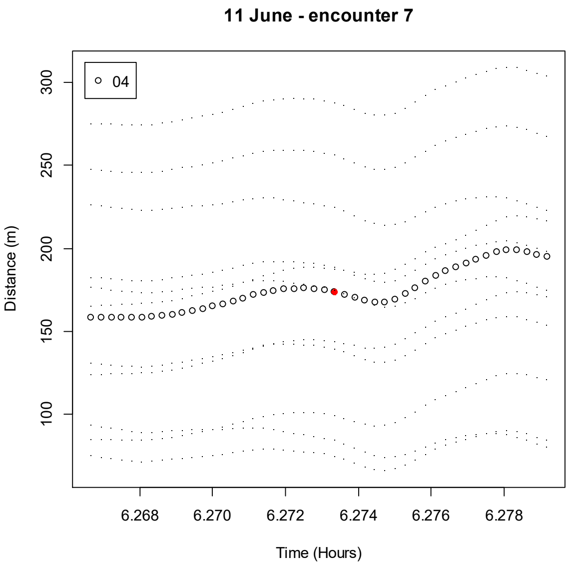
55.4530
55.4540
55.4550
Longitude
10.841
10.842
10.843
10.844
10.845

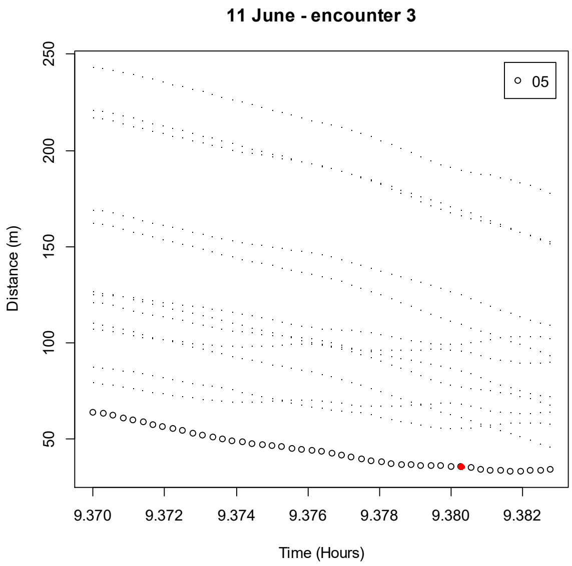

18 June - encounter 4
Latitude
55.4520
55.4530
55.4540
55.4550
Longitude
10.841
10.842
10.843
10.844
10.845

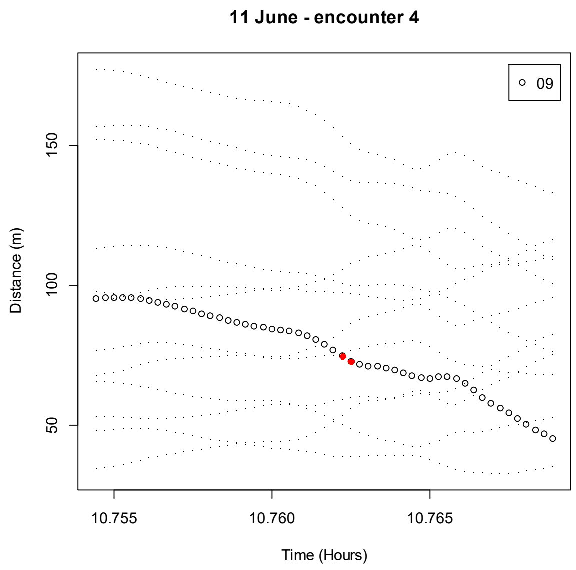
Appendix C Distances of the harbour porpoises to each location

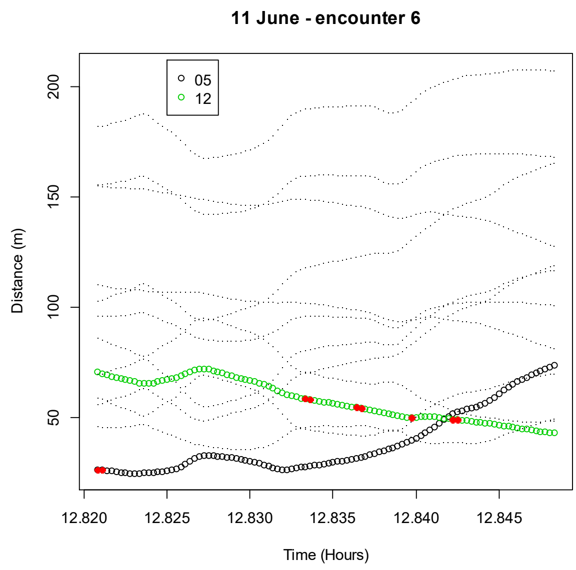
The plots below show the distances of the harbour porpoise to each station at each second of the encounter. The open circles indicate that a click was detected (sometime) at that location (number of the location shown in the legend) and solid red circles indicate when a click was detected. The dots indicate devices that did not detect any clicks. Only encounters where clicks were detected are plotted.

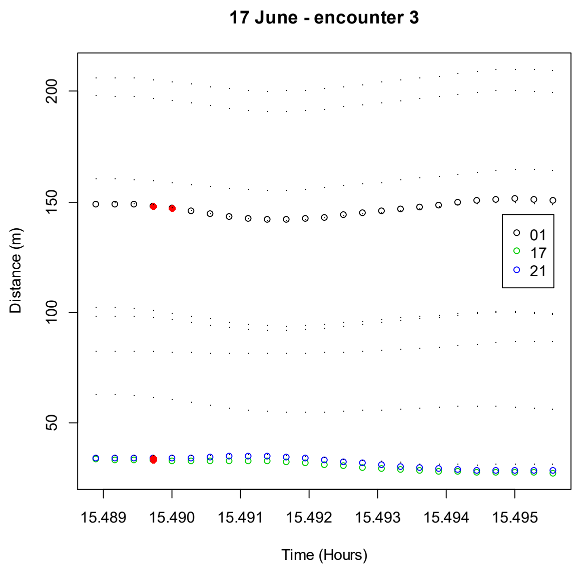


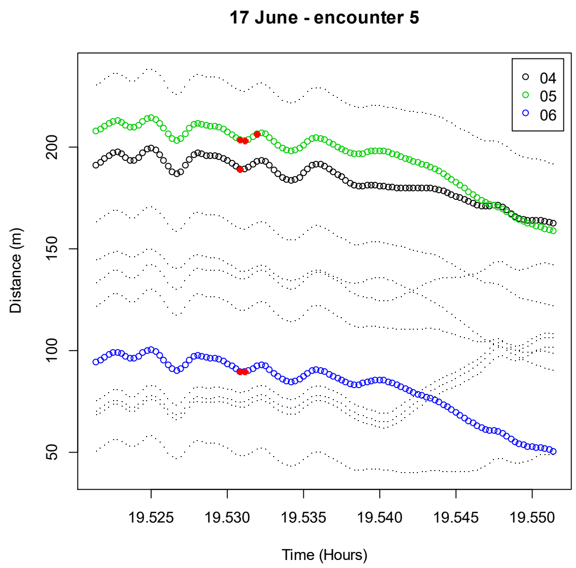


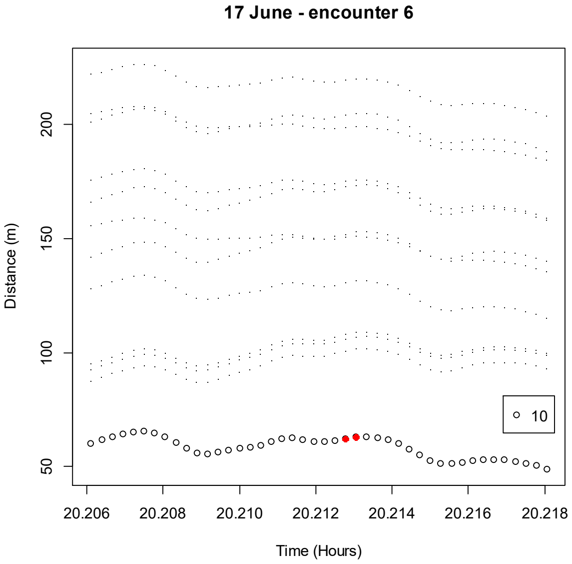


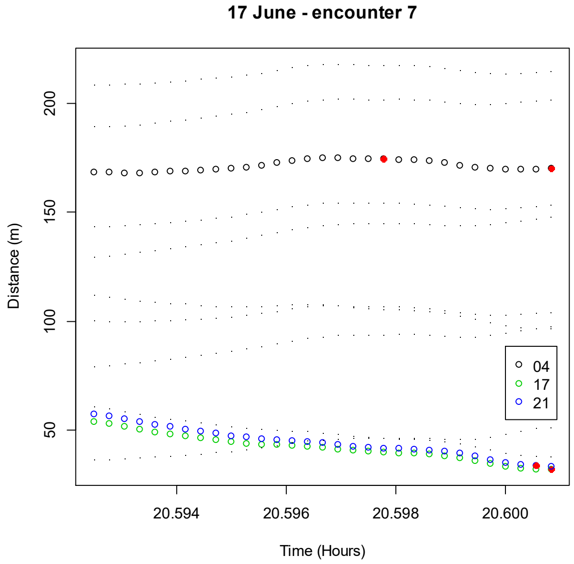

11 June - encounter 4
09
Distance (m)
50
100
150
10.755
10.760
10.765
Time (Hours)

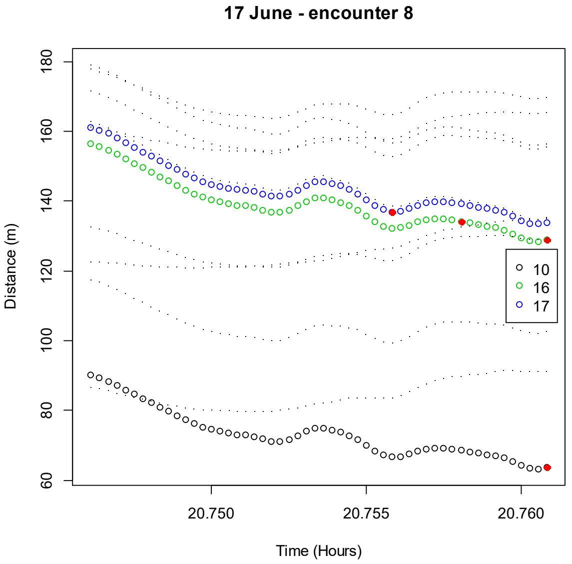

11 June - encounter 6
05
12
Distance (m)
50
100
150
200
12.820
12.825
12.830
12.835
12.840
12.845
Time (Hours)

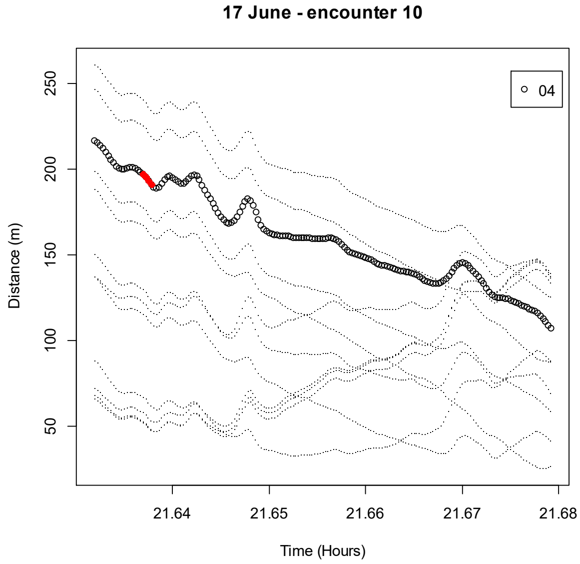

17 June - encounter 3
01
17
21
Distance (m)
50
100
150
200
15.489
15.490
15.491
15.492
15.493
15.494
15.495
Time (Hours)

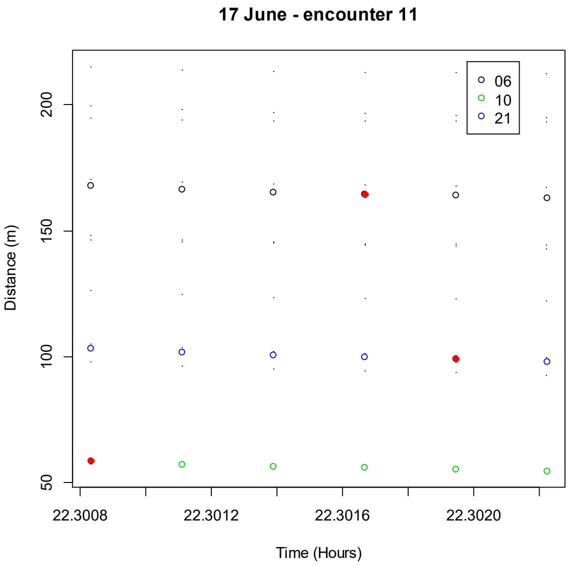

17 June - encounter 5
04
05
06
Distance (m)
50
100
150
200
19.525
19.530
19.535
19.540
19.545
19.550
Time (Hours)

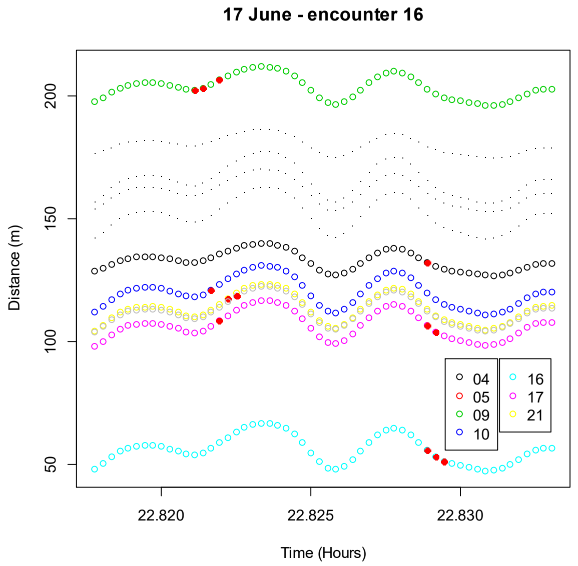

17 June - encounter 6
Distance (m)
Time (Hours)
10

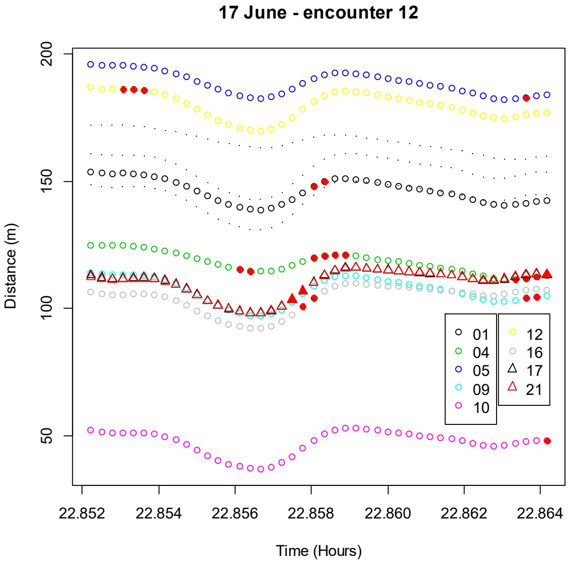

17 June - encounter 7
Distance (m)
Time (Hours)
04
17
21

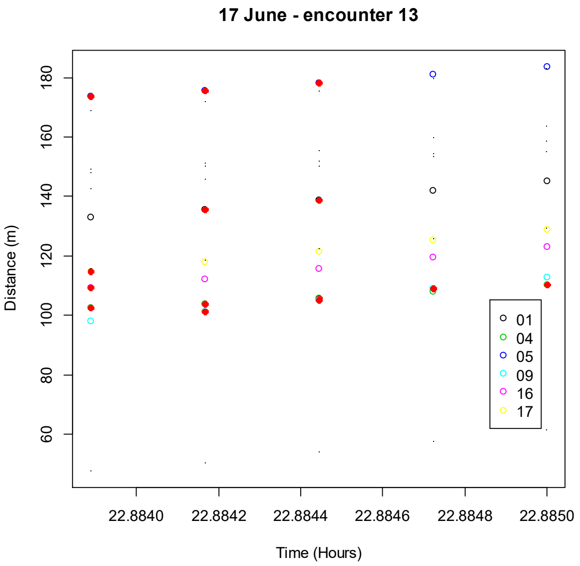

17 June - encounter 8
Distance (m)
Time (Hours)
10
16
17

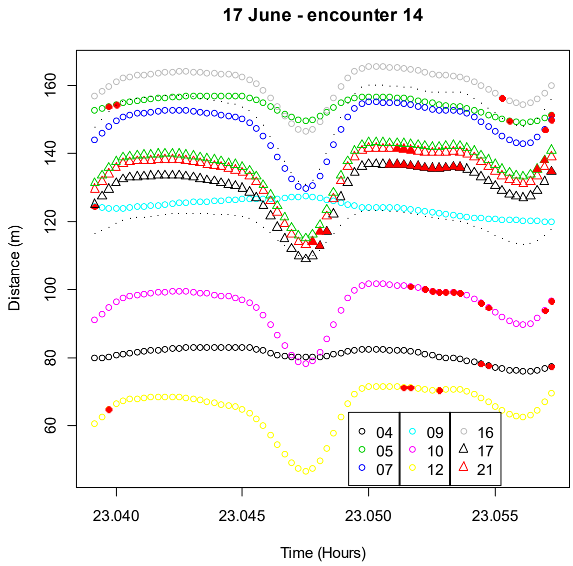

17 June - encounter 10
Distance (m)
Time (Hours)
04

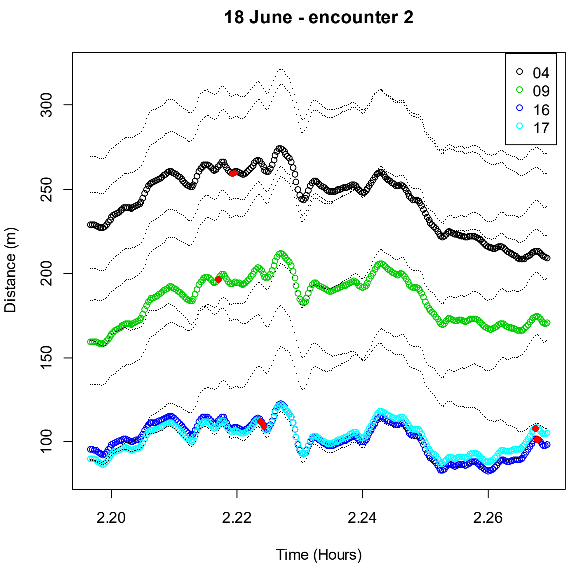

17 June - encounter 11
Distance (m)
Time (Hours)
06
10
21

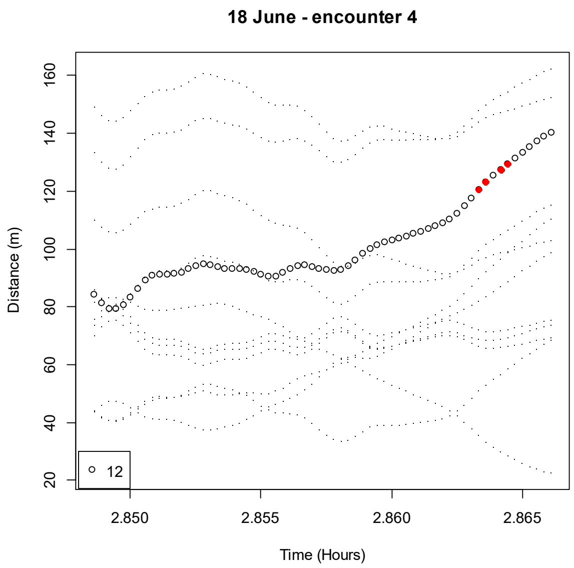

17 June - encounter 16
Distance (m)
Time (Hours)
04
05
09
10
16
17
21


17 June - encounter 12
Distance (m)
50
100
150
200
22.852
22.854
22.856
22.858
22.860
22.862
22.864
Time (Hours)
01
04
05
09
10
12
16
17
21


17 June - encounter 13
Distance (m)
60
80
100
120
140
160
180
22.8840
22.8842
22.8844
22.8846
22.8848
22.8850
Time (Hours)
01
04
05
09
16
17


17 June - encounter 14
Distance (m)
60
80
100
120
140
160
23.040
23.045
23.050
23.055
Time (Hours)
04
05
07
09
10
12
16
17
21


18 June - encounter 2
Distance (m)
100
150
200
250
300
2.20
2.22
2.24
2.26
Time (Hours)
04
09
16
17


18 June - encounter 4
Distance (m)
20
40
60
80
100
120
140
160
2.850
2.855
2.860
2.865
Time (Hours)
12

Appendix D Additional analysis

In addition to using the horizontal distance of the porpoise to the device, three addition variables were included as explanatory variables in the model; the depth of the animal, horizontal angle between the porpoise and the pod (ang2pod) and the vertical angle of the porpoise (vertang).

The horizontal angle from the pod to the animal was calculated from the bearing of the animal (obtained from the swim track) and the position of the pod. A value of 0^o indicated that the pod was directly ahead and a value of 180^o indicates the pod was directly behind. The distributions for each of seconds of the encounters are shown in Figure D2. The bearing of the animal is unknown for the last second of the encounter and so the angle to pod is unknown, therefore, the penultimate angle was used.

The vertical angle of the animal was obtained from the depth of the animal. A value of 0^o indicates that the animal was swimming at a constant depth, a value of -90^o indicates that the animal was pointing directly down and 90^o indicates that the animal was pointing directly upwards. For the last second of the encounter the angle for the penultimate second was used.

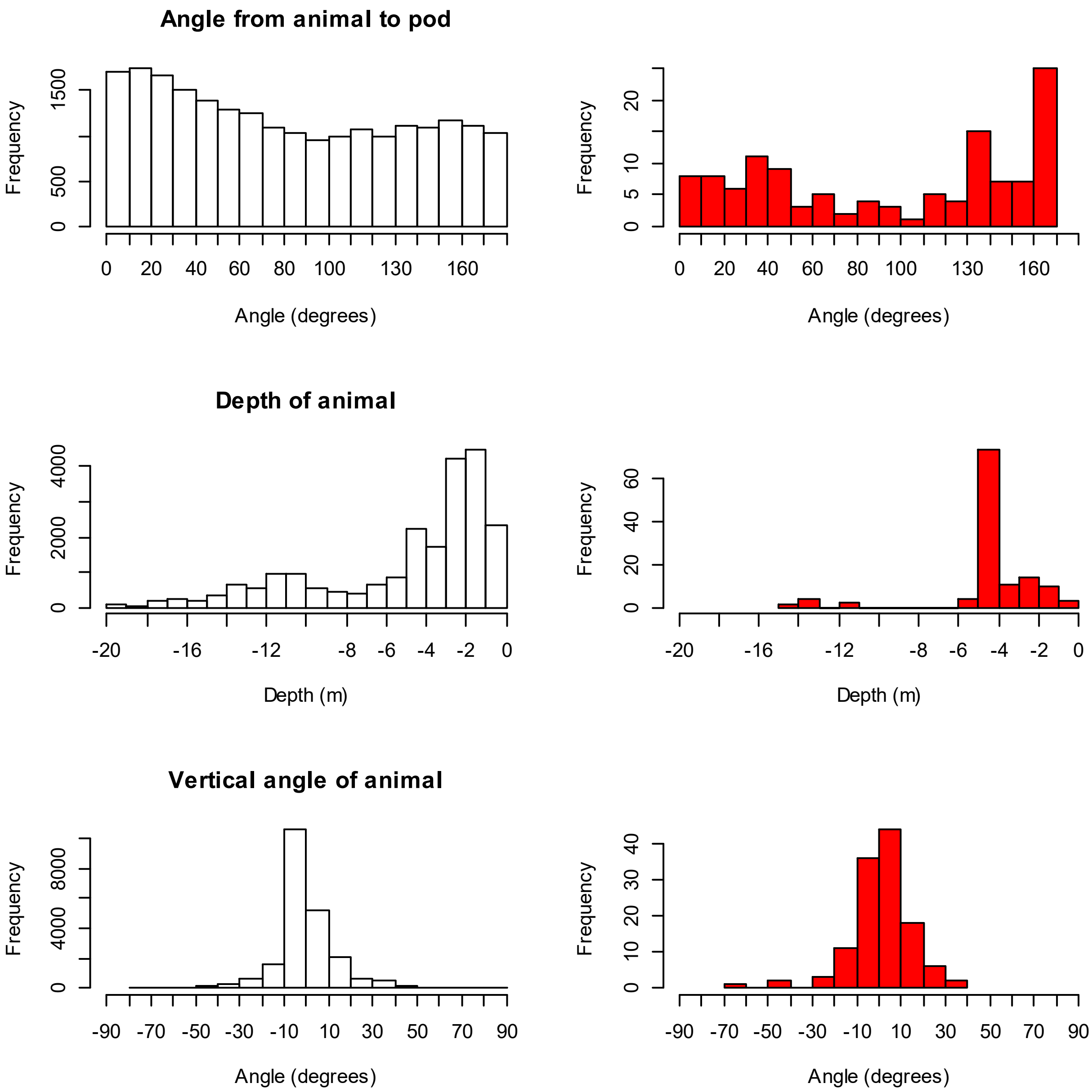
Figure D2 shows the distribution of the variables. Clicks were detected at a limited range of depths and vertical angles compared to the range of possible values. Surprisingly, the distribution of angles of the pod to the animal showed that more clicks were detected when the pod was nearly behind the animal.

Including these variables into the model describing the pattern in PPS shows that depth (in conjunction with the variables already in the model) explains more of the pattern than the other variables (Table D1). However, including depth in the model raises an issue with prediction of EDR as depth would then need to be included in the integration to obtain P_a.

Table D1 Summary of the fitted models, degrees of freedom (df) and AIC; 's' indicates a smooth term and 're' indicates a term fitted as a random effect. Smooth terms were restricted to a maximum of 6 knots.

Number	Model	df	AIC
1	s(distance) + dielp + re(id, by=ind) + re(encounter,by=ind)	28.8	1097
2	s(distance) + dielp + s(depth) + re(id, by=ind) + re(encounter,by=ind)	38.6	1074
2	s(distance) + dielp + s(vertang) + re(id, by=ind) + re(encounter,by=ind)	31.0	1085
2	s(distance) + dielp + s(ang2pod) + re(id, by=ind) + re(encounter,by=ind)	29.9	1095

Figure D2 Distribution of variables for each second of an encounter at each pod; red bars indicate values where clicks were detected and white indicate bars where clicks were not detected. Left plot shows angles where clicks were not detected and the right plot shows angles where clicks were detected. Top plot shows the horizontal angles to all pods for all encounters; middle plot shows the depth of the animal and the bottom plot shows the vertical angle of animal.



SAMBAH Report 2a - Version 2.1
Kerteminde Free-swimming Porpoise Detection Function Analysis

Len Thomas & Louise Burt, CREEM

May 31, 2015

1 Introduction

This report follows on from SAMBAH Report 2 "Assessment of C-PODs to detect porpoise using the Kerteminde study". In that report, we found that analysis of the Kerteminde data alone produces implausible detection functions, likely due to small sample size. Here, we take various approaches to obtaining a detection function from the Kerteminde porpoise encounter data, supplemented by additional information from other studies.

Additional sources of information are:

- A "theoretical click detection function" derived by Line Kyhn from assumptions about source level, propagation loss and detector performance. Note that this is a detection function for clicks, and does not include either the classification stage of processing nor the fact that we are using 1 second snapshots as the object of detection, rather than individual clicks.
- An "empirical snapshot detection function" estimated from porpoise data collected on T-PODs at Fyns Høved in Denmark (Kyhn 2010; Kyhn et al. 2012). Note that these data were collected using T-PODs (so different devices); they are from a different (much more lenient) classifier; they are from binary trials that were set up visually (so include silent animals when Kerteminde does not); they are for 15 second snapshots as opposed to 1 second.
- A diurnal pattern observed in the encounter rate of porpoise-positive seconds from the main SAMBAH survey (see Report 1).

As with SAMBAH Report 1, this report is written using `Knitr` package in `R version 3.1.3 (2015-03-09)`; it is therefore a "live" document in the sense that all values, tables and figures given are the direct output from `R` analyses performed as part of document compilation (except for the bootstrap at the end, where results were cached in advance, as noted in the text).

2 Summary of Kerteminde data

The Kerteminde data consist of 36 porpoise encounters when porpoises were tracked acoustically from a boat; these "known location" animals were used to set up trials for a total of 16 C-PODS moored at known locations. For each C-POD and each second of each encounter, we determined whether the porpoise was detected on the C-POD or not (a trial with a successful or unsuccessful outcome, respectively), and also recorded covariates such as distance from porpoise to each POD, animal bearing, etc. In total there were 26207 trials (i.e., seconds times PODs), of which 137 were successful. Clearly, it is going to be very hard to successfully model the detection function given so few porpoise-positive seconds.

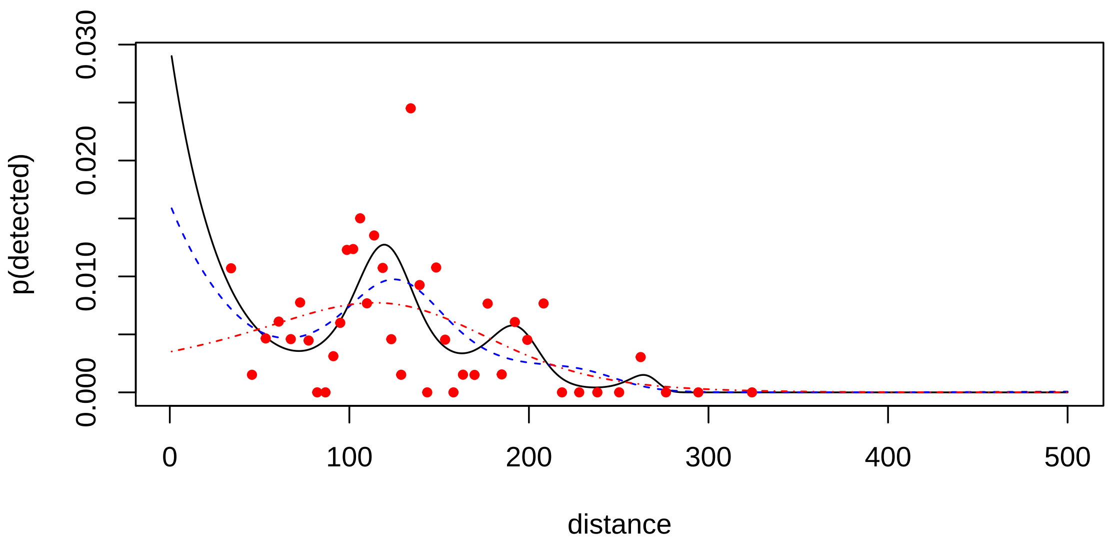


Figure 1: Trials binned into 10m distance intervals (dots), with three binomial GAM fits shown – degrees of freedom estimated (black), maximum 7 (blue dashed) and 5 (red dot-dashed).

In the Figure 1, the trials have been grouped, so that all trials occuring in the same 10m bin of porpoise-C-POD distance are are grouped together. On the x axis is distance; on the y-axis is proportion of trials that were successful – i.e., a raw empirical estimate of probability of detection. A simple Generalized Additive Model (GAM) was fit to the raw data (i.e., 0/1 data on individual trials) – a binary GAM with logit link and distance as the only covairate, and smoothness selected using the standard methods in the `gam` function in the `mgcv` library in `R`. The fitted line is shown in black – note that values for the line outside the range (34.119, 324.245 are an extrapolation. The fitted line shows an implausible non-monotonic shape – we expect that the true detection function will most likely be monotonic non-increasing, rather than trimodal!

To reduce the non-monotonicity, two more GAMs were fit, restricting the maximum degrees of freedom for the smooth to 7 and 5 respectively (dashed and dotted lines in Figure 1). The former is non-monotonic, while the latter has a peak at 120m, which also seems implausible.

An option is, instead, to fit a monotonic smooth. Software is available (the `pcls` function in the `mgcv library`) to fit a monotonic smooth using least squares, with the option of adding constraints to the fit. We used this to fit monotonic cubic regression splines, with the constraint that the fitted function had to be 0 or greater. (Note that the distributional assumption here is different from the previous GAM, which assumed trials are binomial (actually, Bernoulli) and a log link function; here we use least squares, so assume variance is equal for all p, and an identity link function.) Results for 6, 10 and 14 knots (where knots are distributed at even intervals with respect to the observed distances) are shown in Figure 2. These look (to us) distinctly more realistic. We return to this type of function later, after considering the auxiliary data, and how it might be incorporated.

3 Theoretical click detection function

A detection function for single clicks was derived by Line Kyhn (pers. comm.), with values generated by a Monte Carlo simulation she performed in Excel. Values were read in from the file `Output of theoretical detection function.csv`

Figure 3 shows the proportion of positive detections in 10m bins (black dots are the proportions); since the fitting algorithm below needs to have a value for any given distance, we fit a smooth to the data (a simple

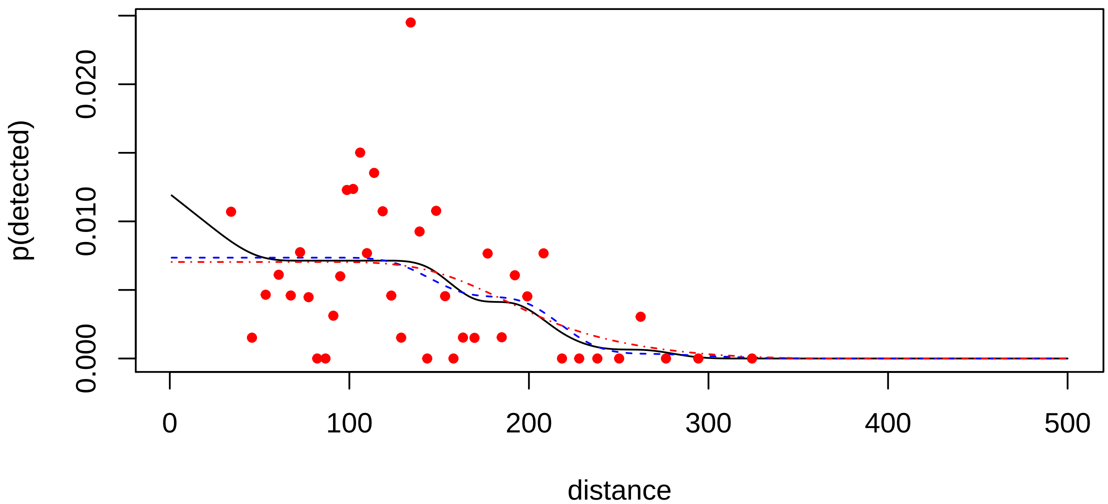


Figure 2: Trials binned into 40 distance intervals, evenly spaced through the trial distances (dots), with monotonic cubic regression line fits shown (least squares fits, constrained to be non-negative). Number of knot points 14 (black), 10 (blue dashed), 6 (red dot-dashed) lines.

GAM, with Gaussian error and log link[1]. The smooth is shown as a solid line.

Let $t(r)$ be the detection probability from the theoretical curve (where r is radial horizontal distance of the animal from the detector). We fit the Kerteminde trial data to following model, assuming each trial at distance r was an independent Bernoulli trial with probability $p(r)$ given by

$$p(r) = g0 \times \frac{t(r/\theta)}{t(0)} \tag{1}$$

where $g0$ and θ are model parameters, estimated from the data. $g0$ is the estimated probability of detection at 0 distance, and θ is a scale parameter. The divisor $t(0)$ simply ensures that when $\widehat{g0} = 1$, $\hat{p}(r) = 1$. We set bounds on $g0$ to keep it in the range (0.05, 1) and on θ to keep it in the range (0.9,20). So, effectively we're using the theoretical function to provide the shape, and we're estimating both the y-intercept and the x-scale.

Estimated values were $g0$ =0.0640944 and θ =1.5020701.[2] The fit is shown in Figure 4.

It's immediately apprarent that the data from 80m inwards is not well fit by the theoretical function.

4 Fyns Høved empirical detection function

Following Kyhn (2010) and Kyhn et al. (2012), we used data with `data.cat==2` (i.e., trains classified as "cet all"), `method==1` (TPOD data), `group.cat==2` (all groups, whether confirmed group size 1 or not) and `cue==15` (15 second snapshot window). A binary GAM, fitted to these data, is shown in Figure 5.

The shape of this function is then used to fit the emprical Kerteminde data, using the same maximum likelihood method as for the previous section (see equation 1, above). (Note - this time the parameter bounds were $g0$ (0.005, 1) and θ (0.9,20).

The fit is shown in Figure 6. Estimated values were $g0$ =0.0078396 and θ =1.7863682

[1] Logit link didn't work as the detection prob at 0 distance is 1, leading to Inf on the logit scale. In a more refined version of this, we'd fit a monotonic non-increasing function to the proportions, or use the raw simulated detection data.

[2] In doing the fitting, it's important to check that the optimization method doesn't hit any of the bounds, above, so best to run the code manually in R before compiling this document.

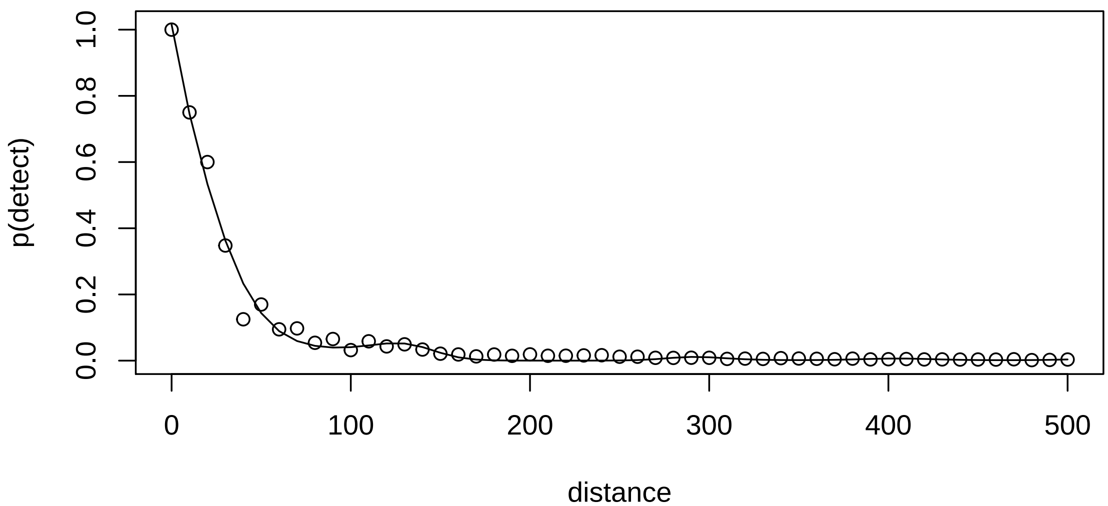


Figure 3: Simulations from a theoretically-derived detection function provided by Line Kyhn. The dots are the simulated proportion of detections per 10m bin; the line is a smooth fit to these proportions – this was then used in fitting the theoretical function to Kerteminde data.

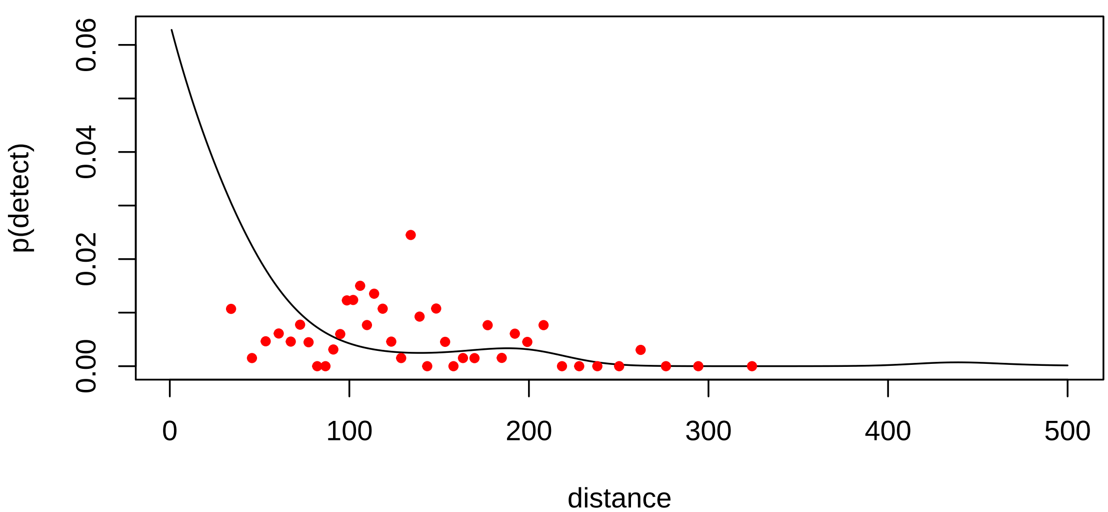


Figure 4: Fit of Kerteminde data to the detection function shape from Figure 3.

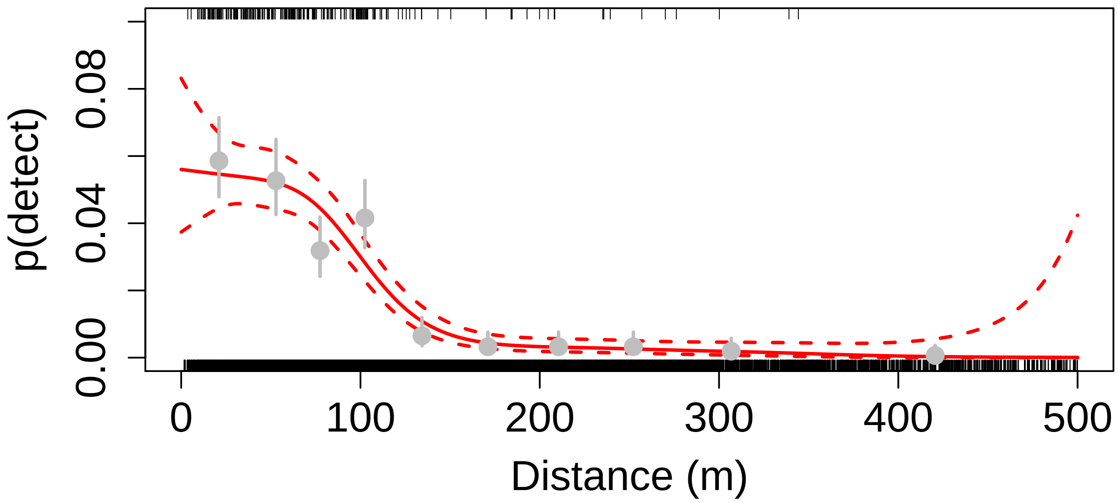


Figure 5: Binary GAM fit to the Fyns Høved data. The data are shown by dashed lines at the top (success) and bottom (failure) of the figure; the fitted line is shown in red, with 95%CI shown as dashed red lines. To help assess goodness-of-fit, the data are also summarizied by dividing into 10 equal parts and for each calculating the mean proportion of successes (the grey dots) and binomial 95%CI (the grey vertical lines).

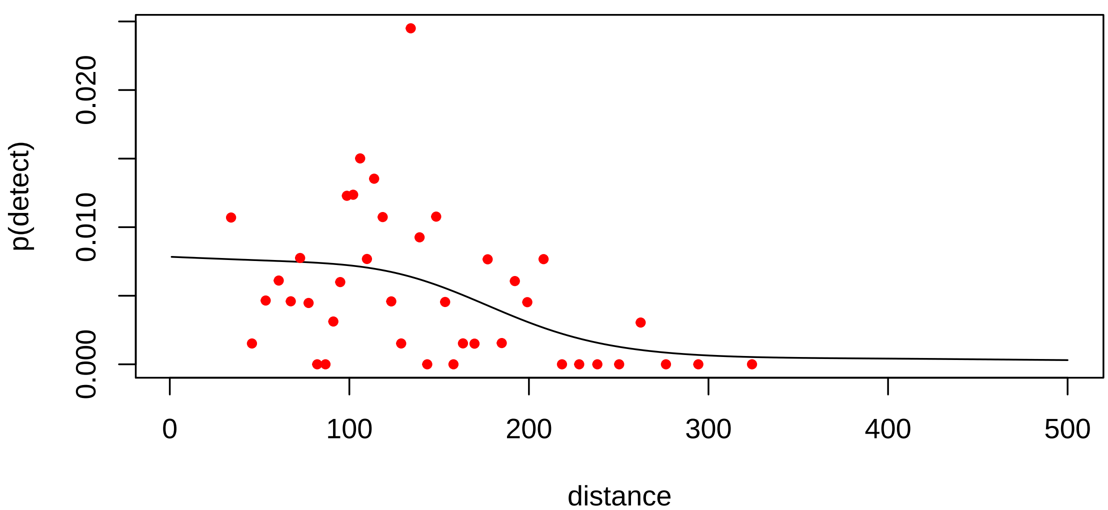


Figure 6: Detection function shape from Figure 5 fit to the Kerteminde data.

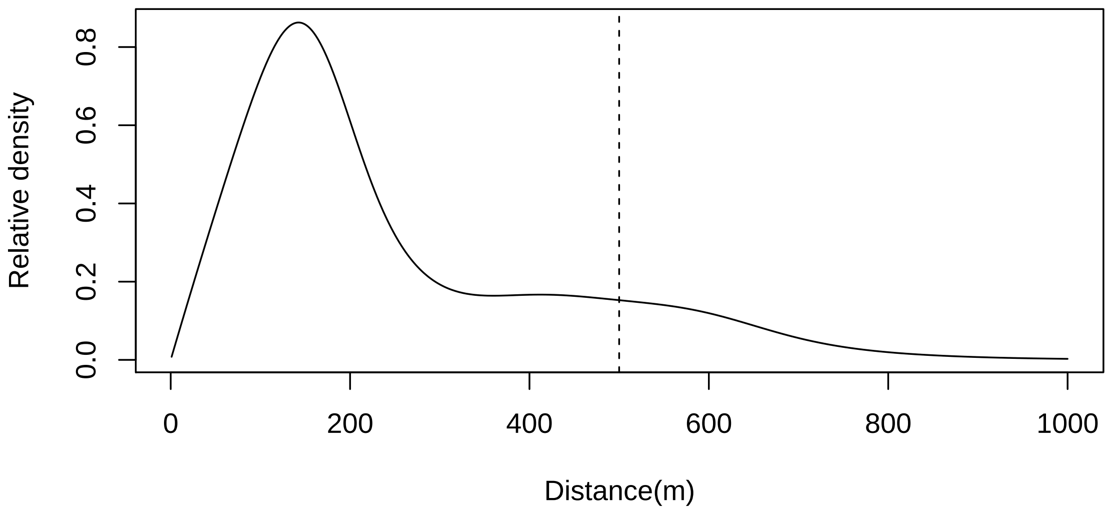


Figure 7: Probability density function (scaled) corresponding to the detection function shown in Figure 6. Note that the x-axis is from 0-1000m; 500m is shown by a dashed line.

One significant problem with this function is that the estimated detection probability declines only slowly from around 400m onwards, and is not exactly zero at 500m. Since the area surveyed from a point (such as a C-POD) goes up linearly with increasing distance, this means a non-negligible number of detections are expected to be made at distances of 500m or greater – as illustrated in the (scaled) probability density function plot in Figure 7 – note that the x-axis here goes out to 1000m.

5 Diurnal data

Table 1 gives the relative encounter rates by phase of day, taken from the analysis in SAMBAH Report 1a, Table 7[3]. As outlined in that report, we can consider these as a good estimate of the relative detectability of porpoises by day phase.

	phase	rel.er	lcl	ucl
1	eve	1.199	0.937	1.534
2	morn	1.424	1.117	1.814
3	night	2.073	1.641	2.618

Table 1: Relative encounter rates by phase of day from model applied to SAMBAH main survey encounter rates (See SAMBAH Report 1a). Day is taken as baseline (i.e., has relative encounter rate of 1.0).

The detections at Kerteminde do not show the same pattern (apart from Morning) relative to the Day phase. Table 2 shows the number of trials, clicks and proportion of successful trials (a simplistic estimate of p) for the Kerteminde data. (These data are also shown in Table 3 of Burt and Thomas Report 2 “Assessment of C-PODs to detect porpoise using the Kerteminde study”). This is likely partly due to different distances being in the trials for each phase but, as was shown in the Burt and Thomas Report 2, even when you introduce distance as a covariate in a GAM, the estimated night and evening curves are much further above the day curve than 1

[3]Note to authors: The .csv file containing this information needs to be copied manually from the “Effort” directory containing the Report 1a .Rnw file to the directory containing this report, and the cache deleted, before compilation.

would suggest is reasonable. [4] Likely this is down to the relatively small sample size of independent encounters in these data, coupled with factors that strongly affect detectability such as animal sonar beam direction, that we did not control for here, and which are likely to be very influential in this small data set.

	diel.phase	click	trial	p.success	relative.p
1	day	12	14547	0.00082	1.000
2	eve	16	2695	0.00594	7.197
3	morn	8	5137	0.00156	1.888
4	night	101	3828	0.02638	31.985

Table 2: Number of click positive seconds (click), trial seconds (trial), proportion of click positive seconds by diel phase and proportion relative to the lowest.

6 Suggested approach v1

The most promising approach of those trialed in this report so far is the monotonic smooth, which produced a reasonable detection function, with a monotonic decrease and estimated detection probablity of zero at around 300m. However, it was not possible to obtain reasonable estimates from this when diel pattern was included as a covariate, because the estimated detection probability for "night" was far higher than is believable. Therefore it seems most sensible to continue fitting to the combined data, to obtain an "average" detection probability over the whole day, and then to covert to a diel phase-specific detection probability using the results from Table 1, above.

However, we should not use one of the detection functions from Figure 2 as an "average" detection function, because we did not sample during each diel phase in proportion to the amount of each phase in the day. Hence, we will need to do a weighted regression, where we up-weight trials from phases that were under-sampled in the Kerteminde experiment, and down-weight trials that were over-sampled.

	diel.phase	day.mins	day.prop	trial	trial.prop	weight
1	day	924	0.660	14547	0.555	1.189
2	eve	118	0.084	2695	0.103	0.820
3	morn	118	0.084	5137	0.196	0.430
4	night	240	0.171	3828	0.146	1.174

Table 3: Amount of the day in each diel phase, number of trials in each diel phase, and weighting to correct for the imbalance.

Table 3 shows the proportion of each diel phase in the day at Kerteminde during the time of the experiments, and the proportion of trials in each phase. It can be seen that day and night are somewhat under-represented in the trials compared with the amount of day-time in Kerteminde during that time of year; morning is rather over-represented. Dividing the proportion of each diel phase in the day by the proportion of trials in that phase gives the appropriate weight to use. Figure 8 shows the monotonic regression with the weighted data. To produce the dots, the data for each diel phase were divided into a number of quantiles with respect to distance, for each quantile, the proportion of positive clicks clicks was plotted. The number of quantiles for each phase was determined by the total number of dots desired multiplied by the proportion of the day in each diel phase – hence the number of dots for each phase is in proportion to their influence on the regression.

Now there is the question of how many knot points to use. From the above plots, something in the range 6-14 seems reasonable; also we would hope that the choice would not make much difference to the estimated effective detection radius (EDR). We computed EDR and effective detection area (EDA) for a wide range of knot numbers – results are given in Table 4. At 7 knots and above it does indeed make little difference; the values are a little higher for 6 or fewer knots, possibly becuase the fitted detection probability is slightly higher around 250m – see Figure 8.

[4] Attempts to introduce diel phase as a covariate into the monotonic GAMs also produced similar results.

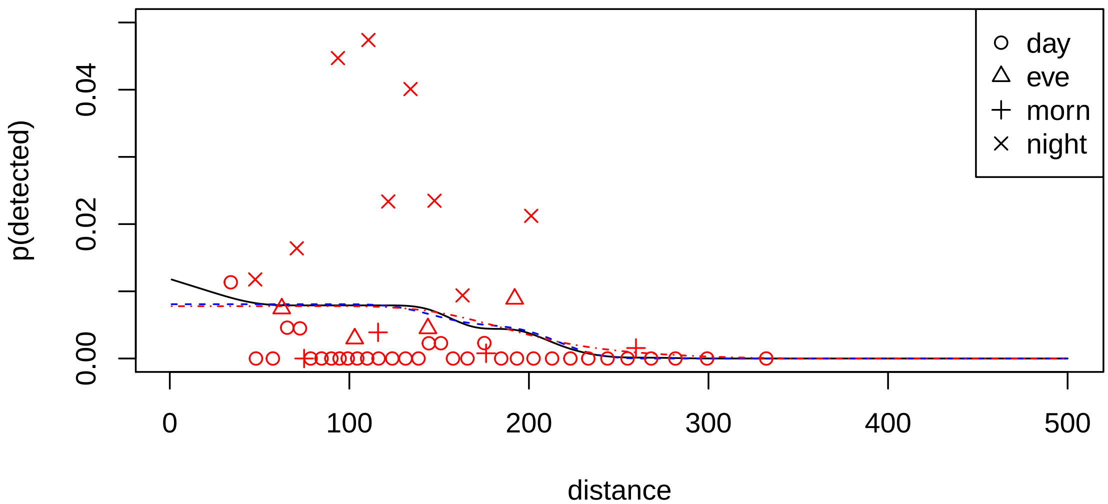


Figure 8: Trials binned into 50 distance intervals, in proportion to the amount of time in the day each diel phase, and spread evenly through the distances in each diel phase (dots). Monotonic cubic weighted regression line fits are also shown (least squares fits, constrained to be non-negative). Number of knot points 14 (black), 10 (blue dashed), 6 (red dot-dashed) lines.

Our inclination is to go with the lowest number of knots that gives a reasonable and stable fit, and hence we choose 7. The final fit is given in Figure 9, and the estimated EDR and EDA are ρ =17.344 and ν =945.02, respectively.

The last task is to calculate the EDR and EDA for each diel phase, given the above average EDR and EDA, the proportion of the day in each diel phase shown in Table 3, and the SAMBAH-wide relative encounter rates given in Table 1. For example, taking EDA, let $\bar{\nu}$ be the daily average EDA (i.e., the quantity we just calculated), d be the diel phase ($= 1, \ldots, 4$ corresponding with day, eve, morn and night), ν_d be the EDA for phase d, π_d be the proportion of the day that corresponds to phase d and e_d be the SAMBAH-wide relative encounter rate from Table 1 (where they are calculated relative to the day phase, so $e_1 = 1$, then:

$$\bar{\nu} = \sum_{d=1}^{4} \pi_d e_d \nu_1. \tag{2}$$

Solving this for ν_1 and then for the other νs (and the same for the ρs) gives the values in Table 5. [5]

7 Suggested approach v2

After some discussion, we decided to take another look at the idea of fitting a function that is monotonic non-increasing, but that has a factor for diel phase at Kerteminde. It did not seem straightforward to use the `pcls` function utilitzed previously to achieve a monotonic function, so instead we fitted a standard binomial GAM, but hand selected the number and placement of knots, using a cubic regression spline basis, and fixed the degrees of freedom of the smooth. Three knots (i.e., 2df) gave a reasonable function, with knot points at 100, 300 and 500m. (The fitted function was reasonably robust to small changes in number and location of knots, although it did vary with larger changes in knot positioning; the Effective Detection Area, however, did not

[5] As a check, if you take the weighted mean of the values of ν for each phase, weighting by the proportion of the day in each diel phase, you get 945.02.

	k	nu	rho
1	4	1066.811	18.428
2	5	1167.746	19.280
3	6	1039.311	18.189
4	7	945.015	17.344
5	8	954.229	17.428
6	9	959.272	17.474
7	10	943.833	17.333
8	11	956.340	17.447
9	12	936.528	17.266
10	13	942.573	17.321
11	14	936.712	17.267
12	15	956.939	17.453
13	16	932.958	17.233
14	17	930.665	17.212
15	18	944.431	17.338
16	19	923.599	17.146
17	20	935.989	17.261

Table 4: Effective detection area (nu) and effective detection radius (rho) as a function of number of knot points.

	diel.phase	nu	rho	p300	p500
1	day	764.3127	15.5977	0.00849	0.00306
2	eve	916.2644	17.0779	0.01018	0.00367
3	morn	1088.0384	18.6100	0.01209	0.00435
4	night	1584.5357	22.4583	0.01761	0.00634

Table 5: Estimated values of EDA and EDR by diel phase for Kerteminde. Also given are the estimated probability of detecting a porpoise during a 1 second period given that it is within a circle of 300m or 500m around a CPOD at Kerteminde.

vary much.) The reason for a small nummber of knots was to achieve a very smooth function. The resulting fit is shown in Figure 10.

The estimated effective detection areas and radii are shown in Table 6. The overall average effective detection area for Kerteminde (averaging over diel phases) is estimated to be 1101.7 with corresponding effective detection radius 18.727. Table 6 also shows the estimated EDA and EDR for the SAMBAH region, calculated using Equation 2. These are the values that will be used in estimating density in the SAMBAH region.

	diel	nu.kert	rho.kert	nu.SAMBAH	rho.SAMBAH	p300.SAMBAH	p500.SAMBAH
1	day	187.6068	7.7277	891.0508	16.8413	0.00990	0.00356
2	eve	1137.6045	19.0292	1068.1990	18.4396	0.01187	0.00427
3	morn	350.8693	10.5681	1268.4565	20.0938	0.01409	0.00507
4	night	4972.5648	39.7846	1847.2829	24.2489	0.02053	0.00739

Table 6: Estimated values of EDA (nu) and EDR (rho) by diel phase for Kerteminde (.kert columns), and for the SAMBAH region (.SAMBAH colmns). Also given are the estimated probability of detecting a porpoise during a 1 second period given that it is within a circle of 300m or 500m around a CPOD in the SAMBAH region.

8 Variance estimation

We have implemented variance estimation via a non-parametric bootstrap. The sampling unit was the encounter, and we conditioned on the number of encounters per diel phase – these numbers are shown in Table 7. The total

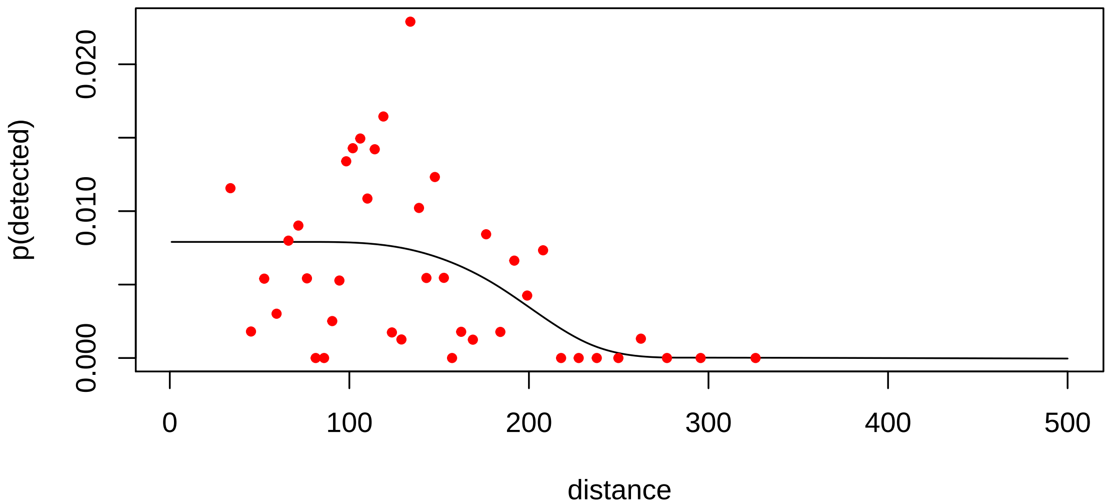


Figure 9: Trials binned into 40 distance intervals spread evenly through the distances (dots), with a 7-knot monotonic cubic weighted regression line fits are also shown (least squares fits, constrained to be non-negative).

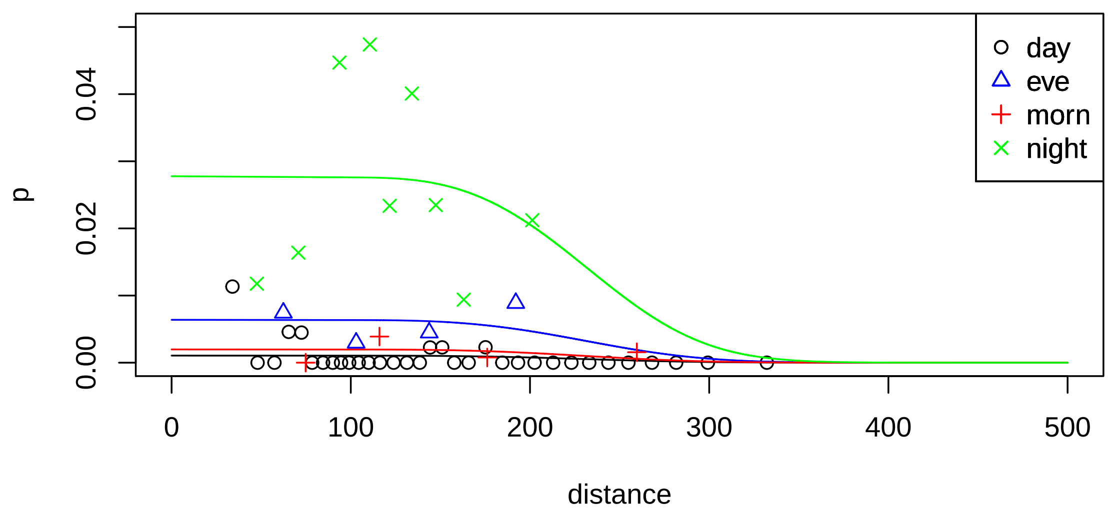


Figure 10: Trials binned into 50 distance intervals, in proportion to the amount of time in the day each diel phase, and spread evenly through the distances in each diel phase (dots). Binomial GAM (cubic regression spline with 3 hand-placed knots) fit, with additive term for diel phase is also shown.

	n.ids.byphase
day	21
eve	5
morn	4
night	6

Table 7: Number of encounters by diel phase

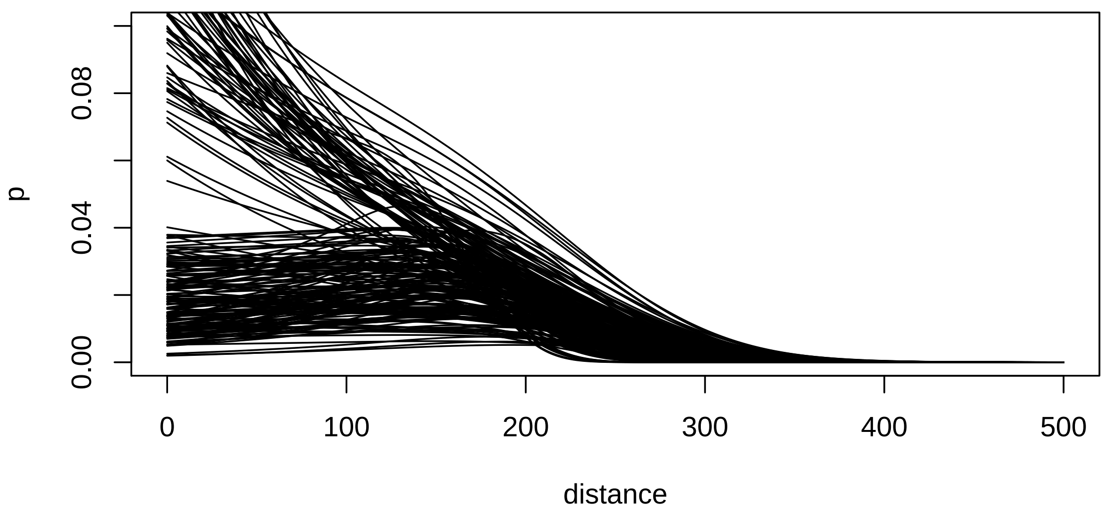


Figure 11: Some example bootstrap replicate predictions for the night diel phase.

number of bootstraps was 1000. We added a large number (25,000 per diel phase) of structural zeros at 500m to ensure the bootstrap replicate detection functions declind to zero by 500m – without this, many actually increased outside the range of the data (i.e., 380m and above) in some bootstrap replicates.

The random seed used for generating bootstraps was 384762.

The first 200 bootstrap replicate predictions for the night diel phase are shown in Figure 11.[6] A histogram of the bootstrap estimates of EDA is shown in Figure 12. The bootstrap mean is 1152.7 (compared to the original mean of 1101.7), while the CV (bootstrap se/original mean) is 0.42552 and a 95% percentile CI is (564.67, 2277.7).

An alternative method of variance estimation is a parametric bootstrap. However, trials within encounters are not independent, so the variance estimated from the model used would be an under-estimate. It is, in theory, possible to fit encounter as a random effect, but attempts to to this failed in practice because (a) the estimated detection functions were highly implausible when degrees of smoothness was estimated, (b) when degress of smoothness were fixed then (i) the random effects did not seem normally distributed using diagnostic plots and (ii) the R function `gam.vcomp` doesn't work, so we could not see how to get out the random effects variance. These issues are likely solveable, but the bootstrap approach used above is robust to model mis-specification, so preferred in any case.

9 Discussion

The solution we have chosen to use (Suggested approach 2) is data driven, in that the detection function is estimated from the trial data and variance is estimated via a non-parametric bootstrap – however, the model is

[6]to save time in compiling this document, the bootstrap replicates have been cached in a file.

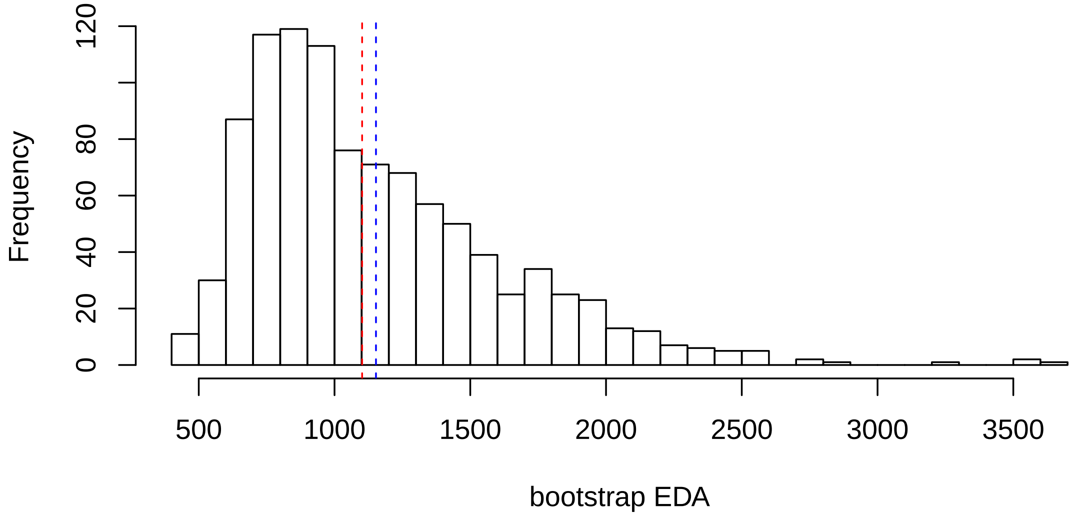


Figure 12: Histogram of bootstrap estimates of effective detection area. The bootstrap mean, and the mean from the original data are shown as blue and red vertical lines, respectively.

heavily constrained to obtain a reasonable result. A low-dimensional smooth is used for fitting, with hand-chosen knot points; for the variance estimation structural zeros were added at 500m.

In defining a "reasonable" result, we assume that diel pattern at Kerteminde is like that in the SAMBAH main area. Instead, it may be that animals in Kerteminde are in reality much more vocally active at night. This could only be tested with more data. Our original plan was to undertake tracking experiments at more sites, but without such data we feel the above represents the most reasonable option for analysis.

The initial fit assumes each trial is independent, but by bootstrapping by encounter, the variance estimate does not require such an assumption, so our result is robust in the sense that it does not suffer from pseudoreplication.

SAMBAH Report 3 Version 1.2

Estimating the effective detection area of C-PODs from playback experiments in the Baltic Sea and Kerteminde

ML Burt and L Thomas, CREEM, University of St Andrews

SUMMARY

This report describes the analysis of data collected during playback experiments to predict the detection of porpoise-like clicks on C-PODs. Playback experiments were conducted when C-PODs were either deployed or recovered at stations in the Baltic Sea as part of the SAMBAH project and also as part of a study of porpoise in their natural setting at Kerteminde, Great Belt. The aim of the analysis was to predict the probability of detection of porpoise-like clicks based on environmental and temporal conditions and hence predict an effective detection area (EDA) over which C-PODs detect these artificial clicks. Due to the different conditions at Kerteminde compared to the Baltic Sea, models were fitted to the Kerteminde data and the SAMBAH data separately. This meant that only a relatively simple model was fitted to the Kerteminde data. The estimated EDA for Kerteminde, June 2013, was estimated to be 8,333m^2 (CV=0.32). Environmental and temporal variables were included in the SAMBAH playback model. The estimated EDAs for all stations in the Baltic Sea for the period May 2011 to April 2013, inclusive, ranged from 184m^2 (CV=**) to 263,867m^2 (CV=**). These values will be used to scale an effective detection area over which C-PODs detected porpoise clicks at Kerteminde so that it can be applied to the Baltic Sea.

INTRODUCTION

When C-PODs were deployed, or recovered, from stations in the Baltic Sea during the SAMBAH project (and at a few other times), playback experiments were conducted to assess the performance of the devices. Porpoise-like clicks were played at different distances and at different source levels and the number of clicks detected by the devices were recorded. A similar experiment was conducted at Kerteminde, Great Belt, in June 2013, as part of an experiment to assess C-PODs with porpoise in their natural environment (SAMBAH Report 2). The propagation of sound through the water can be effected by the environmental conditions. Using the proportion of clicks detected as the response variable, the intention was to use generalised additive models to model the proportion of clicks detected as a function of environmental and temporal conditions. The purpose of the analysis was to predict the probability of detection of artificial clicks to obtain an effective detection area (EDA) for a C-POD at Kerteminde and for any station in the Baltic Sea (not just those used during the playback experiments) for each month throughout the duration of the SAMBAH project (May 2011 to April 2013, inclusive). These EDAs of C-PODs for porpoise-like clicks will then be used to scale an EDA of C-PODs for real porpoise obtained from a study at Kerteminde (see SAMBAH Report 2).

EXPERIMENTAL METHODS

Baltic Sea

From April 2011 to May 2013, playback experiments were conducted when devices were deployed or recovered although a few experiments took place between deployments and some experiments were not assigned to specific deployments and took place in August 2013 (Table 1). There were no data for Estonia.

C-PODs were moored on the sea bed in water depths ranging from 6m to 88m. Porpoise-like clicks were played from a transducer at various source levels (from 138dB to 185.5dB) and from a set of distances to the devices (from 5m to 462m) (Table 2). One source level played at different distances was called a 'playback'. The numbers of clicks that were detected (out of either 10 or 20 clicks) for a given source level and distance were recorded. Various sets of equipment were used to produce the clicks; SE 6251, SE 6361, SE 6356 and DK.

Kerteminde

Eleven C-PODs were deployed as part of a 4x4 grid at a distance of 50m apart. The hydrophones of the detectors were deployed 2m above the seafloor which was at a depth of 19.5m over the whole site. Different C-POD devices were arranged in a cluster close to each other.

The experiment played clicks from a transducer at eleven source levels (from 138dB to 168dB) and from a set of distances to the devices (from 4m to 426m). One set of calls played at all source levels at a fixed position was called a 'playback' and there were 85 playbacks in total. Nine devices received all 85 playbacks with one device receiving only one playback (C-POD 1466). The numbers of clicks that were detected (out of 10) for a given source level and position of transducer were recorded (Table 3). The set of equipment used for the experiments was SE 6356.

ANALYSIS METHODS

The aim of the analysis was to estimate an EDA for detecting porpoise-like clicks for the site at Kerteminde in June 2013 and for any site in the Baltic Sea for the duration of the SAMBAH project. For details of estimating EDA see SAMBAH Report 2. The estimation of the probability of detection, $g(r)$, differs to that described in SAMBAH Report 2 in that the response variable in the model used here is the number of porpoise-like clicks detected out of a possible 10, or 20, clicks emitted and environmental and temporal variables are used as explanatory variables. It was envisioned that the data from both Kerteminde and SAMBAH experiments would be combined into one analysis, however preliminary analysis suggested that Kerteminde was sufficiently different from the Baltic Sea (in terms of environmental conditions) such that it was difficult to combine the data into one model (see SAMBAH Report 3a). Therefore, separate models were fitted to the Kerteminde and Baltic Sea data: the model fitted to Kerteminde was relatively simple including terms for distance and source level and the model fitted to the Baltic Sea data included environmental and temporal variables.

Probability of detection

The probability of detection (number of porpoise-like clicks detected out of the number of porpoise-like clicks played) was treated as the response variable in a generalized additive mixed model framework (GAMMs; Wood 2006) and was assumed to be a binomial random variable. Note that the probability of detection incorporated the probability of clicks being produced by the transducer, detected by the C-POD and classified as a click. A logit function was specified to link the response variable with the explanatory variables. Environmental conditions can affect the sound propagation through the water and so environmental data were collected covering the spatial and temporal extent of the SAMBAH project (see SAMBAH Report 3a). Explanatory variables were included in the model in three stages; playback variables, environmental variables and finally other temporal and spatial variables. For the model fitted to the Kerteminde data only playback variables were included as potential explanatory variables. Variables were included using a forward, stepwise approach and the model with the lowest AIC was selected. The potential explanatory variables, fitted as smooth functions, were as follows (the numbers in parentheses indicate the stage at which the variable was included):

- (1) Distance - distance (m) from the device to the transducer
- (1) SL – planned source level (dB) of the click
- (2) Depth – water depth (m) at station
- (2) SST – sea surface temperature (°C)

- (2) SBT – sea bottom temperature (°C)
- (2) SSsal – Sea surface salinity (PSU)
- (2) SBsal – Sea bottom salinity (PSU)
- (3) Month – month (1-12) when experiment took place
- (3) Doy – day of year (i.e. 1 = 1st Jan, 2 = 2nd Jan, …. 365 = 31 Dec)
- (3) Lon – longitude of station (°E)
- (3) Lat – latitude of station (°N)

One factor variables were included:

- (2) Geo – sediment type (6 levels)

Some variables were correlated ($|r|>0.5$) with other variables (e.g. SST with SBT; SSsal with SBsal) and so once one of the pair of correlated variables was included in the model, the other variable was not considered further. Day of year and month were fitted as cyclic smooths e.g. for doy, day 1 was constrained to have the same value as day 365 but as with other correlated variables, once one of these variables was included, the other was not considered.

To avoid fitting unrealistically complicated models, smooth functions were limited to a maximum of 5 degrees of freedom (df; 5 knots). Two dimensional functions were limited to 15 knots. All models were fitted in the statistical software program R (3.0.2; R core team 2013) using the gam function available in the mgcv library (version 1.7-27; Wood 2004).

There was some evidence that the detection of clicks was compromised at high source levels (Ref to work by Jens; pers. comm. from M. Amundin) and so clicks produced with a SL of greater than 171dB were excluded from the analysis.

The depths and gradients of a pycnocline, halocline and thermocline, when they occurred, were also measured for SAMBAH playback experiments. Some cline depths were greater than the water depth and so, since water depth was correlated to the cline depths, water depth was used as a potential variable in the model. Preliminary analysis indicated that outliers in the cline gradients caused unrealistic smooth functions of the gradient terms and so outliers were poorly predicted. The models were to be used for prediction (see below) and the prediction data had a wider range of values than the data used for model fitting and so any edge effects would be exaggerated. Therefore, cline gradients were not considered further.

To account for repeated measurements at stations in the Baltic Sea and differences in the C-PODs, two variables were considered for possible inclusion as random effect terms in the model: C-POD device id and deployment (a combination of station and period of deployment). However, there were a large number of deployments (216 levels) and different C-PODs (194) and several C-PODs were used in several locations and so in the final model selection were not considered.

Prediction

The aim of the analysis was to use the selected models to predict the EDA of C-PODs for detecting porpoise-like clicks at Kerteminde, June 2013, and to predict the EDA for every station in the Baltic Sea for the months May 2011 to April 2013, inclusive. Thus, values of all covariates selected in the model are required for these months – see SAMBAH Report 3a for time series plots of the environmental covariates. A SL will also be required for prediction, if selected in the final model; a SL of 158dB was chosen because it was in the mean SL used in the playback experiments.

Measurement of uncertainty

The variance of the each prediction was estimated using a parametric bootstrap; 1,000 realizations of the parameters in the selected model were generated using a multivariate random normal distribution. For each realization, a new EDA was obtained. The 2.5% and 97.5% quantiles of the bootstrap distribution provided the lower and upper confidence intervals, respectively. The standard deviation (SD) of the bootstrap distribution was used to estimate a coefficient of variation (CV=SD/estimate) for each prediction.

RESULTS

Playback experiments were conducted at over half (55%) of the stations in the Baltic Sea and during all months of the year except January and September (Tables 1 and 2). The locations of the stations tested are shown in Figure 1. Table 2 summarises the water depths at the stations and the distances from the device and source levels used by each country.

The model fitted to the Kerteminde experiments included a 2D smooth for distance and SL and random effect terms for C-POD and playback (Figure 2a).

To model the SAMBAH playback data the variables were included in three stages and AIC values for the fitted models are given in Table 4. The final model included distance, SL, sea surface temperature, sea surface salinity, depth, sediment type and month (Figure 2b). To informally assess the fit of the detection functions to the data, the observed proportions of clicks detected and the predicted detection functions for the stations used in the experiments are shown in Figure 3.

Predicted values of EDA

The aim of the analysis was to estimate an EDA for Kerteminde in June 2013 and for all stations in the Baltic Sea for every month for the duration of the project. The estimated EDR for Kerteminde, June 2013 was 67m (CV=**) and hence the estimated EDA (for a SL of 158 dB) was 14,083m^2 (CV=**).

The time series of estimated EDA for all stations in the Baltic Sea over the time period of interest are shown in Figure 4. The EDAs ranged from 270m^2 (at station 8008 December 2011) to over 165,200m^2 (station 3026 July 2011). The median value for all stations and time points was 32,740m^2.

DISCUSSION

GAMs were fitted to the proportion of porpoise-like clicks detected at C-PODs in order to estimate the EDA for C-PODs. The intention had been to combine the playback experiment data from Kerteminde with that from the playback experiments in the Baltic Sea and use environmental, spatial and temporal variables as explanatory variables. However, conditions at Kerteminde in June 2013 were sufficiently different from those in the Baltic Sea that the two datasets were modelled separately. A relatively simple model was used for the Kerteminde data, including distance from the C-POD to the transducer and the SL of the clicks. These variables were also included in the Baltic Sea model as well as sea surface temperature and salinity, sediment type, water depth and month. Using the fitted models and a SL of 158 dB, estimated EDAs were obtained for Kerteminde in June 2013 and for all stations in the Baltic Sea for each month from May 2011 to April 2013, inclusive. These values will be used in the estimation of an EDA of a C-POD to detect harbour porpoise in the Baltic Sea.

REFERENCES

R Core Team (2013) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/

SAMBAH Report 2: Assessment of C-PODs to detect porpoise report using the Kerteminde study. Unpublished report by ML Burt and L Thomas, CREEM, University of St Andrews

SAMBAH Report 3a: Summary of the environmental covariates used to model playback experiments. Unpublished report by ML Burt and L Thomas, CREEM, University of St Andrews

Wood SN (2006) *Generalized Additive Models: An Introduction with R*. Chapman and Hall/CRC

Wood SN (2004) Stable and efficient multiple smoothing parameter estimation for generalized additive models. *Journal of the American Statistical Association*. 99: 673-686

Table 1 Summary of playback experiments conducted in the Baltic Sea as part of SAMBAH ; total number of stations, the number of stations used for experiments, number of experiments performed, , the number of different C-PODs used in the experiments, deployments where experiments took place and the experiment setup.

Country		Total number of stations	Playback experiments				
			Stations	Experiments	C-PODs	Deployments	Setup
1	Sweden	99	70	70	70	D	SE 6251
2	Finland[1]	46	25	25	25	D	SE 6361
3	Estonia	40					
4	Latvia	34	9	12	9	G	SE 6251; SE 6361
5	Lithuania	9	6	10	6	E, F or G	SE 6251; SE 6361
6	Poland[2]	39	26	26	26	D, E or F	SE 6251; DK
	Poland[3]		37		2	During and/or after E	
7	Germany	16	16	32	24	D to I	SE 6356
8	Denmark	21	16	36	33	A to F	DK
	Total	304	168		194[4]		

[1] Experiments where playback counts are missing have been excluded
[2] Experiments assigned to deployments
[3] Experiments not assigned to deployments
[4] C-POD 1076 used at stations 5006 and 8021

Table 2 Summary of conditions during playback experiments in the Baltic Sea. The distances and SL are the values used for the experiments.

Country		Depth (m)		Distance (m)		Source level (dB)			Clicks emitted	Month of experiment
		Min	Max	Min	Max	Levels	Min	Max		
1	Sweden	7.8	88.0	15.0	218.0	11	155.0	185.0	20	May 2012
2	Finland	19.0	82.0	16.4	292.5	11	155.0	185.0	20	May 2012, June 2012
3	Estonia									
4	Latvia	8.0	51.4	50.0	200.0	11	155.0	185.0	20	Feb 2013, May 2013
5	Lithuania	24.0	61.0	25.0	150.0	11	155.0	185.0	20	June 2012, Oct 2012, Feb 2013
6	Poland[1]	9.0	75.0	199.0	500.0	10	153.5	180.5	10	Dec 2012, Mar 2013, Apr 2013
	Poland[2]	14.0	75.0	200.0	500.0	21	153.5	185.0	10 or 20	Apr 2013, Aug 2013
7	Germany	6.0	44.0	5.3	458.0	11	138.0	168.0	10	June 2012, Aug 2012, Nov 2012
8	Denmark	12.5	80.0	76.1	462.0	21	153.5	185.5	10	Apr 2011, Aug 2011, Oct 2011, Jul 2012, Nov 2012
	Total	6.0	88.0	5.3	462.0		138.0	185.5		

[1] Experiments assigned to deployments
[2] Experiments not assigned to deployments

Table 3 Summary of C-PODs used at Kerteminde, their layout and detection threshold

Layout	Device id	Detection threshold (dB)	Number of playbacks
Cluster	809	115.8	41
	815	113.9	20
	824	110.6	43
	1462	112.5	17
	1466	122.0	1
	1474	116.3	20
Grid	466	116.9	85
	804	115.0	61
	806	112.3	48
	819	114.5	85
	822	113.1	85
	1465	120.3	85
	1470	124.3	85
	1472	127.6	85
	1480	116.6	85
	1829	114.4	85
	1830	114.5	48

Table 4 Summary of the fitted models, degrees of freedom (df), AIC values and adjusted R^2 values after each stage. The selected model is shown in bold typeface.

Stage	Model	df	AIC	Adjusted R^2
1				
2				
3	te(distance,SL) + geo + s(depth) + s(SST) + s(SSsal) + s(month)	42.8	83139	0.561

Figure 1 Location of all stations used in the SAMBAH project. Filled circles indicate stations where playback experiments were conducted. Colour indicates the country responsible for deployment. The location of the experiment at Kerteminde is indicated by a triangle.

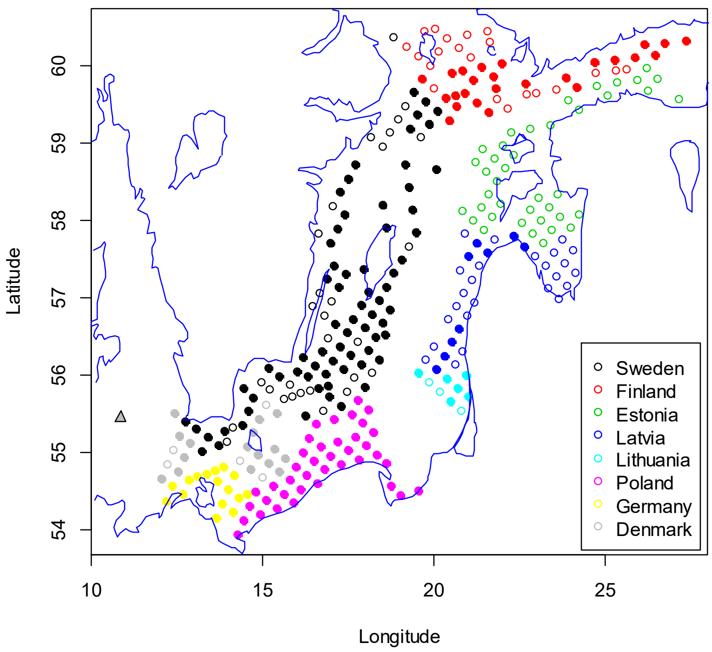
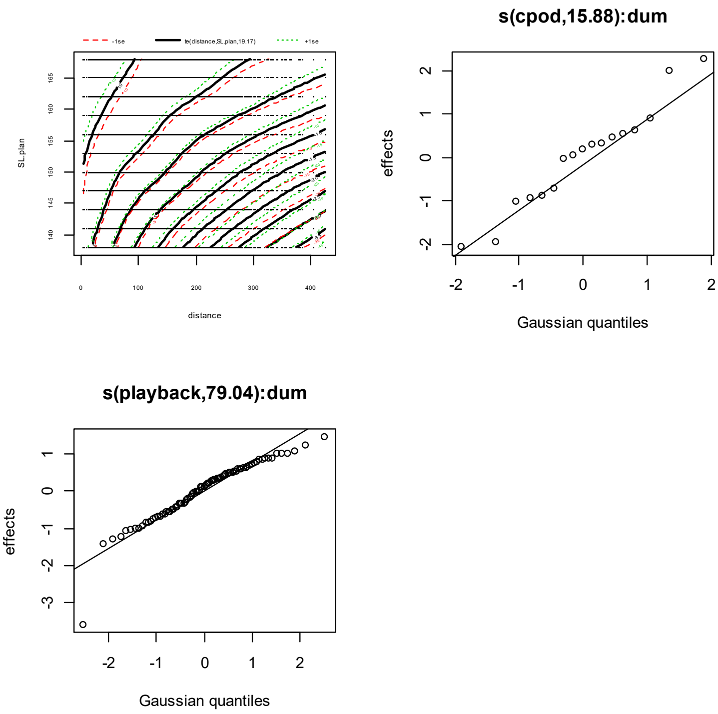


Figure 2 Plots of the smooth functions for each covariate included in the selected modesl for a) Kerteminde and b) SAMBAH playback experiments. Tick marks along the x-axis indicate the range of values observed for the covariate. The y-axis is on a logit scale.

a) Kerteminde



b) SAMBAH

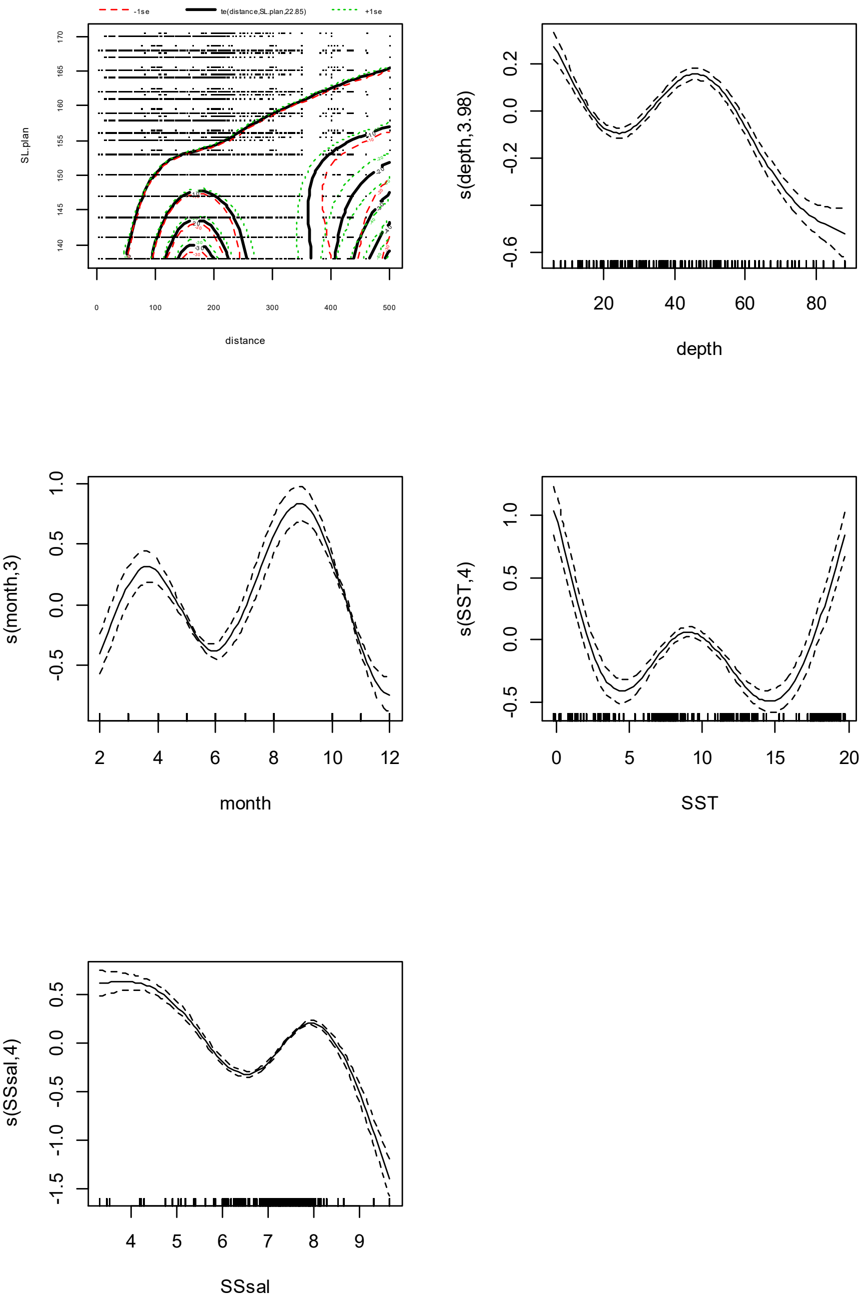

-1se
te(distance,SL.plan,22.85)
+1se
SL.plan
distance
s(depth,3.98)
depth
s(month,3)
month
s(SST,4)
SST
s(SSsal,4)
SSsal

Figure 3 Plot of observed proportion of clicks detected (open circles) and predicted detection functions (lines) for each country: the circles show the observed proportions of clicks detected for different distances and SLs; <150 dB (red), 150 – 160 dB (black) and >160 dB (green).The lines show the average detection function predicting for a SL of 158 dB averaged over all stations used in the playback experiments for each month when experiments were conducted (see Table 2). The black dots indicate the predicted values for each station used in the experiments. Countries are Sweden (1), Finland (2), Latvia (4), Lithuania (5), Poland (6), Germany (7) and Denmark (8).

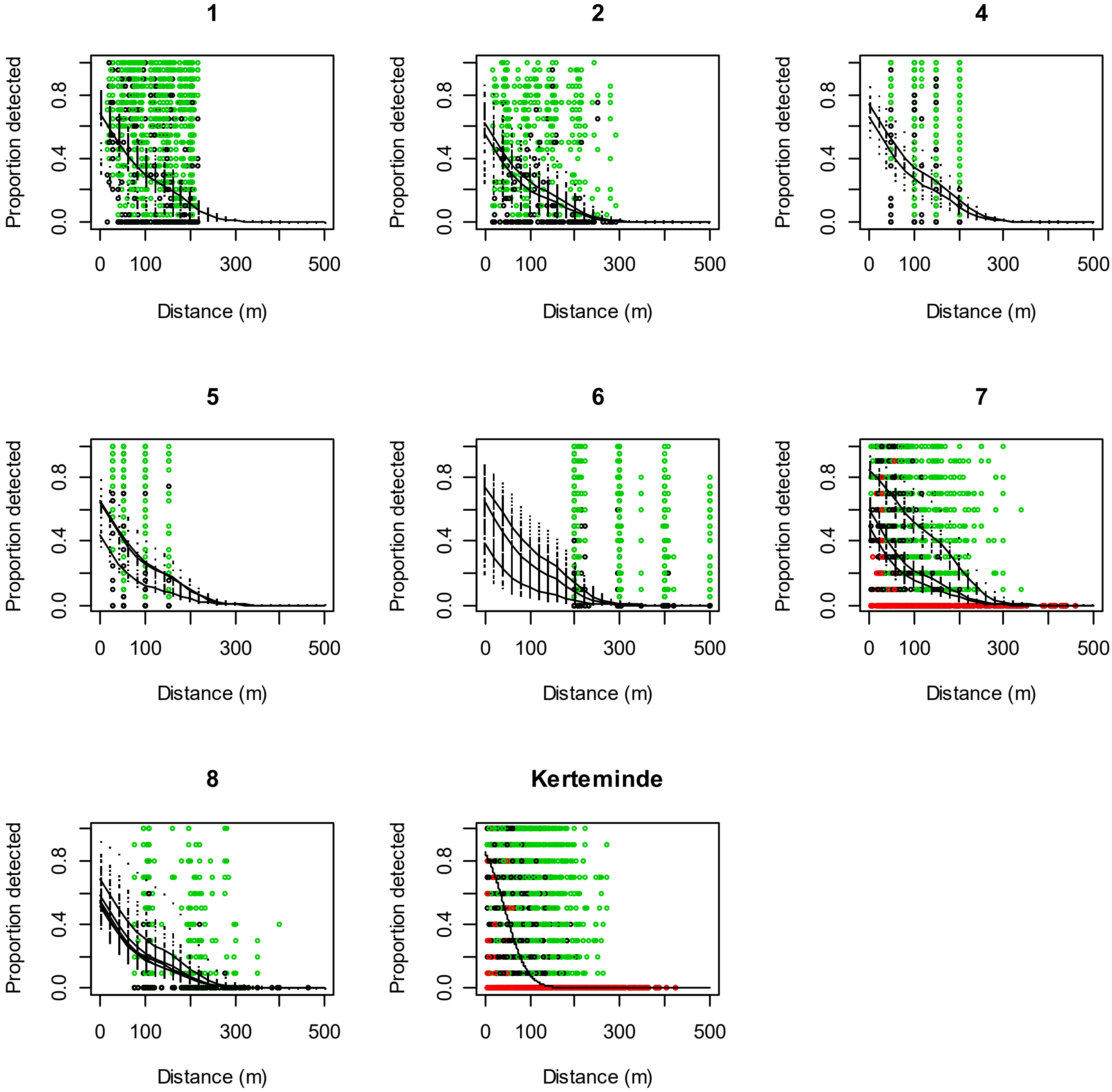
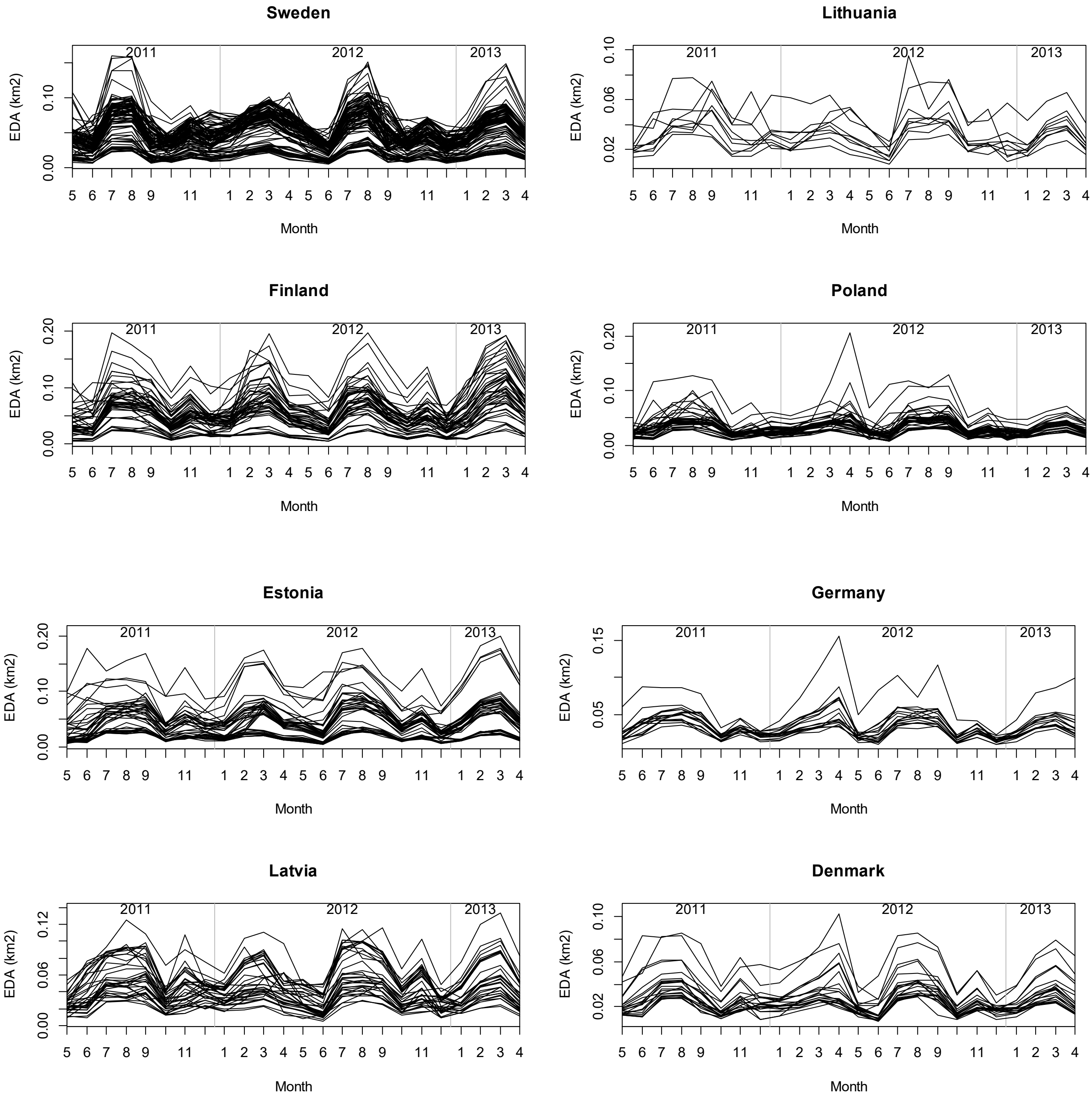


Figure 4 Time series of estimated EDA (km^2) for each station in the Baltic Sea by country. The vertical grey lines differentiate years.



SAMBAH Report 3a - Version 1.1
Further analysis of Kerteminde playback experiments

Len Thomas & Louise Burt, CREEM

April 5, 2015

1 Introduction

This document contains some further exploration of the Kerteminde playback experiment data. It was written for internal use by SAMBAH researchers. As with some of the other SAMBAH reports, it was written using `Knitr` package in `R version 3.1.3 (2015-03-09)`; it is therefore a "live" document in the sense that all values, tables and figures given are the direct output from `R` analyses performed as part of document compilation.

2 Exploratory analysis

The playback protocol was to anchor somewhere, play a recording that consisted of sets of 10 clicks at each of 11 increasing source levels, and then move farther away and repeat. Each set of 10 clicks times 11 source levels (i.e., 110 clicks) is called a playback. There were 85 sets of playbacks in total. This set up 10813 sets of 10 trials in total, over all source levels, distances and C-PODs (recall that the same click emitted set up a trial for all C-PODs in the podgarden). The largest distance for a successful detection was 271.84, and there were 847 sets of 10 trials at larger distances than this, all of which recorded no detections. A summary of the proportion of successes, by source level and distance is given in Figure 1.

3 Whole-dataset modelling

We fit some GAMs to the whole dataset (only a few of those tried are shown here). Results are shown in Table 1

	model	AIC
1	s(distance)+s(SL.plan)	26677.99
2	te(distance,SL.plan)	26174.25
3	s(distance)+s(SL.plan)+s(fcpod,bs='re',by=dum)+s(fplayback,bs='re',by=dum)	19750.94
4	te(distance,SL.plan)+s(fcpod,bs='re',by=dum)+s(fplayback,bs='re',by=dum)	19392.57

Table 1: Models fit to Kerteminde playback data

The best fitting model includes the random effects (which really should be included in any case, given the model set up) and a tensor product of source level and distance. A view of the model is given in Figure 2

In Figure 3 we use the fitted model to predict the EDA (EDA.pred) using the usual approach of setting the random effect to zero, and compare it with the EDA predicted from the original GAMS (that were fit separately

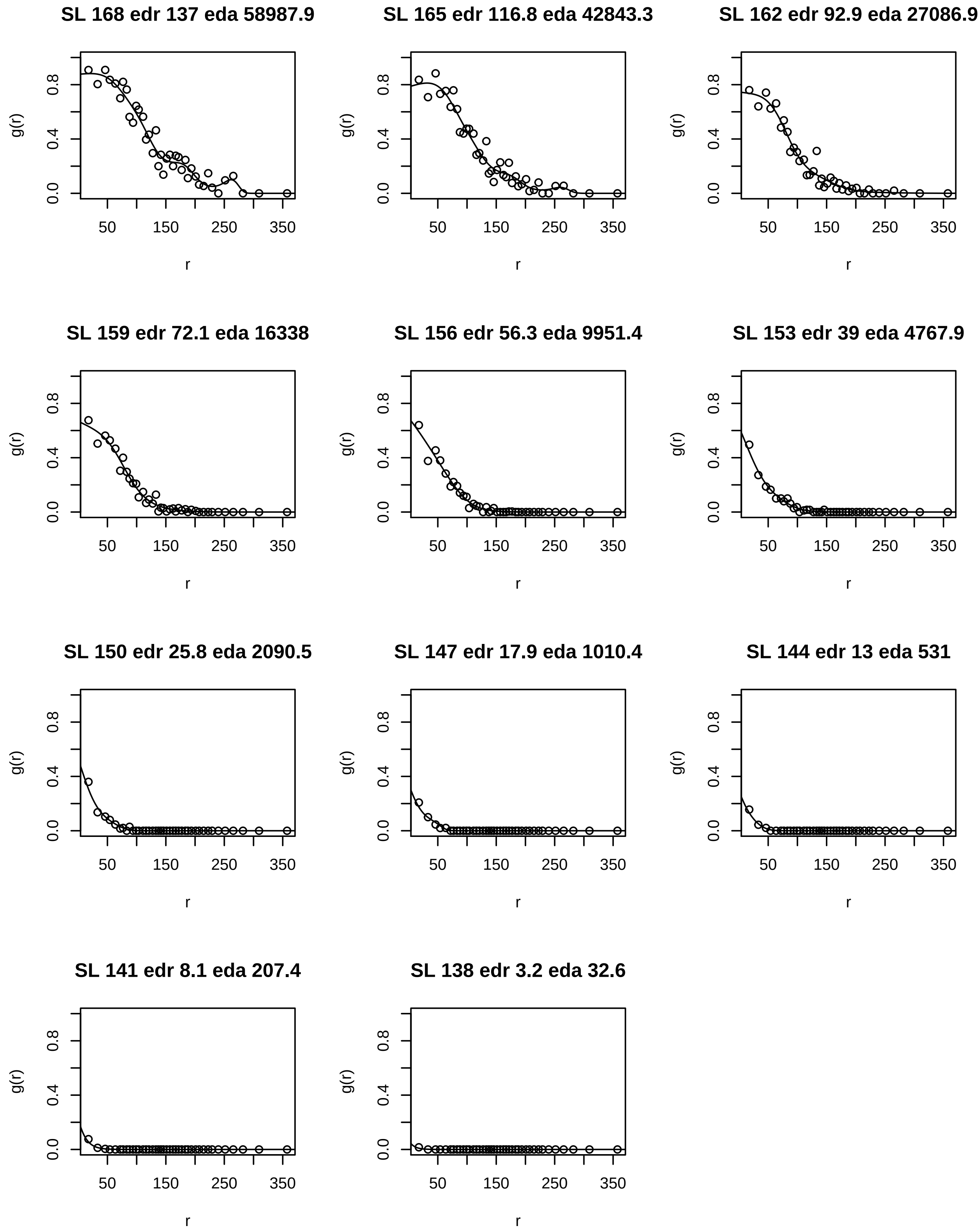


Figure 1: Proportion of successes in 40 bins (circles) plotted for each source level, with a binomial GAM fit separately to each soure level (line).

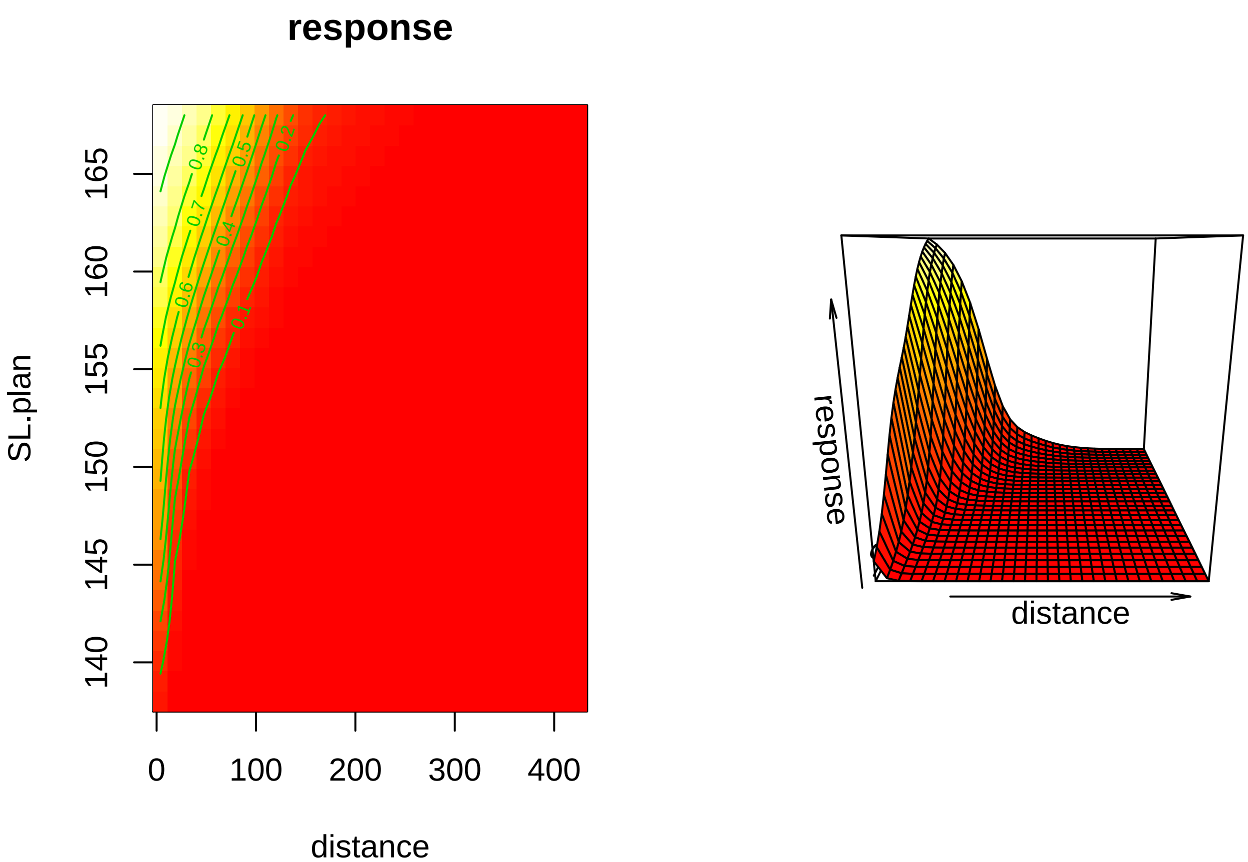


Figure 2: View of best fitting model to Kerteminde playback data.

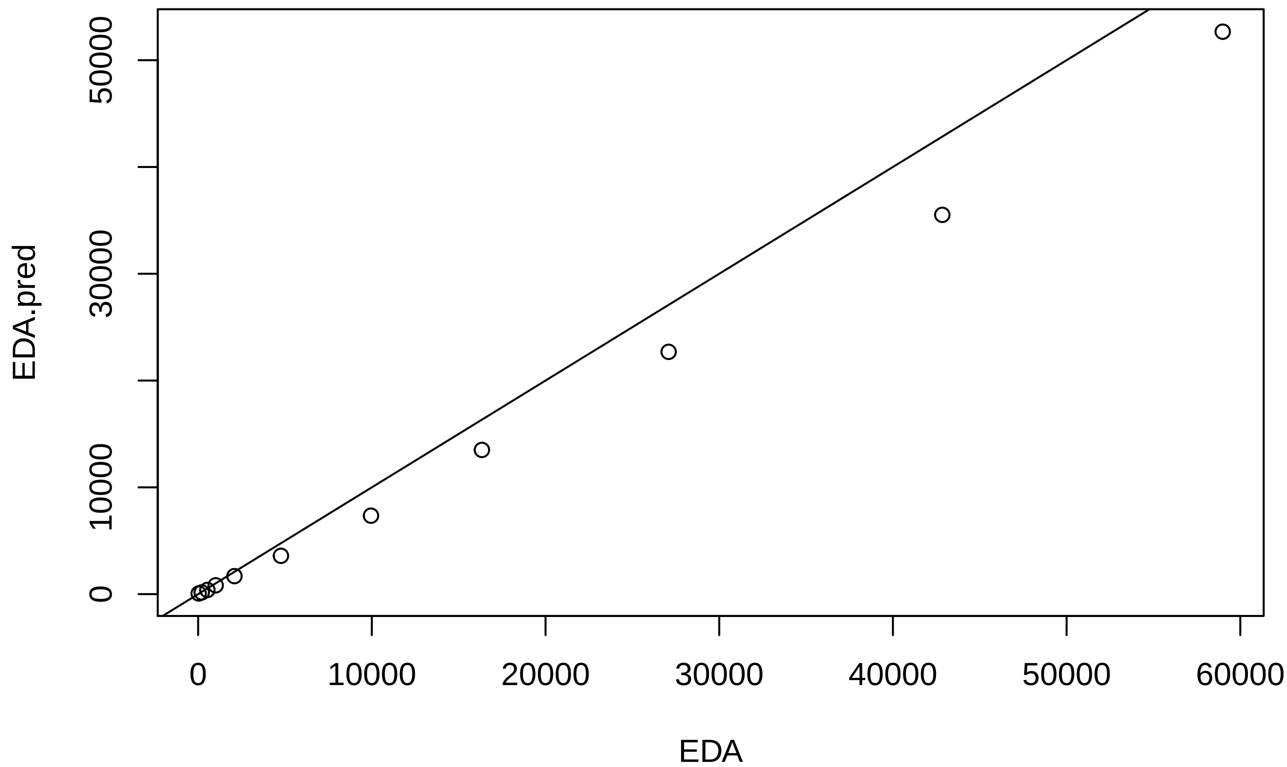


Figure 3: EDA predicted from best fitting model (y-axis) against that from the GAMS fit to each source level. Predictions set the random effects to zero. The 1:1 line is also shown.

to each source level). We find the new model under-predicts EDA at higher source levels. This explains an earlier observation of ours that using the model with random effects resulted in a smaller EDA.

One alternative approach, instead of setting the random effect to zero and the predicting on the response scale, is to predict on the scale of the link function, add random samples from the random effect (i.e., a normal distribution with the correct sd) to the predictions, back transform, and take the mean. (A possibly even better approach would be to sample uniformly along the quantiles of a normal distribution, and integrate out using these.) Results using the random integration approach (with 1000 samples) are shown in Figure 4 (using 1000 samples).

(Note, the random seed used for this was 89714.)

So, we can use this approach to obtain an EDA for the best fitting model. Which source level should we use? After some discussion, we decided to use the maximum available, 168.

Using 168 and the integration method, we obtain an estimated EDA of 62235 and EDR of 140.75. This is the EDA that will be used in producing the final density estimate, together with the bootstrap distribution derived below for variance estimation.

4 Variance estimation

We used a parametric bootstrap to produce a variance estimate, with each replicate of the parametric bootstrap integrating out the random effect. (Note - we constrained the prediction for distance to 400m as the smooth sometimes predicted wild values at 450m onwards – not surprising given the largest data point was 425m.)

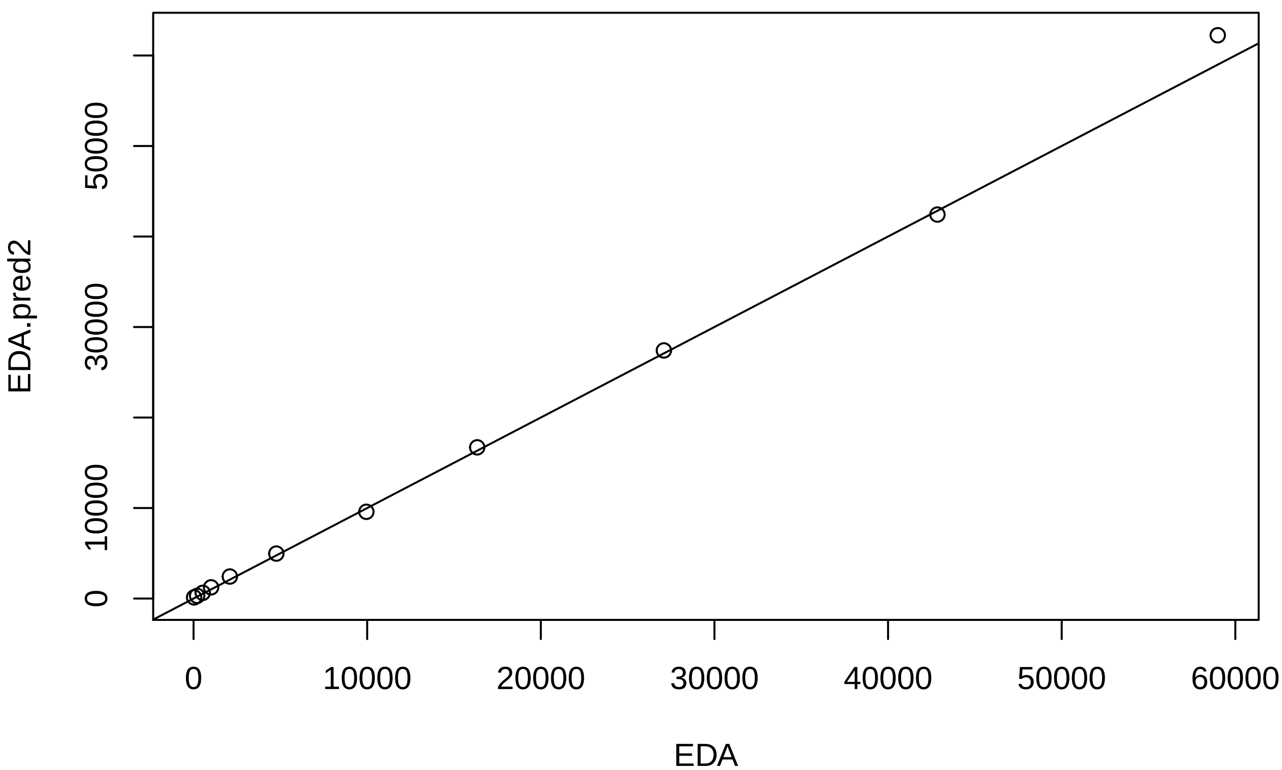


Figure 4: EDA predicted from best fitting model (y-axis) against that from the GAMS fit to each source level. Predictions integrate out the random effect on the scale of the link function. The 1:1 line is also shown.

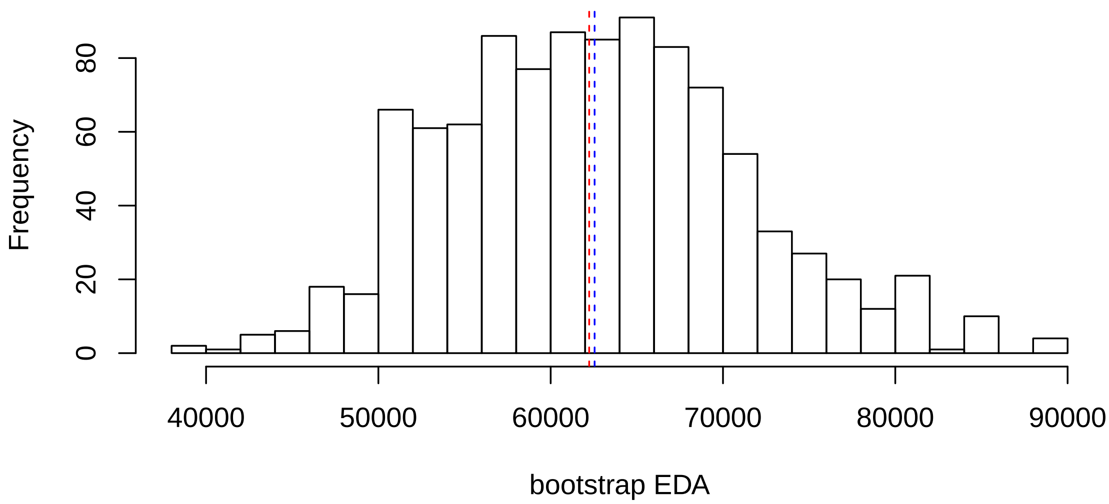


Figure 5: Histogram of bootstrap estimates of effective detection area. The bootstrap mean, and the mean from the original data are shown as blue and red vertical lines, respectively.

We need to check that a truncation at w =400 is far enough that we don't miss any significant mass during the integration, so we tracked the value of $g(w)$ - the maximum was 0.014102.

The resulting bootstrap EDAs look quite reasonable – see Figure 5. The bootstrap mean is 62550.26 (compared to the original mean of 62234.73), while the CV (bootstrap se/original mean) is 13.829% and a 95% percentile CI is (47560.95, 81141.49).

SAMBAH Report 3b - Version 1.1
Further analysis of SAMBAH playback experiments

Len Thomas & Louise Burt, CREEM

June 2, 2015

1 Introduction

This document contains some further exploration of the main SAMBAH playback experiment data. It was written for internal use by SAMBAH researchers. As with some of the other SAMBAH reports, it was written using `Knitr` package in `R version 3.1.3 (2015-03-09)`; it is therefore a "live" document in the sense that all values, tables and figures given are the direct output from `R` analyses performed as part of document compilation, except for the bootstrap analysis, which is cached because it takes a long time to run (see Section 4).

2 Exploratory analysis

	country	name	positions	playback.stations	prop.playback.stations	playbacks	n.playbacks.per.station
1	1	Sweden	99	70	0.71	70	1.00
2	2	Finland	46	25	0.54	25	1.00
3	3	Estonia	40	0	0.00	0	
4	4	Latvia	34	9	0.26	12	1.33
5	5	Lithuania	9	6	0.67	10	1.67
6	6	Poland	39	39	1.00	68	1.74
7	7	Germany	16	16	1.00	32	2.00
8	8	Denmark	21	16	0.76	36	2.25

Table 1: Summary of number of stations at which playbacks were performed, and number of playbacks performed at each station for which playbacks were done.

There were a total of 253 playback experiments, at 181 station – see Tables 1 and 2. Only Germany has a perfect record of all stations with playbacks, and 2 playbacks per station (which was our original plan). Note that more playbacks were actually performed by the SAMBAH field teams, but due to equipment damage (a damaged transponder), these additional playbacks coulnt not be used in the analyses reported here.

One potential issue is that many countries did not appear to do playbacks at many distances - see Table 3. Another is that some countries did not have a very good distribution of distances for playbacks – see Table 4 – for example, for Poland and Denmark, the average closest (i.e., minimum) playback distance was well over 150m - a distance at which it's unlikely there'd be many positive detections at the median source level used (see Table 5).

	month	playbacks
1	1	0
2	2	8
3	3	15
4	4	27
5	5	89
6	6	25
7	7	2
8	8	48
9	9	0
10	10	17
11	11	21
12	12	1

Table 2: Summary of number of playbacks per month.

This means that we may not be able to model the detection function shape close to 0 distance well; it also means that we many not want to use the median playback source level as the reference level – rather something higher. Indeed we may even want to discard some of the lower source level playbacks, since they will convey no information about the shape of the detection function.

	country	name	min.n.distances	median.n.distances	max.n.distances
1	1	Sweden	1	3.5	8
2	2	Finland	2	4.0	7
3	3	Estonia			
4	4	Latvia	2	3.0	4
5	5	Lithuania	2	3.0	4
6	6	Poland	3	4.0	4
7	7	Germany	4	7.0	8
8	8	Denmark	1	3.0	15

Table 3: Summary of number of distances per playback.

	country	name	mean.min.dist	mean.median.dist	mean.max.dist
1	1	Sweden	68.84	133.44	190.54
2	2	Finland	51.04	137.45	226.63
3	3	Estonia			
4	4	Latvia	70.83	123.54	170.83
5	5	Lithuania	45.10	80.00	125.00
6	6	Poland	201.46	351.32	500.00
7	7	Germany	41.39	173.73	357.90
8	8	Denmark	176.16	211.32	250.36

Table 4: Summary of mean of min, median and max distance per playback experiment.

The largest playback distance at which a click was detected was 200, at source level 170.

3 Detection function model fitting

We tried a variety of models (some of which are in the code underlying this document), but our final model was this:

	country	name	mean.min.SL	mean.median.SL	mean.max.SL
1	1	Sweden	155.00	162.50	170.00
2	2	Finland	155.00	162.50	170.00
3	3	Estonia			
4	4	Latvia	155.00	162.50	170.00
5	5	Lithuania	155.00	162.50	170.00
6	6	Poland	154.32	161.82	169.32
7	7	Germany	138.00	153.00	168.00
8	8	Denmark	154.83	162.33	169.83

Table 5: Summary of mean of min, median and max of the planned (as opposed to measured, calibrated) source level per playback experiment.

```
mod<-gam(cbind(n.detected,n.not.detected)~te(distance,SL.plan)+geo+s(depth,k=5)+
  s(month,k=5,bs="cc")+s(SST,k=5)+s(SSsal,k=5),data=dat,family=binomial(link=logit),
  knots=list(month=c(1,12)))
```

We applied this model to the playback data and environmental covariates, but we first trimmed the top 1% of SSsal values (Sea Surface salinity), setting them to be equal to the highest 99th quantile. This is because the value was quite an outlier, and this was affecting the fit.[1] Also, there were very few records of `geo` type 7, so we binned it with type 6.

Model output is given below[2], and the fitted smooths are shown in Figures 1 and 2.

```
##
## Family: binomial
## Link function: logit
##
## Formula:
## cbind(n.detected, n.not.detected) ~ te(distance, SL.plan) + geo +
##     s(depth, k = 5) + s(month, k = 5, bs = "cc") + s(SST, k = 5) +
##     s(SSsal, k = 5)
##
## Parametric coefficients:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept) -5.78083    0.79190   -7.30 2.88e-13 ***
## geo2         0.43557    0.02184   19.94  < 2e-16 ***
## geo3         0.99549    0.02923   34.06  < 2e-16 ***
## geo4         1.11058    0.02544   43.66  < 2e-16 ***
## geo6         1.00065    0.03836   26.08  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                         edf Ref.df  Chi.sq p-value
## te(distance,SL.plan) 23.721  23.93 29563.4  <2e-16 ***
## s(depth)              3.986   4.00   433.8  <2e-16 ***
## s(month)              2.993   3.00   522.3  <2e-16 ***
## s(SST)                3.998   4.00  1579.1  <2e-16 ***
## s(SSsal)              3.992   4.00  1340.9  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
```

[1] We should go back and put more details here.
[2] An interpretation of the geo levels would be in order at some point; also some model diagnostics.

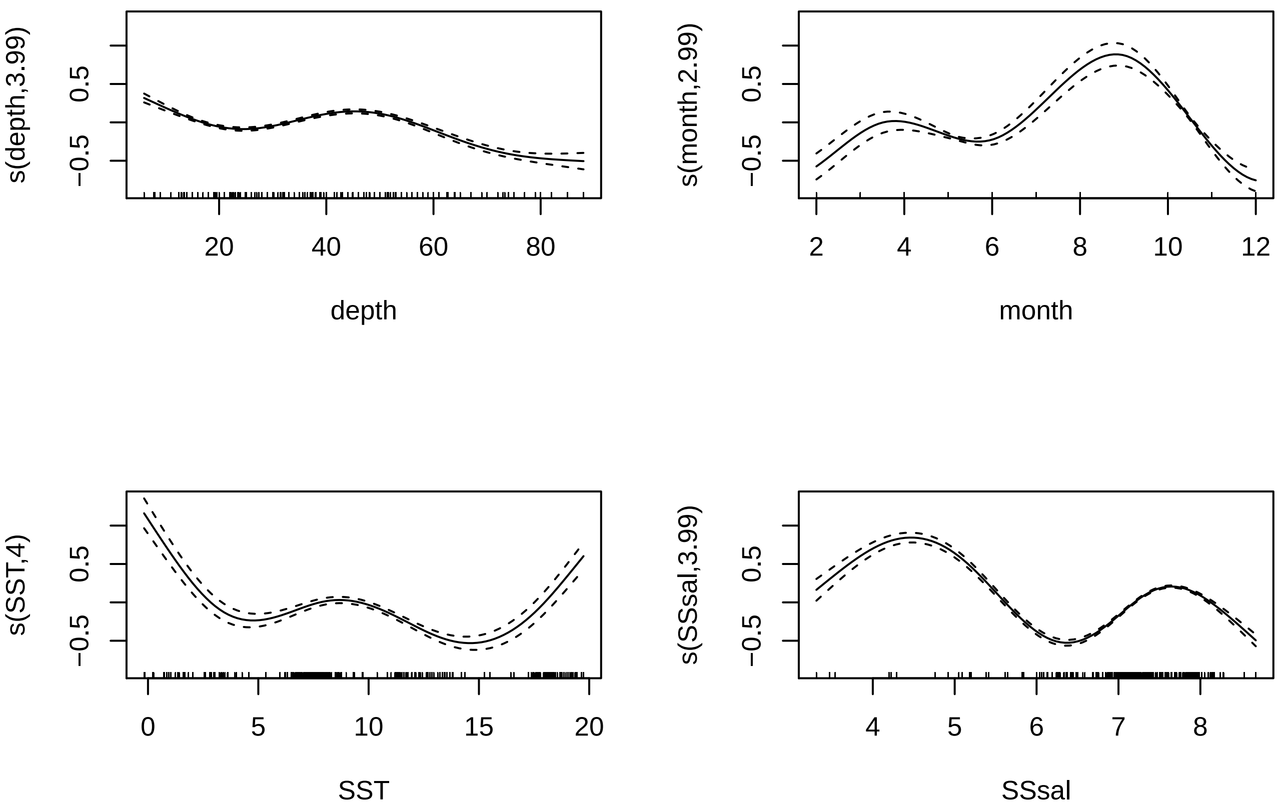


Figure 1: SAMBAH playback data fitted smooths, on the scale of the link function. The 2-d smooth of distance and SL is shown in the next figure.

```
## R-sq.(adj) =  0.565   Deviance explained = 54.9%
## UBRE = 3.9027  Scale est. = 1         n = 14443
```

4 Prediction

We wish to predict effective detection area (ν) for each month and location in the SAMBAH data. To do this, we need to choose a source level. As we showed in Section 2, since many of the playbacks started rather far from the CPODs, a high source level should be used. After some preliminary exploration, we elected to use 168dB, which is the highest level used in the Kerteminde playback experiments (recall that the outputs of this analysis, and the outputs of the Kerteminde playback analysis, will be used together in the density estimation calculations, so it makes some sense for the two playback analyses to use the same source level for prediction).

Before making predictions, we also constrained all covariates so that they lie within the range of values for the stations where playbacks took place.

Note that we are predicting over all SAMBAH data, not just that used in the design-based estimation, because we wish to make predictions by month and station for the model-based analysis as well.

We integrated out to 1000 meters. To check this is far enough, we show in Figure 4 the detection function (and density) corresponding to the record with the biggest estimated Effective Detection Area[3] – we note that

[3] For info, we also show the smallest.

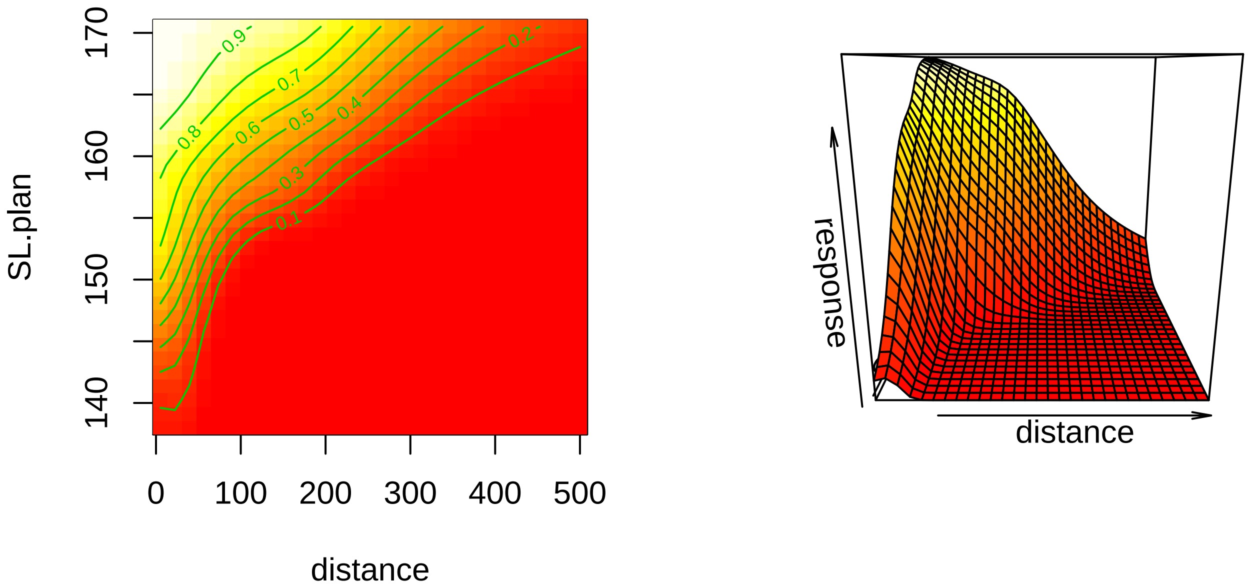


Figure 2: Two views of the SAMBAH playback data fitted 2-d smooth of distance and SL, on the response scale.

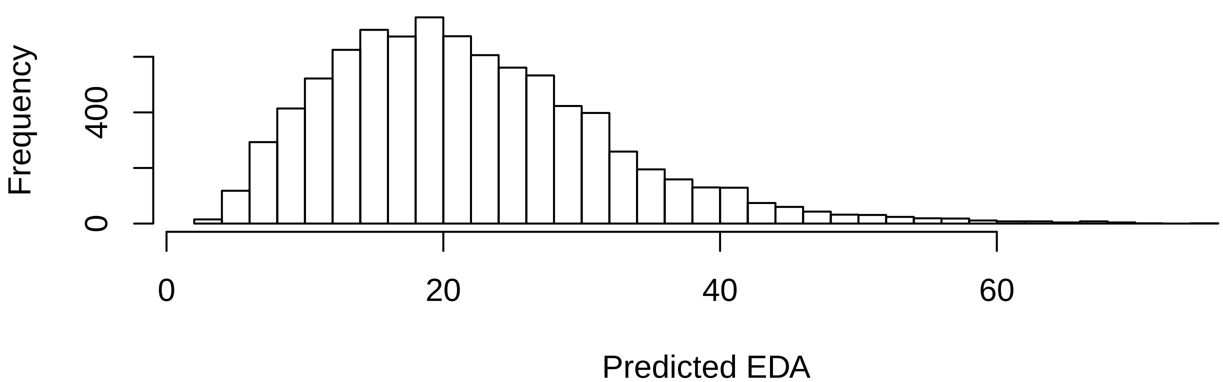


Figure 3: Histogram of predicted EDAs in hectares (i.e., 10,000 square meters).

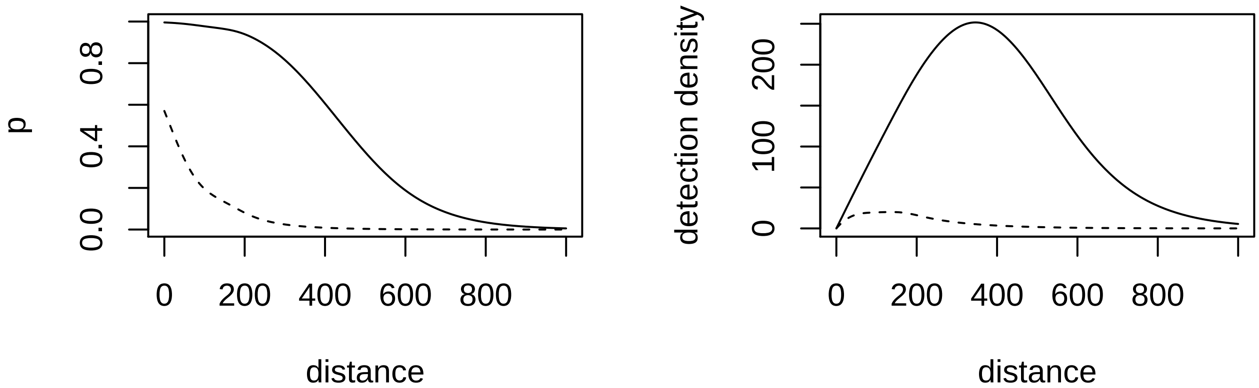


Figure 4: Detection function and distance density corresponding to the highest and lowest detectable combinations in the predicted data.

the detection probability of density are both very small at 1000 meters, so we do not miss any significant detection density farther out than this distance.

5 Variance estimation

Variance estimation is via a non-parametric bootstrap, with the sampling unit being a playback session (i.e., a set of playbacks at a station on the same date). These are referred to as "playback" in Table 1. We performed 1000 bootstrap resamples, and for each calculated the EDA for each prediction point; these were then saved into an `.RData` file for use in the density estimation routines.

Just for the record, the random seed used for resampling was 471739.

One thing to check is that the maximum distance used in the integration for the bootstrap analysis (which was 1200 meters) is far enough out so that the estimate of EDA is accurate. One way to check this is to track the estimated detection probability at this distance, which should be close to zero for all stations in all bootstrap replications. In practice, using an arbitrary value of $g(w) = 0.01$ as cause for concern, the percentage of stations with a value of $g(w)$ greater than this across all bootstraps was 0.18%. We conclude that the value of maximum distance used was big enough.

We summarize the results as follows. We began by taking the mean of the predictions for each bootstrap replicate. The mean of these means is 222491, compared with a mean of the original data predictions of 218769. The CV (i.e., sd(boot)/mean(original)) is 13.314%; 95% percentile confidence intervals are 175566, 291531.

Draft last updated 04/12/2014

SAMBAH Report 3c Version 1.0

Summary of the environmental covariates used to model playback experiments

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SUMMARY

This document summarises the environmental covariates considered for use in the modelling of the playback experiments to assess the performance of C-PODs (see SAMBAH Report 3). Experiments took place throughout the Baltic Sea from April 2011 to August 2013 and at Kerteminde, in Danish waters, in June 2013. Environmental conditions will affect the ability of the acoustic devices to detect sounds travelling through the water and so data on the conditions at the time of the experiments have been obtained. Monthly values of environmental conditions are also required for prediction. This report summarises the data measured for the Baltic Sea and at Kerteminde.

INTRODUCTION

For the SAMBAH project, passive acoustic detectors were deployed at 304 locations (stations) around the Baltic Sea (Figure 1) from April 2011 to July 2013, inclusive. Playback experiments were performed at deployment and recovery of some of these detectors. Since environmental conditions may affect the ability of the C-POD to detect sounds, data on conditions have been obtained to help model the patterns detected in the playback data. The following environmental variables have been provided for every station by the Swedish Meteorological and Hydrological Institute):

1. Water depth (m)
2. Bottom sediment type
3. Sea surface salinity (PSU)
4. Sea surface temperature (^{o}C)
5. Bottom salinity (PSU)
6. Bottom temperature (^{o}C)
7. Halocline depth (m)
8. Halocline gradient (PSU/m)
9. Pycnocline depth (m)
10. Pycnocline gradient ((kg/m^3)/m)
11. Thermocline depth (m)
12. Thermocline gradient (^{o}C/m)

The oceanographic variables were obtained from a grid with cell sizes of approximately 5km by 10km; depth was obtained from a grid with cells of size 500m by 500m. The temporal resolution of variables numbered 3 to 12 was monthly and monthly averages have been provided from April 2011 to July 2013, inclusive. Values were assigned to the playback data based on the location, month and year.

This document summarises the variables listed above and also considers the relationship between the variables. Explanatory variables included in the statistical models of playback should be independent of each other and so the relationships between the variables are examined. In addition, some playback experiments (at stations 6001-6039) were performed in August 2013 (outside the range for which the environmental data were available) and so values for August 2013 have been extrapolated.

METHODS

To avoid including two related variables into the playback model, the strength of the linear relationship between pairs of environmental covariates was examined using the correlation coefficient, r, and scatterplots. A strong relationship is defined to be one in which $|r| \geq 0.8$ and a moderate relationship is one in which $0.5 \leq |r| < 0.8$.

Values for August 2013 at stations 6001-6038 were obtained by calculating the average of August 2011 and August 2012 for each station. An alternative to this empirical method would be to fit a statistical model with month, station and country as possible explanatory variables but after some preliminary analysis such simple models were not satisfactory with some variables (i.e. bottom temperature).

RESULTS

Figure 2 shows the depth at each station. The depth was measured at each deployment of detectors (and recorded in the metadata) and the average depth recorded at each deployment was used as the station depth. (All depth values were used whether or not they were recorded as 'good' or not.) The depths ranged from 3m at station 7016 to 92m at station 3040.

Figure 3 shows the bottom sediment types. Nearly 33% of stations were classed as 'mud to sandy mud', with 26% classed as 'mixed sediment' and 22% as 'sand to muddy sand' (Table 1). Times series plots of variables numbered 3-12 are shown in Figures 4-13. Sea surface temperature exhibited the most regular seasonal pattern over all stations.

The correlation coefficients between all pairs of (non-factor) variables were calculated (Table 2). Sea surface salinity and bottom salinity were moderately correlated (r=0.76) as were surface and bottom temperature (r=0.65).

Values of zero in cline depths can occur for two reasons: the water is so mixed that the there is no cline (and this occurs primarily in shallow waters) or the oceanographic model cannot calculate the depth of the cline because the water depth is too shallow so the model does not have enough 'levels' to calculate the cline depth (I. Carlén pers.comm.). The correlation coefficients between pairs of variables are shown in Table 2. There were two pairs of variables that were strongly related; halocline depth with pycnocline depth and pycnocline depth and thermocline depth. All cline depths were moderately correlated with water depth.

Similarly, halocline gradient is moderately correlated with pycnocline gradient and the pycnocline gradient is moderately, negatively correlated with the thermocline gradient. Given that these cline variables are correlated with each other, and pycnocline is essentially a composite of the other two, then pycnocline variables will be considered as potential explanatory variables in the playback modelling process.

Predicted values for August 2013

Predicted values for the stations 6001-6039 are shown in Figure 15. The predictions look reasonable, except for sea bottom temperature where the range of the salinity values look to be decreasing over time (except for one station). Therefore, taking July 2013 values may be more representative of 2013 than average August values from 2011 and 2012.

Values for Kerteminde

The values of the environmental variables were obtained for Kerteminde at the time of the playback experiments, June 2013. These are given in Table 3.

DISCUSSION

Time series plots show the environmental conditions at all the stations from April 2011 to July 2013. These values will be used in the playback modelling and also for prediction (if the variable is selected in the playback modelling). Some variables are correlated and so this needs to be taken into account in the modelling process.

REFERENCES

SAMBAH Report 3 Estimating the effective detection area of C-PODs from playback experiments in the Baltic Sea and Kerteminde. ML Burt and L Thomas. Unpublished CREEM Report, University of St Andrews

Table 1 Number of stations in each sediment class by stations.

Value	Class	Stations								Total
		1000+	2000+	3000+	4000+	5000+	6000+	7000+	8000+	
1	Mud to sandy mud	23	13	27	11	1	9	3	12	99
2	Sand to muddy sand	2	0	3	13	6	24	12	7	67
3	Coarse-grained sediment	4	2	0	9	1	5	1	0	22
4	Mixed sediment	52	25	1	0	0	1	0	0	79
6	Till and boulders	14	1	9	1	1	0	0	2	28
7	Bedrock	4	5	0	0	0	0	0	0	9
Total		99	46	40	34	9	39	16	21	304

Table 2 Correlation coefficients between pairs of variables. Note that the table is symmetric. Bold typeface indicates that there is a moderate relationship between the variables and bold italic typeface indicates a strong relationship between variables.

Variables	Surface salinity	Surface temperature	Bottom salinity	Bottom temperature	Halocline depth	Halocline gradient	Pycnocline depth	Pycnocline gradient	Thermocline depth	Thermocline gradient
Water depth	0.03	-0.01	0.29	-0.28	**0.64**	-0.19	**0.57**	-0.21	**0.57**	0.12
Surface salinity		0.01	**0.76**	0.04	0.16	0.23	0.15	0.18	0.14	-0.03
Surface temperature			0.05	**0.65**	-0.04	-0.04	-0.20	-0.41	-0.19	**0.65**
Bottom salinity				-0.08	0.44	-0.20	0.35	-0.17	0.30	0.12
Bottom temperature					-0.26	0.09	-0.23	-0.01	-0.24	0.03
Halocline depth						-0.22	***0.85***	-0.18	**0.76**	0.15
Halocline gradient							-0.20	**0.77**	-0.18	-0.15
Pycnocline depth								-0.08	***0.85***	-0.03
Pycnocline gradient									-0.11	**-0.67**
Thermocline depth										-0.01

Table 3 Values of environmental conditions at Kerteminde, June 2013.

Variables	Value
Water depth	19.50
Surface salinity	13.23
Surface temperature	16.39
Bottom salinity	30.76
Bottom temperature	8.18
Halocline depth	12.00
Halocline gradient	-1.28

Pycnocline depth	12.00
Pycnocline gradient	-1.06
Thermocline depth	8.00
Thermocline gradient	0.49

Figure 1 Locations of stations. The numbers represent the station number (adding 1000, 2000 etc. according to colour).

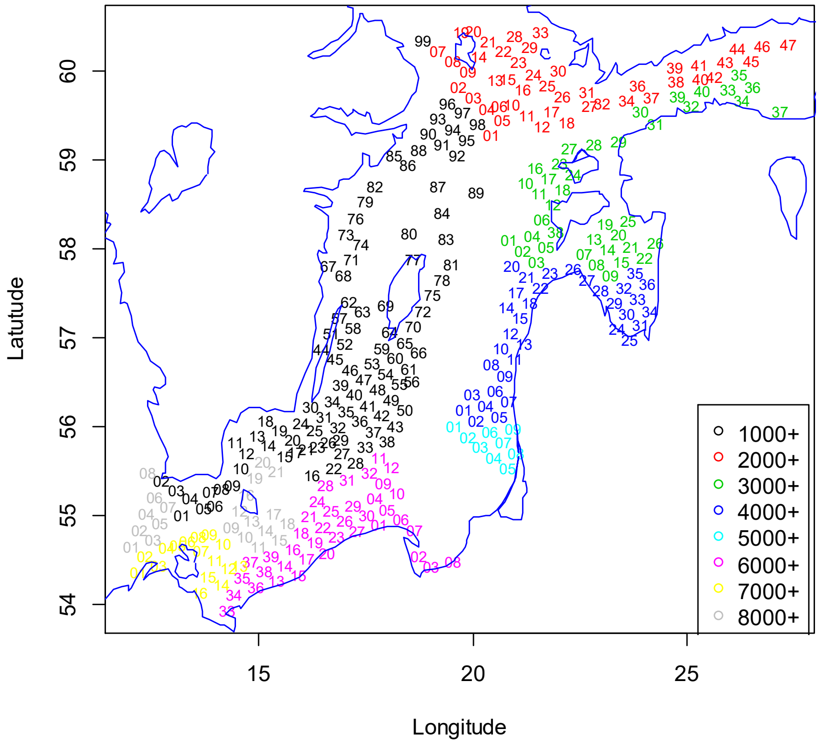
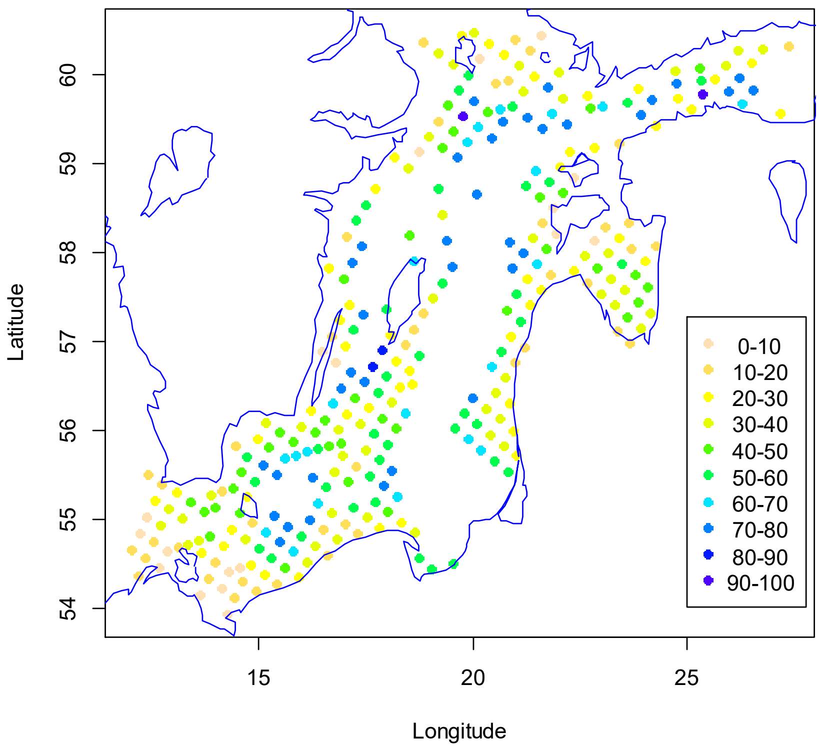


Figure 2 Water depth (m) at each station.



Latitude
54
55
56
57
58
59
60
15
20
25
Longitude
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100

Figure 3 Seabed sediment type at each station.

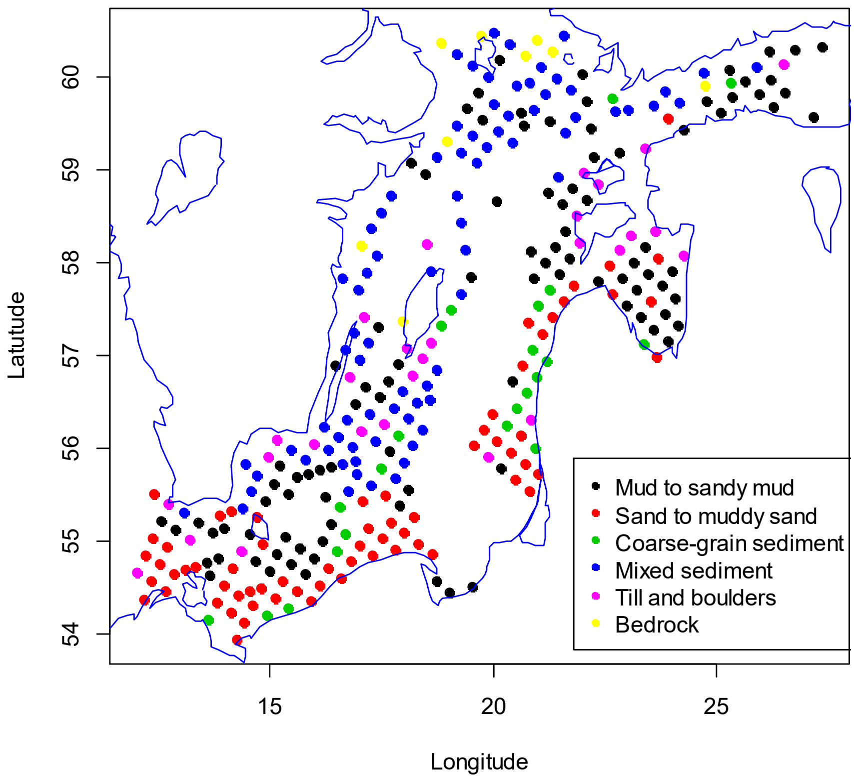


Figure 4 Sea surface salinity (PSU)

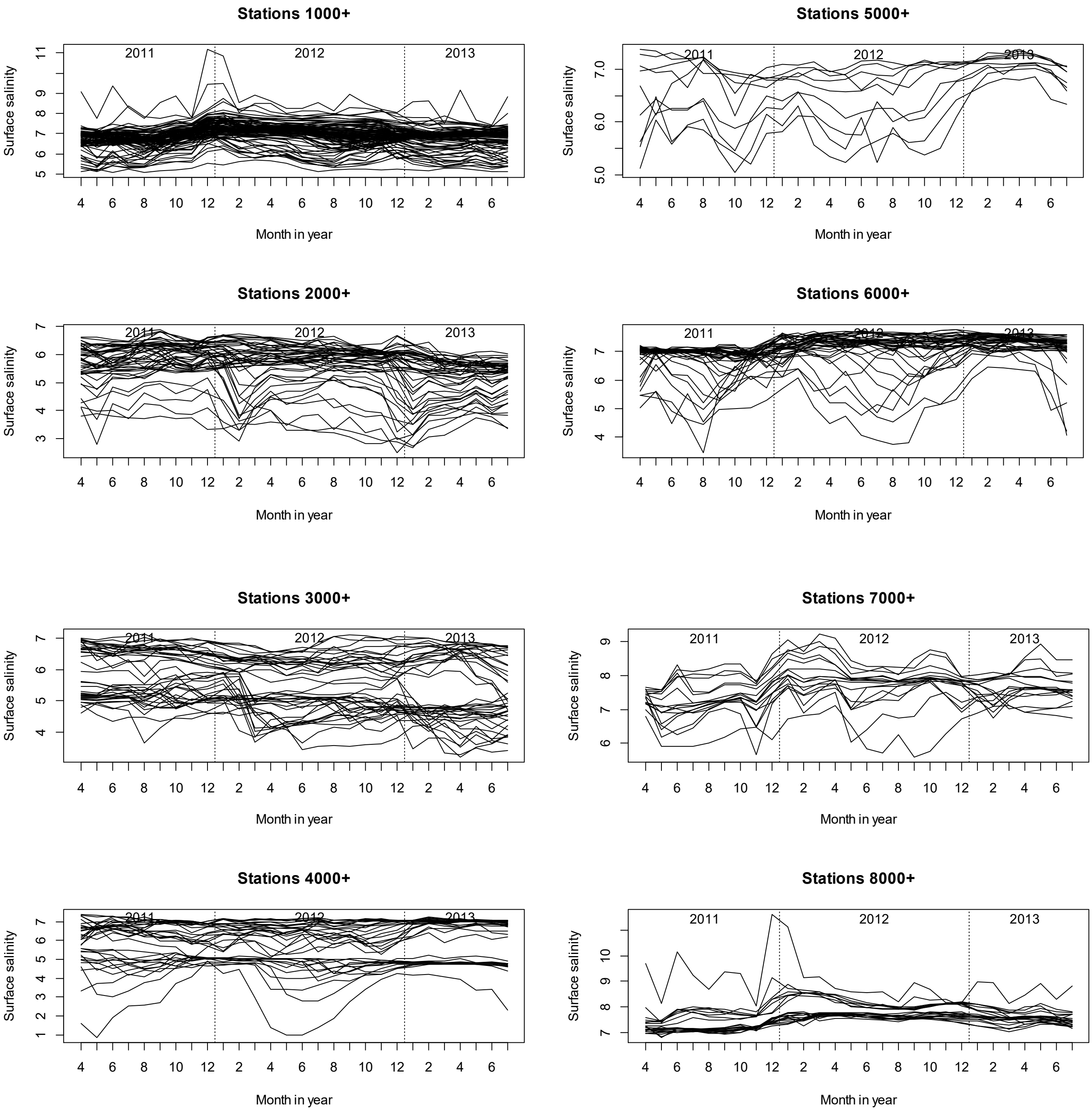


Figure 5 Sea surface temperature (^{o}C)

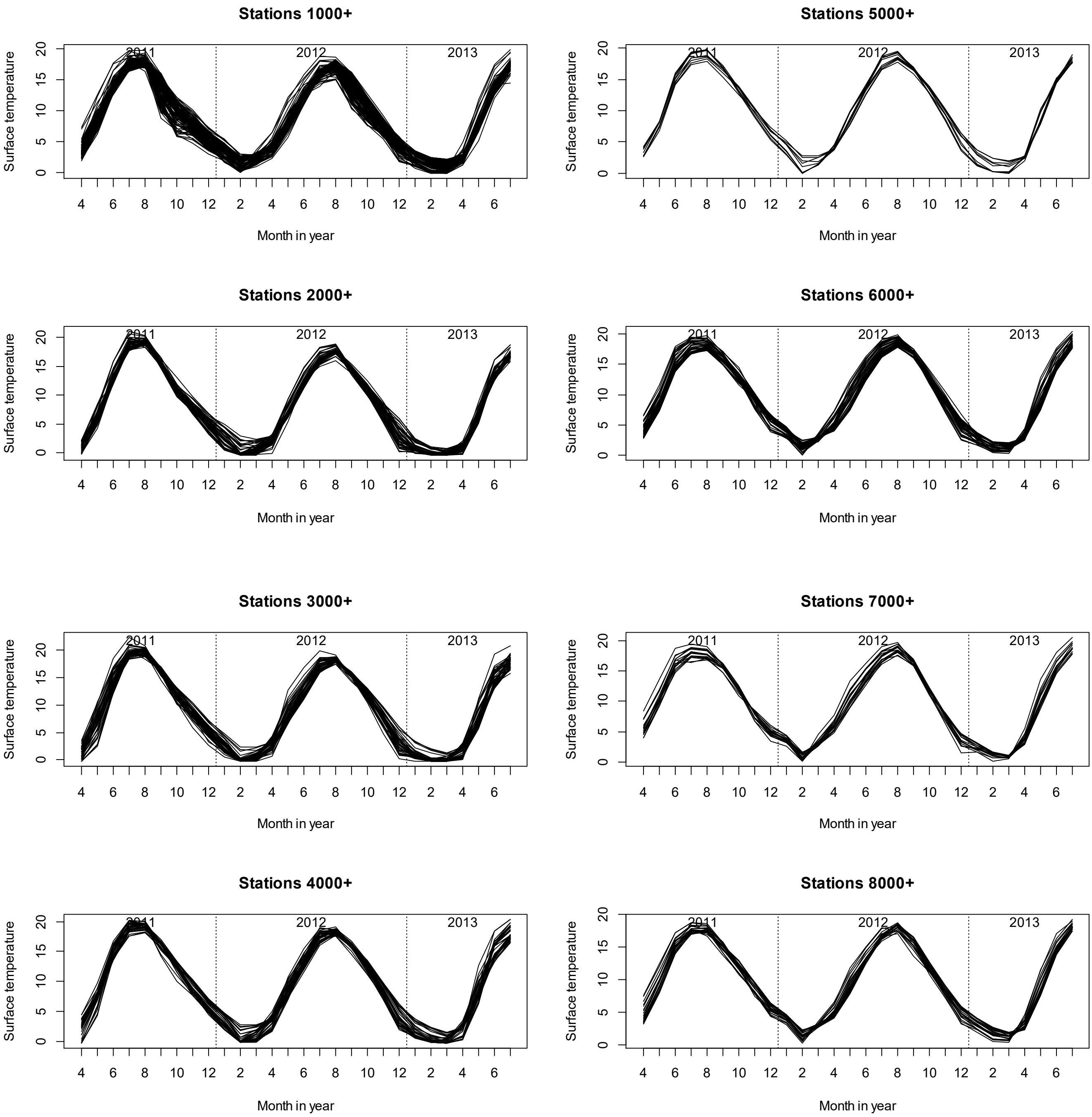


Figure 6 Sea bottom salinity (PSU)

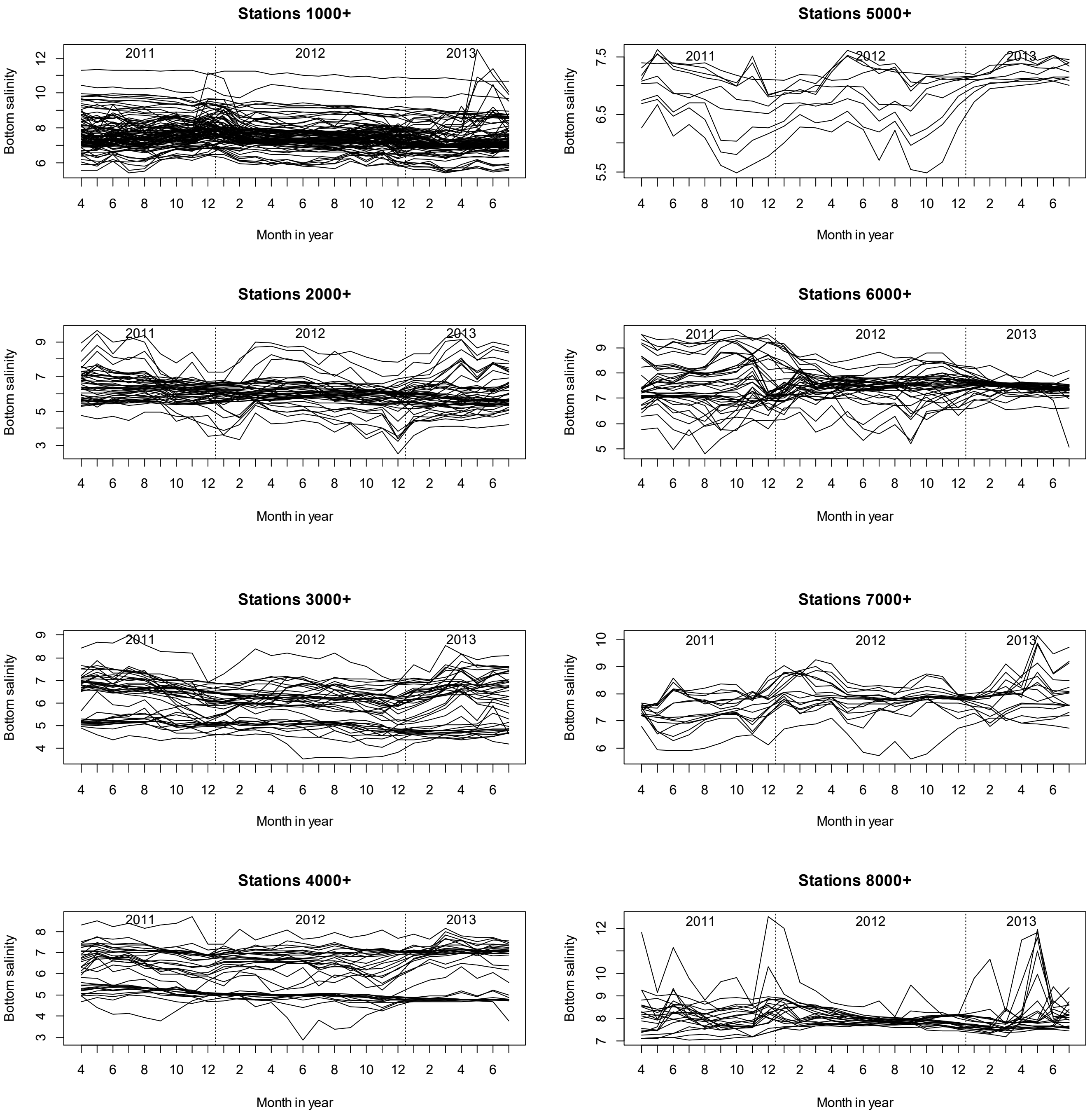


Figure 7 Sea bottom temperature (°C)

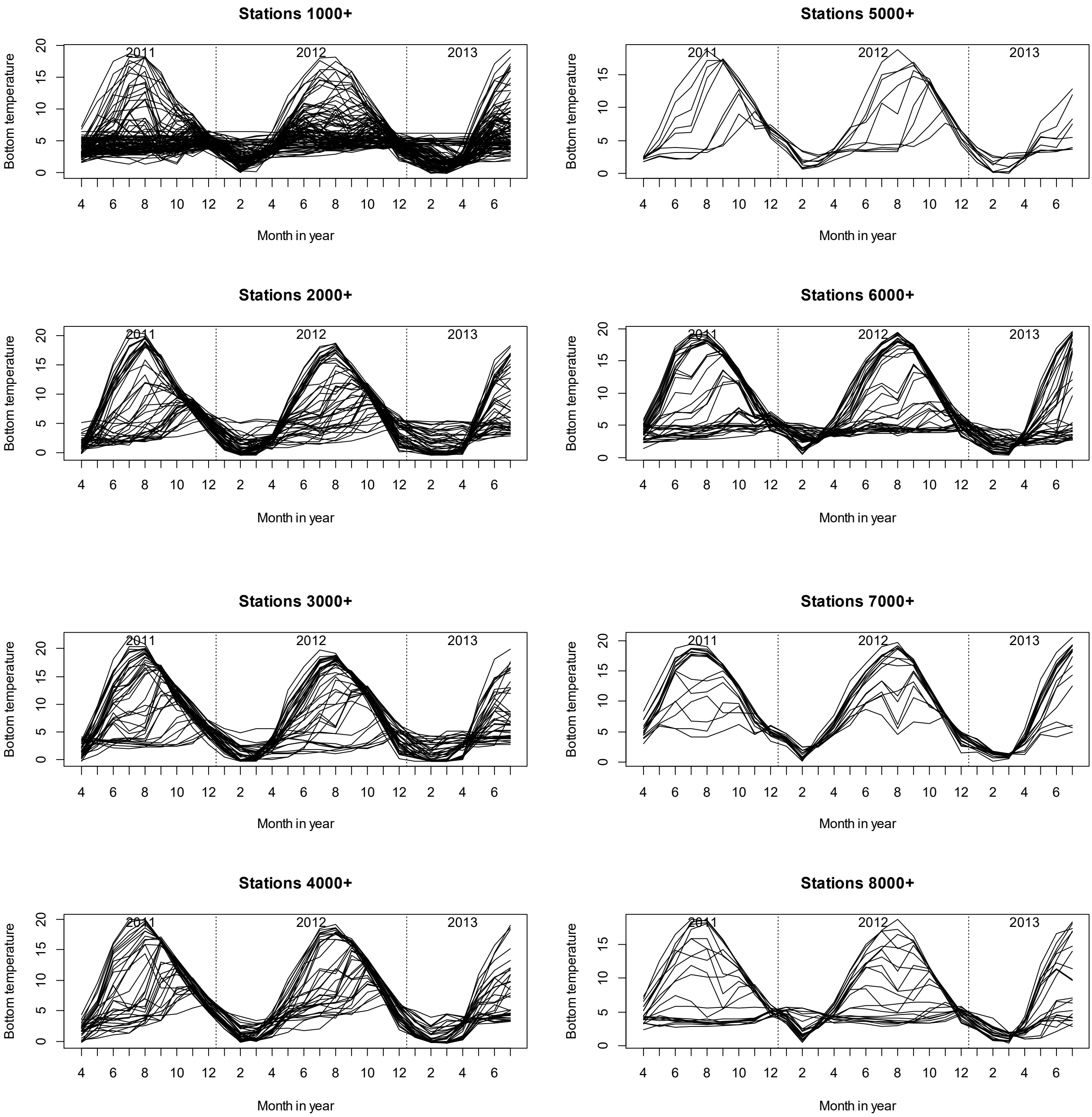


Figure 8 Halocline depth (m)

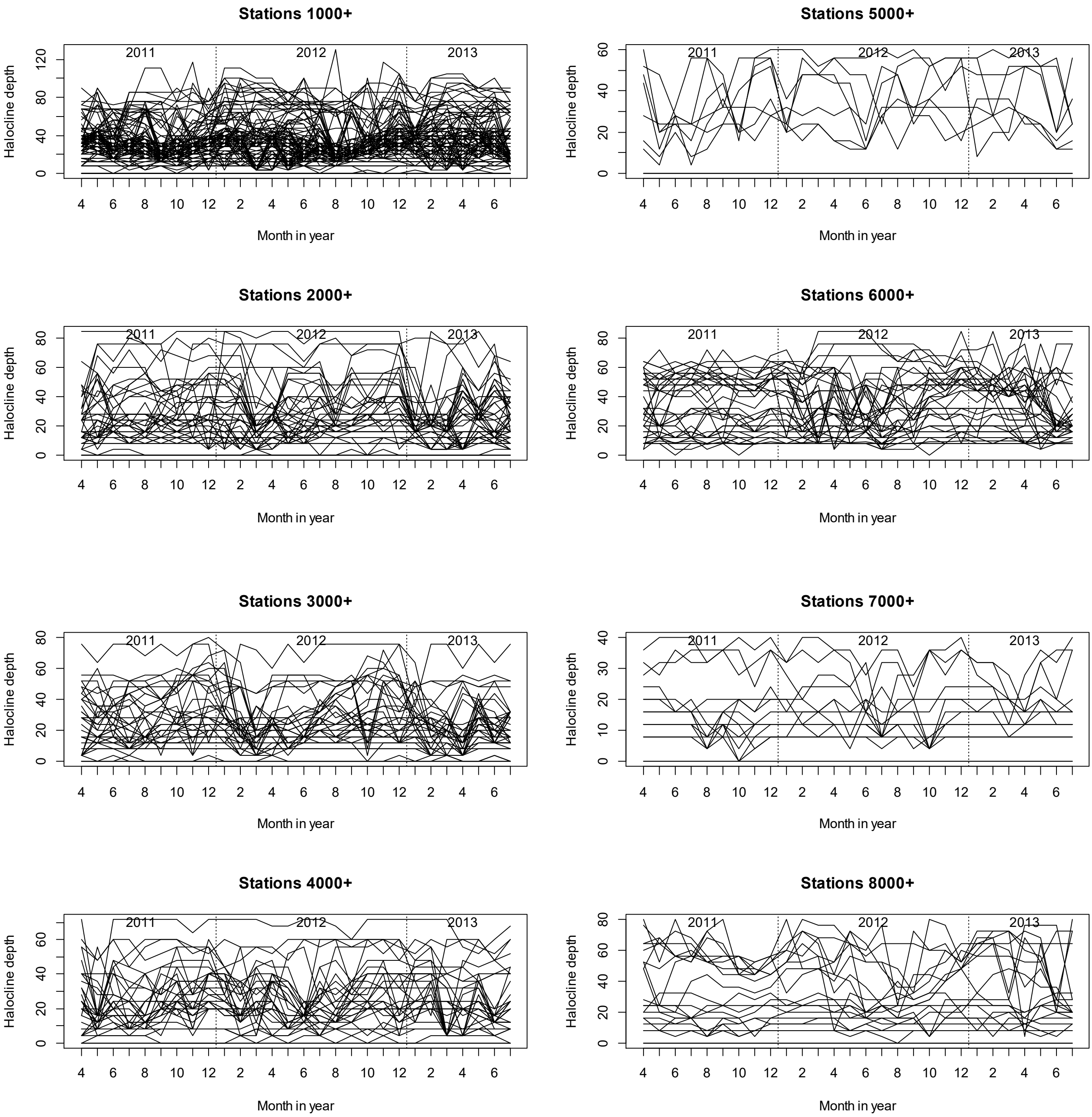


Figure 9 Halocline gradient (PSU/m)

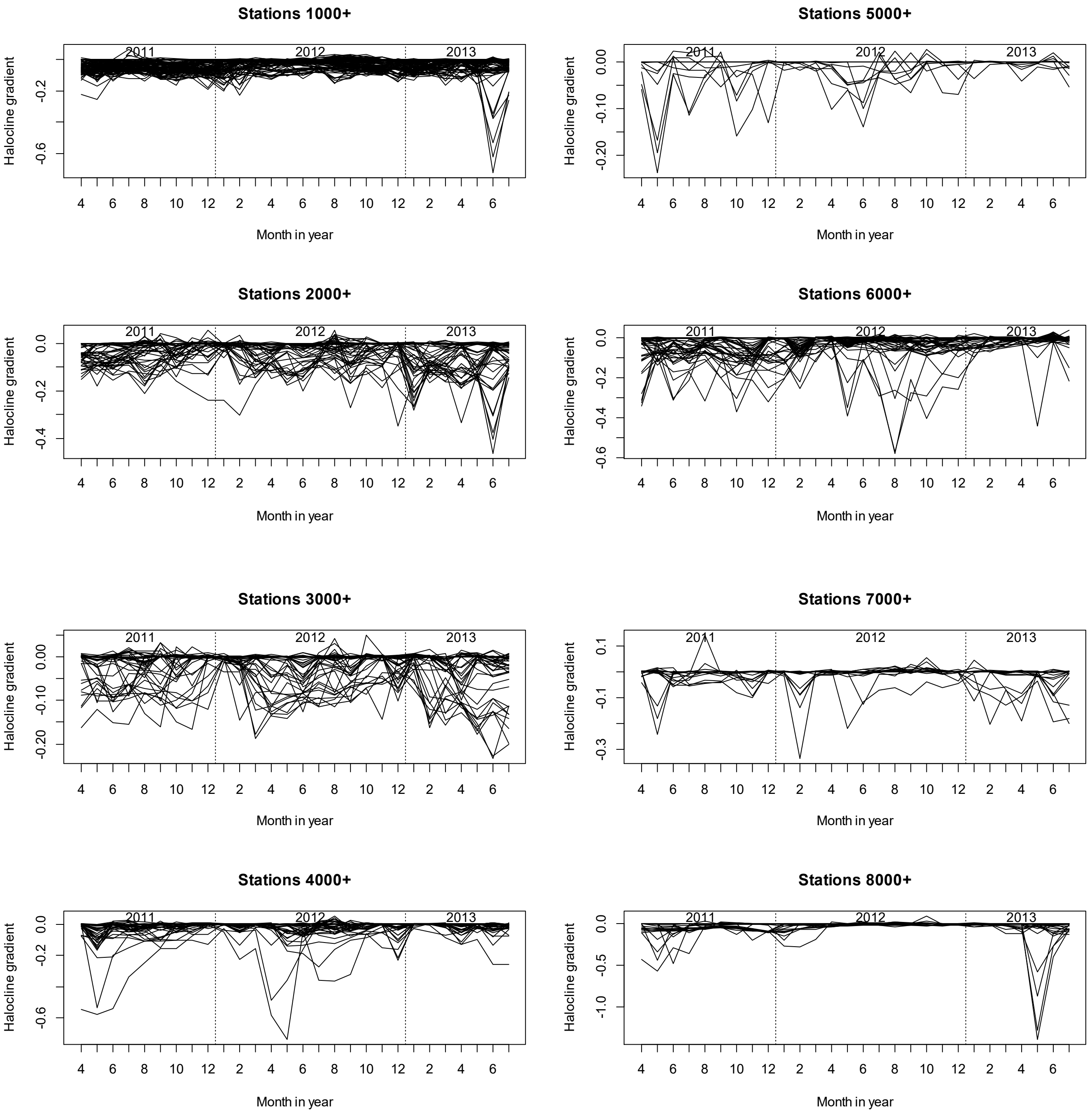


Figure 10 Pycnocline depth (m)

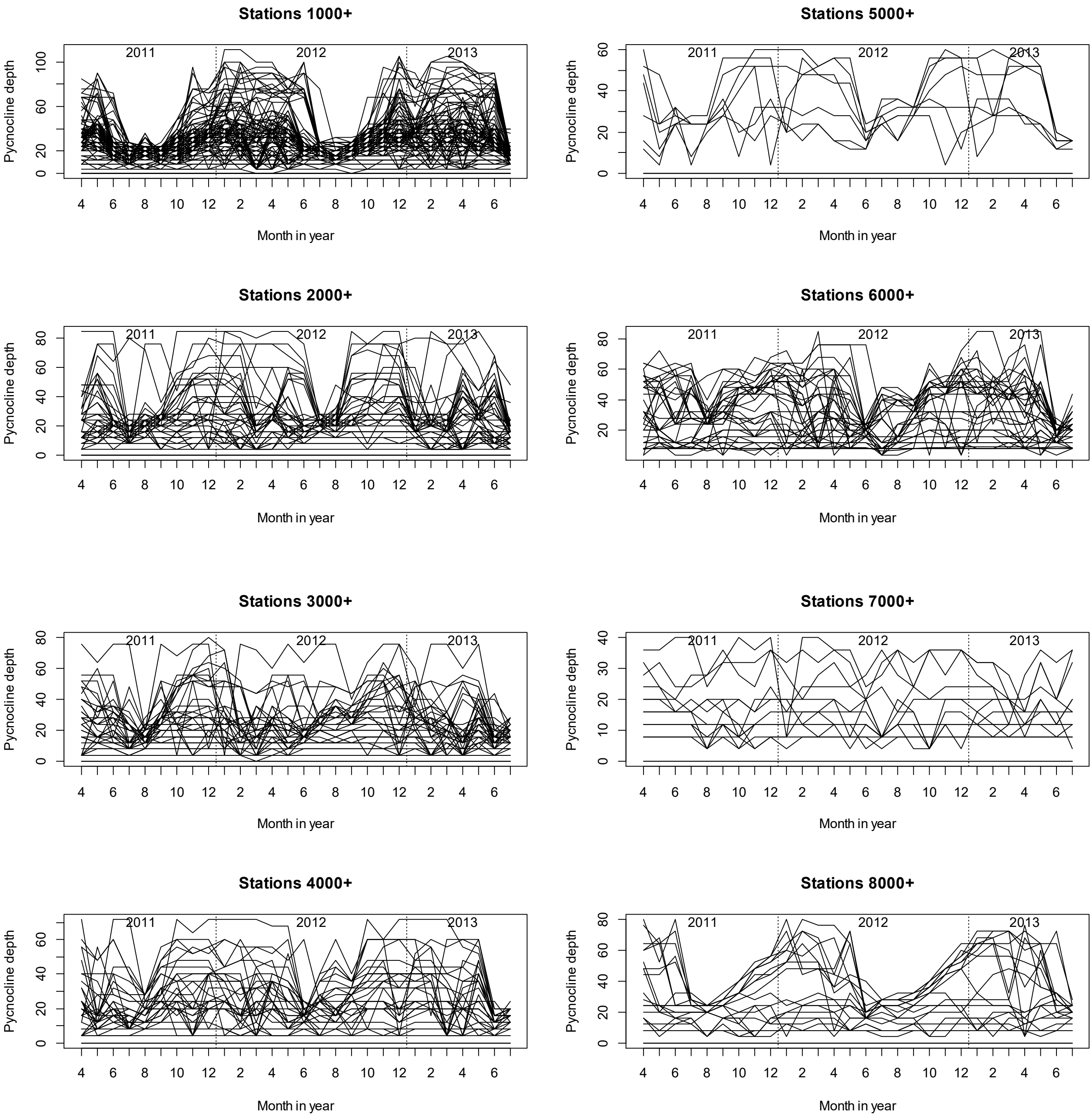


Figure 11 Pycnocline gradient ((kg/m^3)/m)

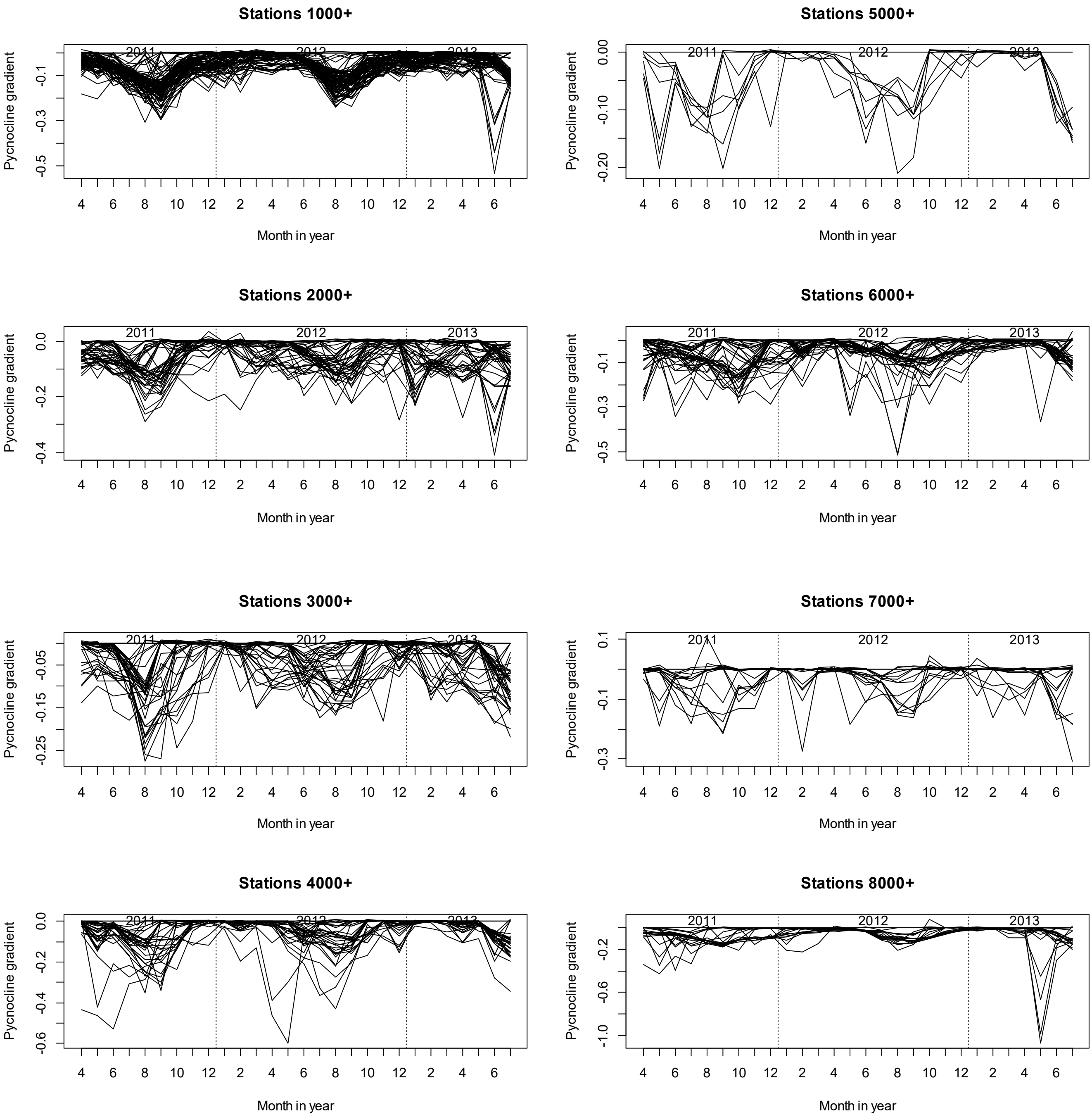


Figure 12 Thermocline depth (m)

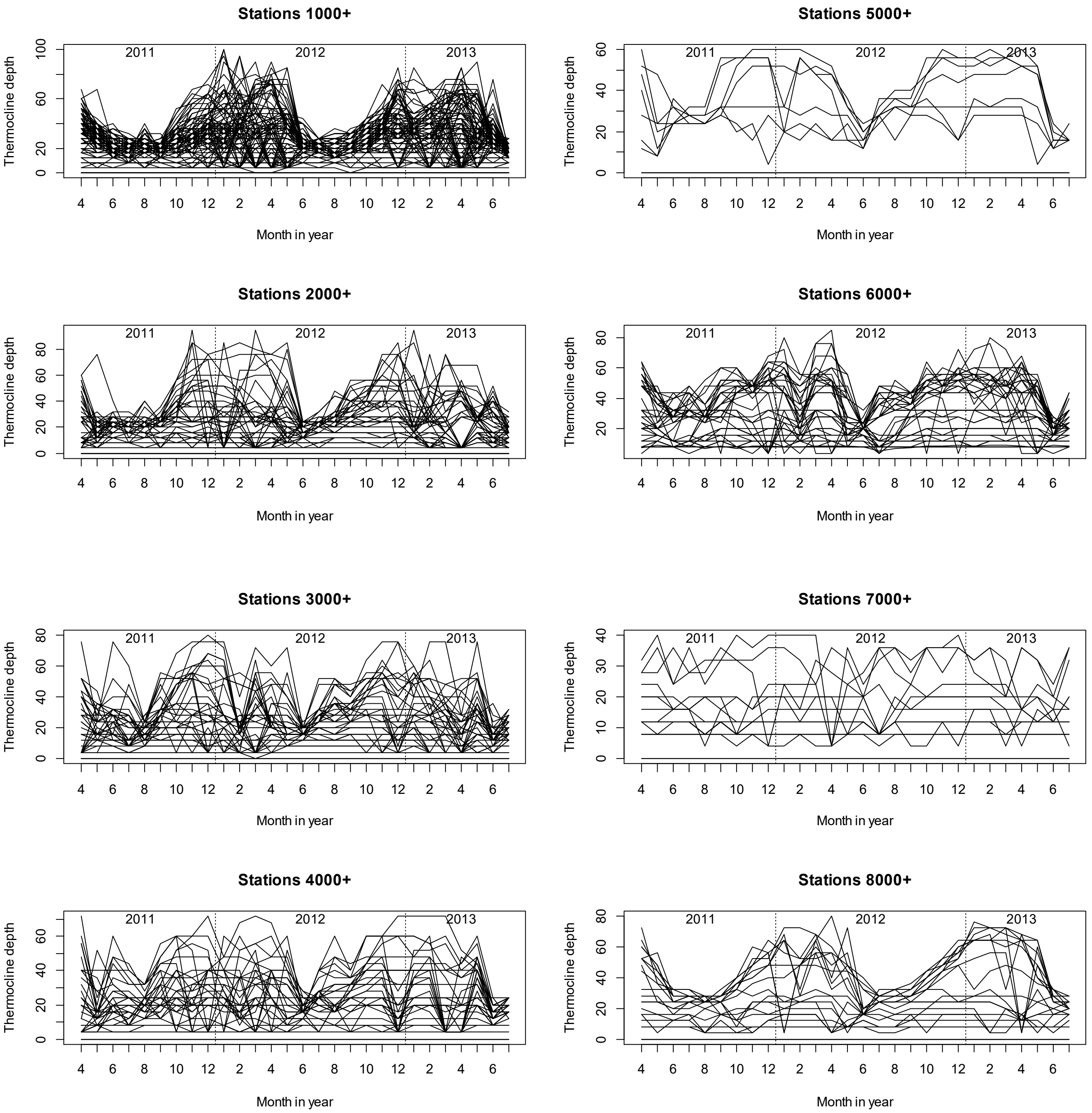


Figure 13 Thermocline gradient (°C/m)

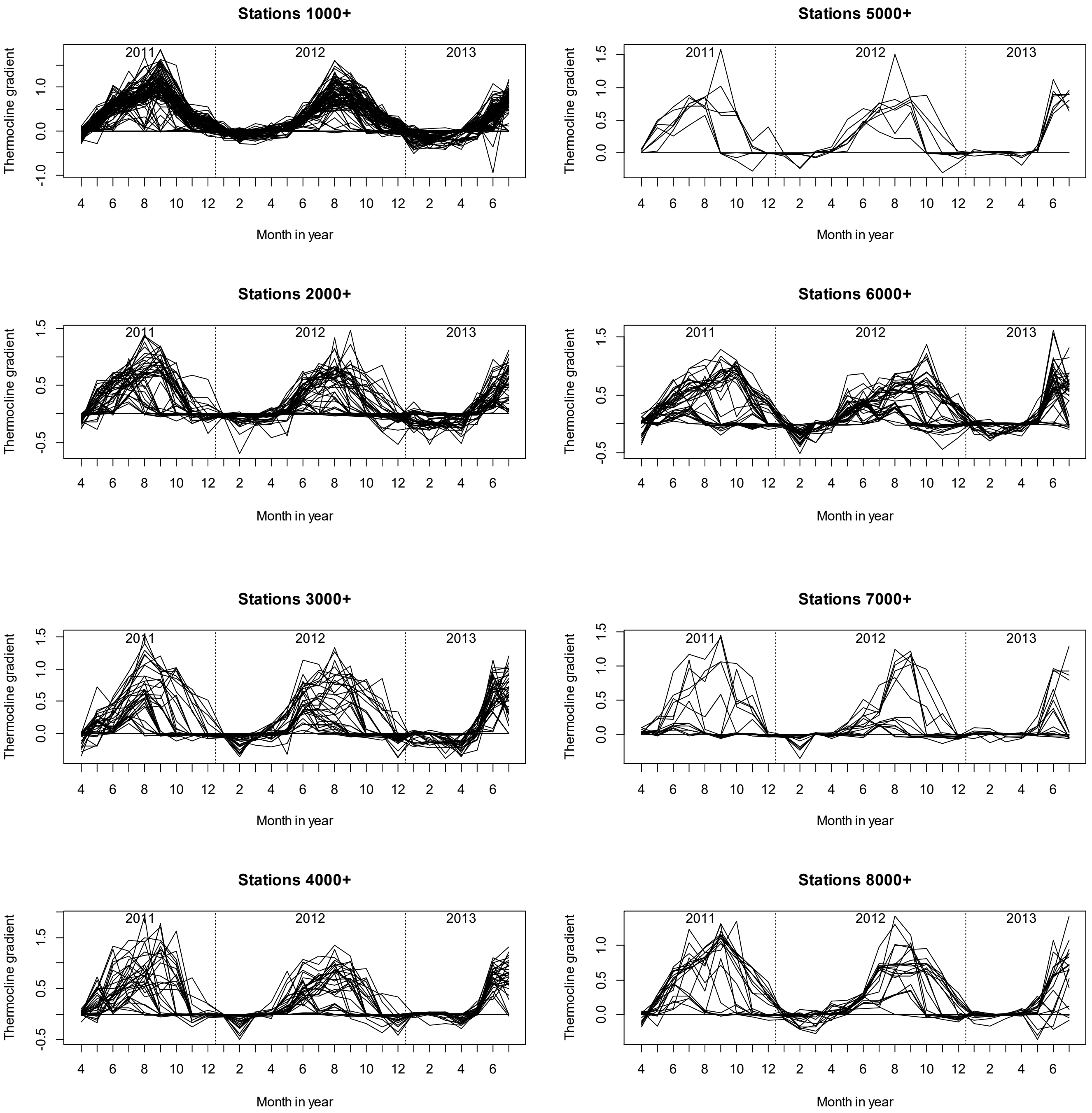


Figure 14 Scatter plots of pairs of variables. See Table 2 for correlation coefficients.

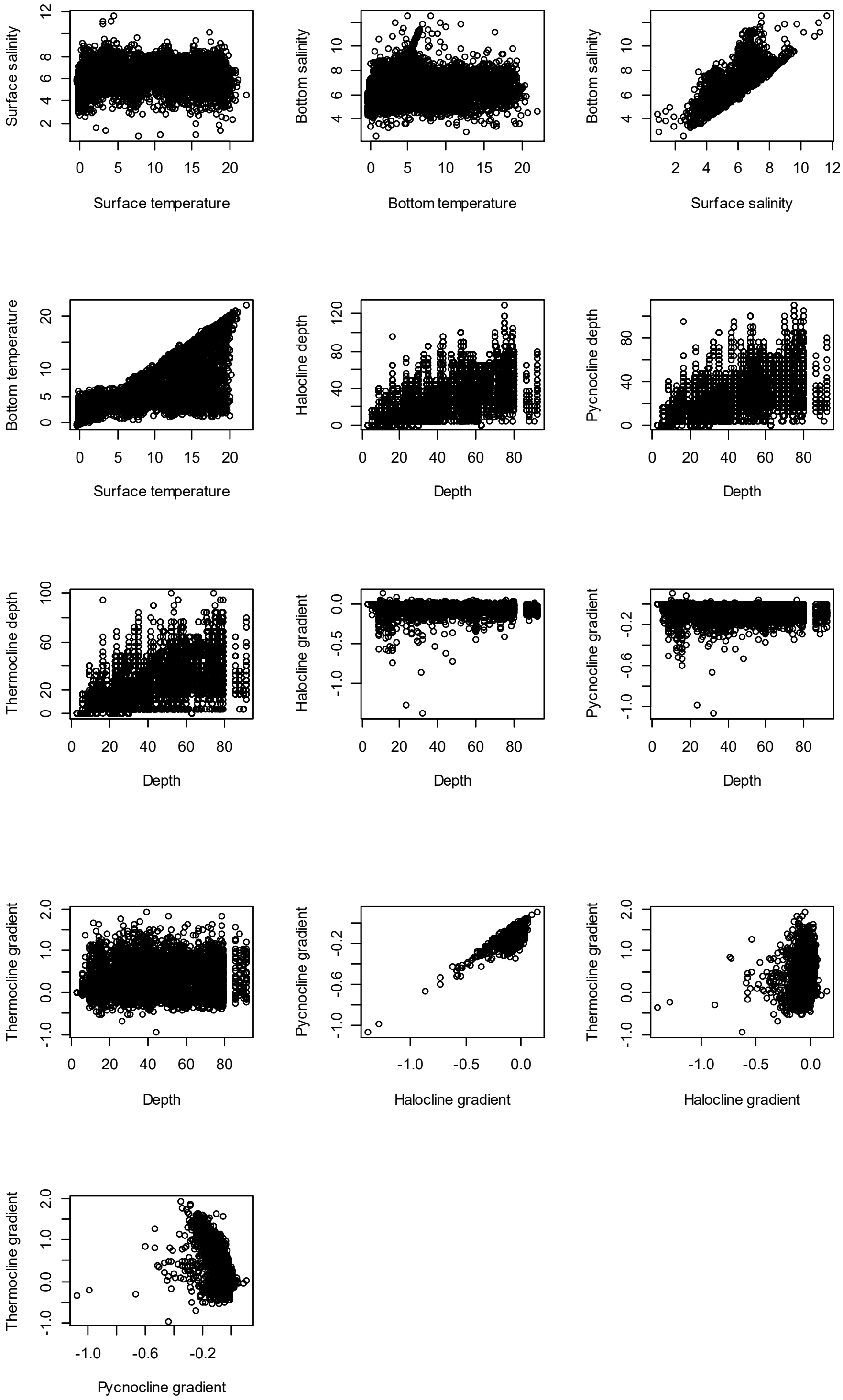
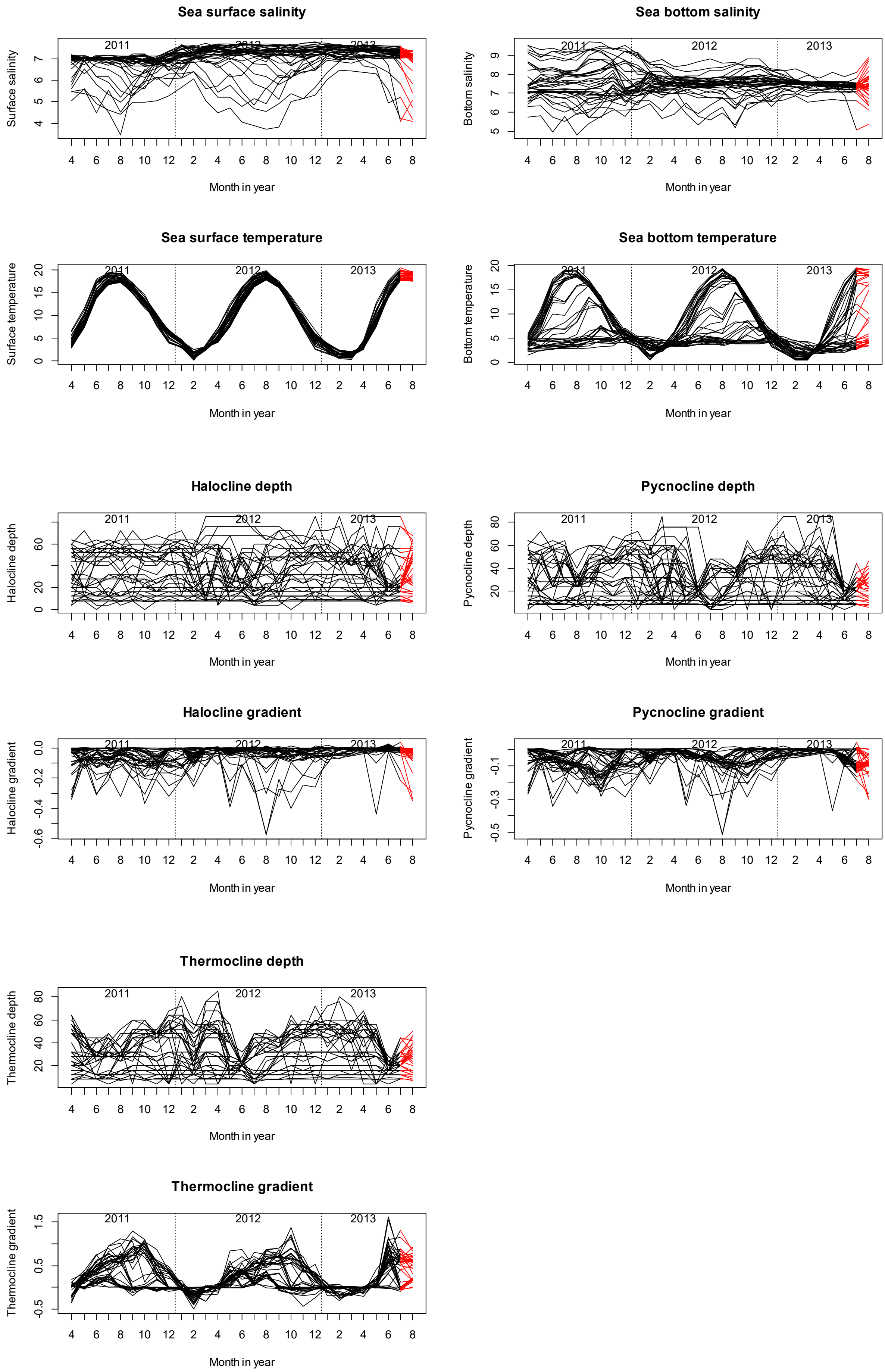


Figure 15 Time series of observed values (black) of environmental variables for stations 6001-6039 with predicted values for August 2013 (shown in red).



SAMBAH Report 4 Version 1.2

Summary of data collected on A-tags attached to harbour porpoise

ML Burt and L Thomas, CREEM, University of St Andrews

SUMMARY

Information on porpoise clicks was obtained by attaching A-tags to six harbour porpoise in Danish waters (Wright 2013). These data were used to estimate the proportion of 60 second intervals that contained at least one porpoise click and also to investigate click patterns throughout the day. The data were filtered before analysis to exclude surface reflections as well as short click trains and clicks that did not come from the direction of the head of the animal, both of which most likely resulted from external noise. The recording periods were divided 60 second intervals and each interval was classified as porpoise positive if there was a click within the interval. The average percentage of PP 60 second intervals was 84% (CV=9.5%).

One porpoise recorded a substantially higher number of clicks per second than the other porpoises; approximately 11 clicks per second compared to 5 clicks per second which was the next highest average number of clicks per second. Analyses indicated that it was difficult, with this small sample, to draw any general conclusions about porpoises regarding changes in click patterns throughout the day due to changes in light levels.

INTRODUCTION

Six A-tags were attached to harbour porpoises in Danish waters in May 2010 and in March, April, May and July 2011 (Wright 2013) and this document summarises the data collected from these tags. Another study in Danish waters followed animals acoustically and visually and the average length of an encounter with a single animal was 60 seconds (see SAMBAH Report 2). In the same study more clicks were recorded during the night that at other times of the day. There were two questions of interest for the SAMBAH project which the A-tag data can potentially be used to answer:

1. The proportion of 60 second intervals that contain at least one porpoise click and
2. Whether the pattern of clicking in 60 second intervals changes throughout the day.

DATA COLLECTION AND PROCESSING

A-tags were attached to six porpoises (identified as HP 1 – HP 6). Animals were fitted with a tag and then released immediately. After a few days, the tags detached from the SPLASH tag they were piggy-backed to and were recovered. Tags recorded on a duty cycle and were thus either 'on' for a proportion of time each hour when they recorded porpoise clicks, or 'off' when no data were recorded. Five tags were 'on' for approximately 10 minutes per hour and, thus, off for 50 minutes. The tag attached to HP 2 was on for 45 minutes and off for 15 minutes (Table 1).

The acoustic data recorded on the tags were processed in the following ways:

- Clicks outside a window of between 55°-65° (depending on the size of the animal) in front of the animal were removed in order to remove clicks originating from other animals.
- All clicks with an inter-click interval of ≤5.5ms were removed to reduce surface reflections.

- The data were smoothed over 3 points to identify and remove jumping inter-click intervals from other animals.

Click data only within the release time and tag off time/end of recording were used in the analysis.

The data were further processed by

- excluding all clicks within 2m of the surface to remove surface noise, and then
- click trains of five clicks or less were excluded; click trains were delimited by inter-click times of at least 1 second (i.e. there was at least one second gap between the end of one click train and the next click).

The diving profiles of the porpoise were available at, approximately, every second for the first three days (from B-tags) and at approximately every 3 seconds for the entire period (from Star-Oddi (SO) sensors) (Table 2).

STATISTICAL METHODS

There are two questions of interest: of primary interest was to obtain an estimate of the proportion of intervals that contain at least one porpoise click and secondly to examine whether there are changes in porpoise clicking throughout a day.

Proportion of intervals HP clicking

The times when the tags were recording were divided into intervals; the time interval considered was 60 seconds because the average encounter time obtained from encounters with wild porpoise at Kerteminde was 63 seconds (SAMBAH Report 2). Intervals were defined as being 'porpoise positive' (PP) if at least one click occurred within the interval. Then the proportion of PP intervals was obtained from:

$$Proportion\ of\ PP\ intervals = \frac{Number\ of\ PP\ intervals}{Total\ number\ of\ intervals}$$

Clicks recorded within 2m from the surface had been removed and so the time periods when the animal spent time within 2m of the surface were also excluded (identified from the SO sensors) initially. Intervals of 60 seconds were then 'stitched' together having removed time periods when the animal was within 2m of the surface. An overall estimate of the proportion of PP intervals was obtained by taking the mean of all porpoises weighted by the total number of intervals. A coefficient of variation (CV) was obtained from the weighted variance of the proportions ($CV = \sqrt{variance}/_{mean}$).

The above analysis essentially ignores time of day (because time periods are stitched together to create 60 second intervals) and so, in addition, 60 second intervals were also generated that included periods when the animal was within 0-2m of the surface. To account for excluded surface clicks, the proportion of time an animal spent within 0-2m of the surface was calculated for each interval. This data was used to consider whether the time of day was related to the probability of a PP interval (see below).

Diurnal patterns in click rate

The A-tags were recording for a proportion of every hour for 24 hours a day and so patterns in clicking could be examined. The time of day was classified into four diurnal phases (morning, day, evening and night) based on light levels defined by the position of the sun. The diurnal phases were obtained from http://aa.usno.navy.mil/cgi-bin/aa_pap.pl using a location of Anholt Island (56°42'N, 11°34'E). The average numbers of clicks per second per diel phase and also the average per hour were calculated taking into account seconds when no clicks were recorded.

Daily patterns in PP intervals were modelled with PP interval (either a 0 or 1) as the response (assumed to come from a binomial distribution) with time of day (as a cyclic smooth) and the proportion of the time interval spent within 2m of the surface as explanatory variables fitted as smooth functions. Intervals spent entirely within 0-2m of the surface were excluded since all clicks had been excluded.

RESULTS

The tags were attached to six animals for about 40 days in total and were recording for over 160 hours (Table 1). A summary of the number of clicks for each animal is given in Table 3. The maximum depths reached by each porpoise were very different; HP 2 and HP 6 reached a depth of about 40m whereas HP 5 went much deeper to nearly 130m (Table 2; Figure 1).

Proportion of PP intervals

Excluding all times when the porpoise was within 0-2m of the surface, then the proportion of PP 60 second intervals ranged from 0.74 with HP 2 to 0.96 with HP 4 (Table 4). The proportion over all animals was 0.84 (CV=9.51%).

Patterns in clicks

Information to determine diurnal phases is given in Table 5. These data were collected during spring and summer months and so the majority of the time was spent in the day phase (Table 6). The number of clicks per second was substantially higher for HP 1 than for the other animals (Table 6); on average 11 clicks per second were recorded for HP 1 compared to 5 clicks per second for HP 3 which recorded the next highest number per second. Within each porpoise the average numbers of clicks per second were similar for each diel phase, with HP 1 exhibiting the largest variation. The highest number of clicks per second occurred in the morning for all porpoises, except HP 4 which recorded the highest number of clicks in the evening (Table 6). The lowest number of clicks per second occurred in the morning for HP 1, 2, 5 and 6, in the evening for HP 3 and in the morning for HP 4. The hourly average of the number of clicks per second is shown in Figure 2; only HP 1 showed a strong daily pattern.

Taking into account time of day and the proportion of time spent within 0-2m of the surface, then each porpoise exhibited slightly different behaviour. For intervals where the porpoise was always deeper than 2m, the probability of a PP interval was estimated be one for all times of the day for HP 1, HP 3 and HP 4 but less than one for the other animals. For intervals when the porpoise spent half the interval deeper than 2m, five of the porpoises had a dip in the probability of a PP interval towards the middle of the day. HP 4 showed the opposite pattern, with virtually all intervals being PP between 05:00 to 15:00 (daylight hours).

DISCUSSION

The main use of this data was to estimate the proportion of PP60 second intervals. Using only time periods when the porpoise was deeper than 2m to obtain 60 second intervals, this proportion was estimated to be 84% (CV=9.51%) over all six porpoises. It has been found that short dives (less than 60 seconds and likely to be close to the surface) tended to be quiet dives (pers.comm. AJ Wright).

The diel phases used in Tables 5 and 6 were based on a location of Anholt Island; if the animals moved substantially either north or south throughout the period of recording then the timing of phases will need to be adjusted. The times shown in Appendix A obtained using the approximate positions of release suggested that these adjustments would be minor (mostly less than 10 minutes).

ACKNOWLEDGEMENTS

The tag data was kindly provided by AJ Wright who also provided useful comments on the report and suggestions for analysis.

REFERENCES

SAMBAH Report 2: Estimating EDA for wild HP using the study at Kerteminde. ML Burt and L Thomas. Unpublished report, CREEM, University of St Andrews, 2014

Wood SN (2006) *Generalized Additive Models: An introduction with R*. Chapman and Hall/CRC

Wright AJ (2013) How harbour porpoises utilise their natural environment and respond to noise. PhD thesis, Aarhus University

Table 1 Release and end of recording dates and time (UTC) for each harbour porpoise, minutes every hour (mm:ss) when the A-tag was on and off each hour.

HP number	Release		End recording		A-tag (MM:SS)			Total number of recording intervals
	Date	Time	Date	Time	Start recording	End recording	Duration	
1	19/05/2010	17:07:22	29/05/2010	09:50:08	42:56.0005	52:56.4620	10:00.462	233
2	14/04/2011	16:10:00	17/04/2011[1]	09:51:52	00:00.0030	45:00:4810	45:00.478	51
3	06/05/2011	17:25:15	08/05/2011	22:52:41	38:52.0005	47:52.3965	9:00.395	54
4	04/07/2011	19:50:28	07/07/2011	05:43:41	52:00.0005	02:00.4790	10:00.479	59
5	15/07/2011	17:19:35	21/07/2011	19:31:59	52:00.0005	02:00.4835	10:00.483	146
6	29/03/2011	14:22:30	09/04/2011	17:09:56	00:00.0005	10:00.4699	10:00.469	267

[1]No click data after 16/04/2011 18:23:35

Table 2 Summary of harbour porpoise depths (m) from Star-Oddi depth sensors within the recording time of clicks.

HP number	Start recording		Sample rate (secs)	Depths (m)	
	Date	Time		Minimum	Maximum
1	19/05/2010	14:02:53	3.000084	-0.41	80.2
2	14/04/2011	16:02:34	3.000018	-0.21	38.0
3	06/05/2011	15:20:48.75	3.000114	-0.47	74.2
4	04/07/2011	15:05:37	3.000135	-0.33	93.7
5	15/07/2011	15:03:07.5	3.000112	-0.46	128.4
6	29/03/2011	14:22:30	3.000051	-0.58	41.0

Table 3 Summary of tag data (after processing).

HP number	First click		Last click		Number of clicks	Number of click trains
	Date	Time	Date	Time		
1	19/05/2010	20:42:56	29/05/2010	09:49:54	690 258	4 663
2	14/04/2011	16:15:02	16/04/2011	18:22:53	56 802	2 462
3	06/05/2011	17:39:22	08/05/2011	22:47:47	91 946	2 338
4	04/07/2011	19:52:04	07/07/2011	05:01:52	61 292	2 432
5	15/07/2011	18:53:22	21/07/2011	19:01:59	176 297	4 727
6	29/03/2011	15:02:54	09/04/2011	17:09:54	83 685	4 125

Table 4 Numbers of PP intervals, total time intervals and proportions of PP intervals.

HP number	Number PP intervals	Total number intervals	Proportion
1	917	1005	0.91
2	518	701	0.74
3	291	305	0.95
4	365	379	0.96
5	751	877	0.86
6	927	1209	0.77
Overall	3769	4476	0.84

Table 5 Times (HH:MM) of civil twilight and sunrise and sunset for the day of release for each porpoise. Times are in Universal Time.

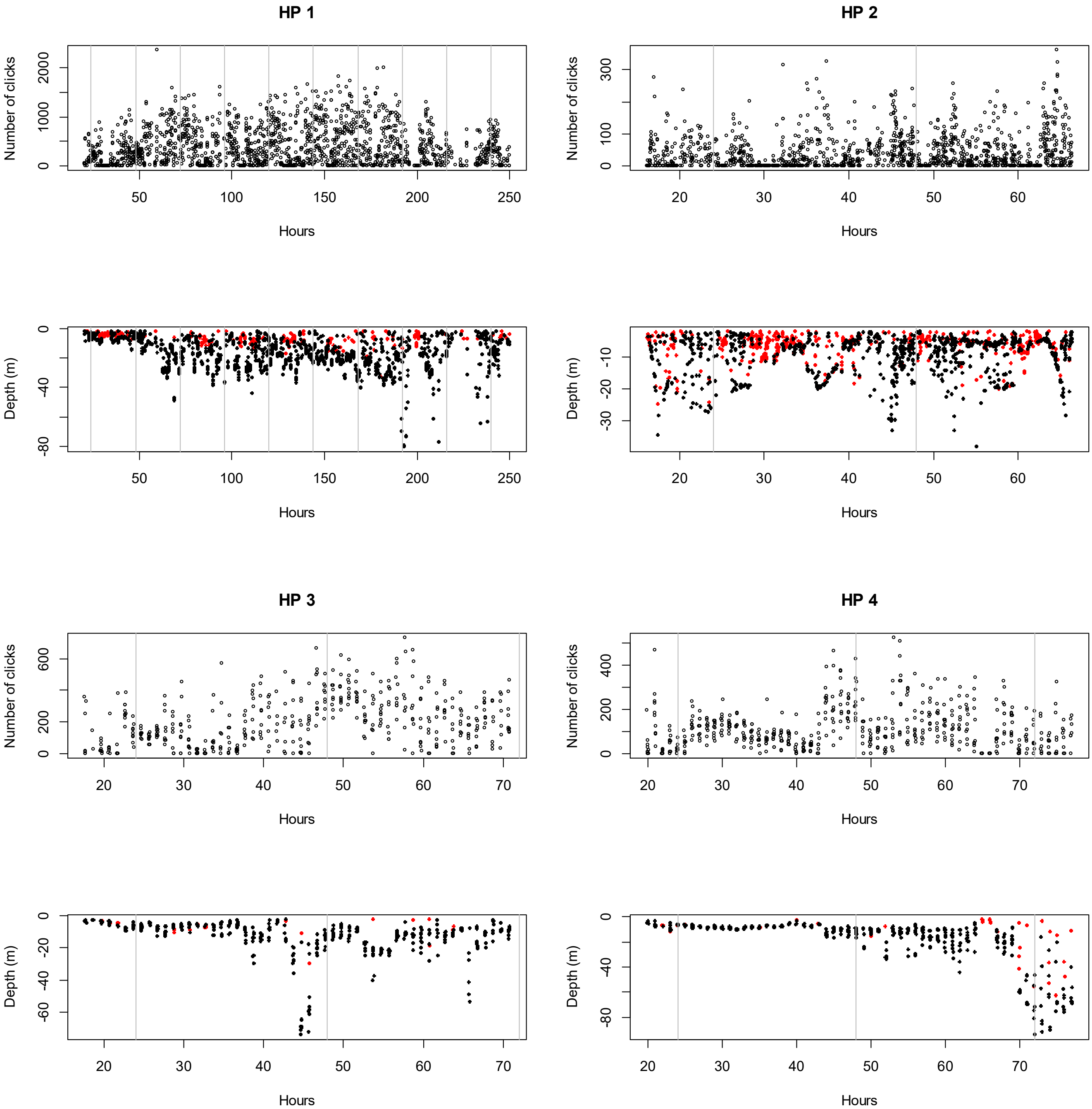
HP number	Date	Begin civil twilight[1]	Sunrise[2]	Sunset[3]	End civil twilight[4]
1	19/05/2010	01:57	02:50	19:32	20:26
2	14/04/2011	03:30	04:10	18:19	19:00
3	06/05/2011	02:29	03:17	19:05	19:53
4	04/07/2011	01:25	02:29	20:06	21:10
5	15/07/2011	01:44	02:43	19:55	20:54
6	29/03/2011	04:44	04:53	17:46	18:24

[1]End of night phase and start of morning. [2]Morning lasted for twice the time between beginning of civil twilight and sunrise. [3]Evening lasted for twice the time between sunset and end of civil twilight. [4]End of evening phase and start of night.

Table 6 Average number of clicks per second by diel phase and the average percentage of time in each phase. The standard deviation is given in parentheses.

HP number	Month	Average number of clicks per second					Percentage of day spent in phase			
		Morning	Day	Evening	Night	Overall	Morning	Day	Evening	Night
1	May	15.4 (14.3)	10.2 (13.5)	12.8 (14.8)	13.2 (13.4)	11.4 (13.7)	7.8 (0.2)	62.9 (0.6)	7.8 (0.2)	21.5 (1.0)
2	April	1.7 (3.2)	1.1 (3.5)	1.7 (4.4)	1.6 (3.5)	1.3 (3.6)	5.7 (0.1)	53.7 (0.4)	5.8 (0.1)	34.8 (0.5)
3	May	6.0 (6.5)	4.9 (6.5)	4.4 (6.2)	5.0 (6.5)	4.9 (6.5)	6.6 (0.1)	59.6 (0.4)	6.7 (0.0)	27.2 (0.3)
4	July	2.2 (3.8)	2.6 (4.2)	4.0 (6.4)	2.3 (4.5)	2.6 (4.6)	8.8 (0.1)	64.5 (0.1)	8.8 (0.1)	18.0 (0.3)
5	July	4.2 (6.3)	3.0 (6.4)	3.1 (6.5)	3.6 (6.3)	3.3 (6.4)	7.9 (0.1)	63.1 (0.3)	7.9 (0.2)	21.0 (0.6)
6	March/April	1.5 (3.5)	1.0 (3.7)	1.2 (3.7)	1.3 (3.6)	1.1 (3.6)	5.4 (0.1)	50.1 (1.1)	5.5 (0.1)	39.1 (1.3)

Figure 1 Time series plots showing the number of clicks (top plot) and maximum depths (bottom plot) per 60 second interval (excluding intervals spent entirely within 2m of the surface) for each porpoise. The red dots indicate intervals that do not contain any clicks. The x-axis is the number of hours since the start of the first day of recording; the vertical grey lines differentiate between days.



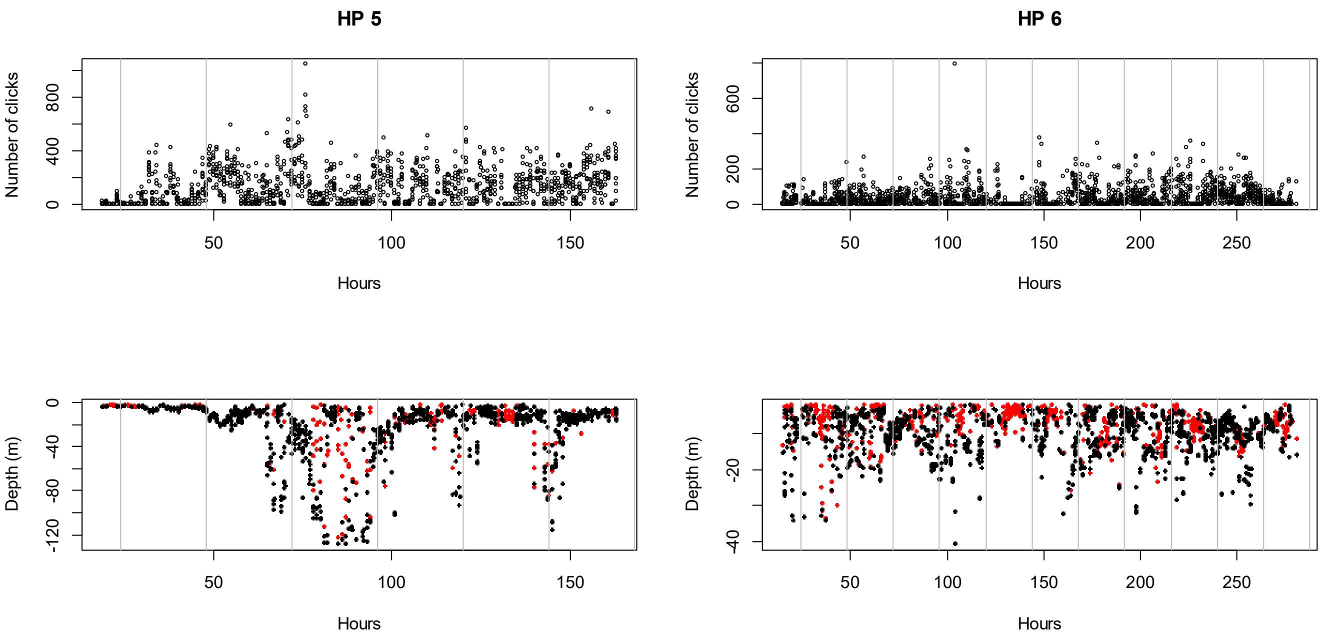


Figure 2 Average click rates per second for each hour in the day by porpoise (HP 1 – HP 6).

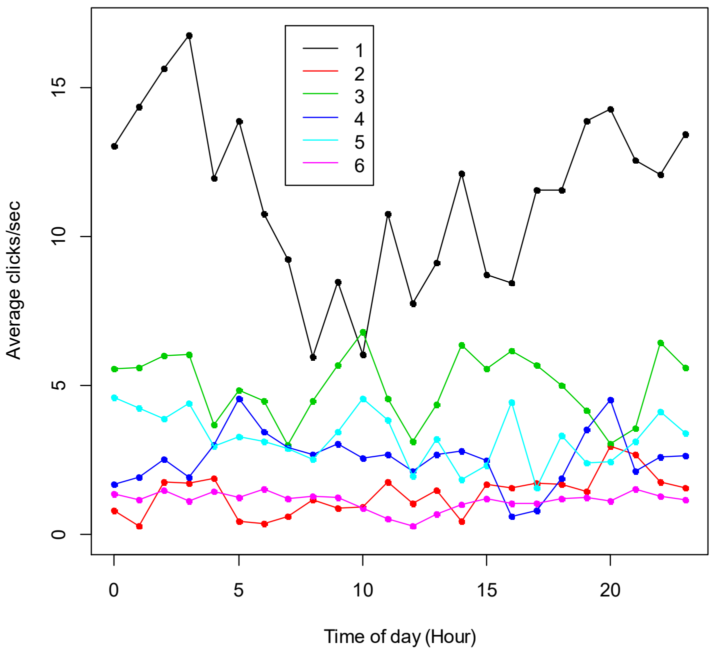
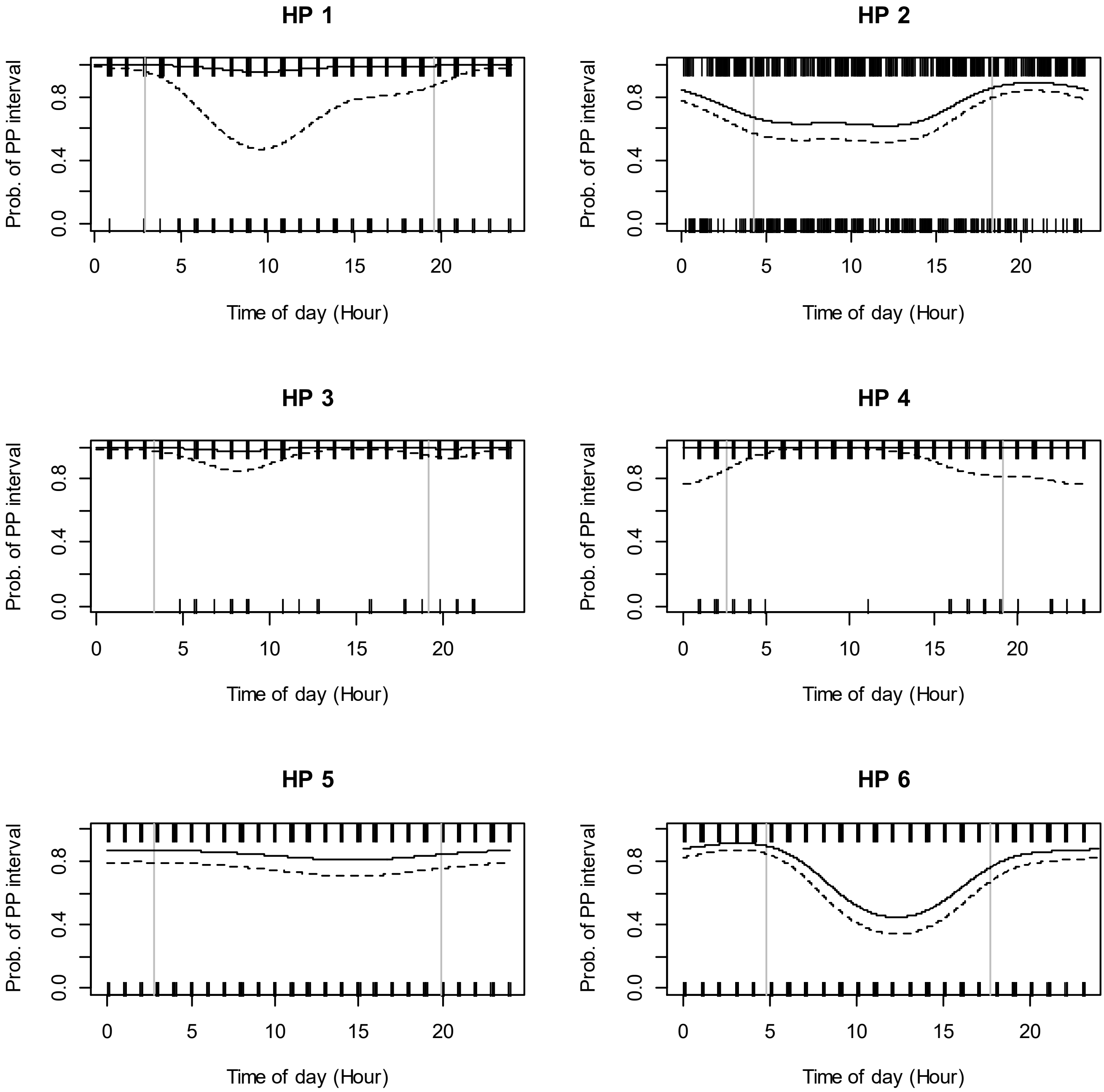


Figure 3 Probability of PP 60 second intervals by time of day. The black ticks indicate the observed values for each interval (with a tick line at 1 indicating a PP interval) and the lines show the estimated values for two values of the proportion of the interval spent within 2m of the surface; always deeper than 2m (solid line) and within 2m of the surface for half the interval (dashed line). The vertical grey lines indicate the times of sunrise and sunset for the day and approximate position of release (see Appendix A).



Appendix A Times of civil twilight, sunrise and sunset for the day of release and approximate position of release for each porpoise.

HP number	Date	Longitude (°E)	Latitude (°N)	Begin civil twilight	Sunrise	Sunset	End civil twilight
1	19/05/2010	10.50	56.50	02:03	02:56	19:35	20:28
2	14/04/2011	10.75	55.30	03:38	04:17	18:19	18:59
3	06/05/2011	10.70	56.50	02:34	03:21	19:08	19:55
4	04/07/2011	10.60	56.50	01:31	02:34	20:09	21:11
5	15/07/2011	10.60	56.50	01:50	02:48	19:58	20:55
6	29/03/2011	12.00	55.50	04:15	04:52	17:43	18:20

SAMBAH Report 4a - Version 1.0
2nd ATag data analysis

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February 8, 2016

1 Introduction

This document describes an analysis of ATag data with the aim of deriving an estiamte of p_c, the average probabilty of a porpoise emitting at least one click during time periods equal to those of the Kerteminde detection trial encounters. It was written for internal use by SAMBAH researchers. As with several other SAMBAH reports, it was written using `Knitr` package in `R version 3.2.3 (2015-12-10)`; it is therefore a "live" document in the sense that all values, tables and figures given are the direct output from `R` analyses performed as part of document compilation.

The trials at Kerteminde (analyzed in SAMBAH Report 2 and 2a) involved acoustic tracking of wild-swimming porpoises; the detection or non-detection of these porpoises on adjacent CPODs was then used to construct a detection function for detectability of porpoises as a function of distance from a CPOD, as well as other explanatory variables such as time of day. This detection function was then used to estimate an effective detection area (EDA) at Kerteminde; this was then combined with playback data from Kerteminde and the SAMBAH stations to estimate the EDA at the SAMBAH stations.

However, since the trials at Kerteminde involved vocalizing animals, they estimate the probability of detection of an animal that is vocalizing, and so over-estimate the population-wide probability of detection and corresponding EDA. We need to adjust the EDA to account for the proportion of the population that is not vocalizing. More precisely, we want to estimate the proportion of animals at Kerteminde that passed by the sensors during the trial but did not vocalize – we define this as p_c, and we use it to reduce the size of the EDA estimated from the acoustic trial data as follows:

$$\hat{\nu}_{i,m,d} = \frac{\hat{\nu}_d^* \hat{\xi}_{i,m}}{\hat{\xi}^*} \times \hat{p}_c \tag{1}$$

Where

- $\hat{\nu}_d^*$ is the estimated EDA for porpoises in diel phase d estimated at the Kerteminde experimental site, using acoustic encounters with porpoises that were clicking;
- $\hat{\xi}^*$ is the estimated EDA for an artificial click at the Kerteminde experimental site;
- $\hat{\xi}_{i,m}$ is the predicted EDA for an artificial click at sampling location i and month m, estimated from the playback study in the SAMBAH area.

We estimate p_c as follows. A sample of data from porpoises (from nearby waters) fitted with acoustic recording tags were available, giving us times of clicks produced by those animals. We assumed click behaviour of these porpoises was representative of porpoises at Kerteminde. (We looked for diel patterns and other things

– see SAMBAH Report 4.) There were 36 encounters of porpoises at Kerteminde, with acoustic track durations ranging from 5 to 263 seconds (median 56, mean 64.1). For each of these encounter lengths, we used the tag data to determine the probability each tagged porpoise would vocalize at least once during that time period, and so be available to be tracked. For each tagged porpoise, we then took the mean of these probabilities (averaging over all 36 encounters) to estimate the mean probablity of clicking at least once during an encounter. Lastly, to obtain the population average, we took a weighted mean across tagged animals, weighting by the number of seconds of data on each tag. This analysis therefore treats the tagged porpoise as the sample unit. More details are given in the remainder of this report.

2 ATag data

There were tag data from 6 porpoises available, with a total deployment time of 802.01 hours (Table 1). The data were rounded to the nearest second to facilitate processing. The acoustic recording tag was duty cycled, so that it was on between 10 and 45 minutes each hour (different tags had different duty cycle regimes); the total ATag on time over all tags was was 162.27. In addition, it was necessary to discard data from when the porpoise was at < 2m depth because interference from surface noise means it is not possible accurately to distinguish clicks from surface noise. Data from two depth sensors were available; we elected to use that from the Star-Oddi sensor because that was available for the entire deployment. Depth was recorded approximately every 3 seconds; we used linear interpolation between these measurements to estimate depth at the resolution of 1 second. Data from seconds where the animal was estimated to be at < 2m depth were discarded, leaving 74.245 hours (i.e., 267281 seconds) of data. In this time, the total number of seconds where a click was detected on the tag was 102247, giving a mean proportion of click-positive seconds of 0.3825. This number is not useful for our purposes, because we need the average proportion of intervals that contain a click where the intervals we average over are the lengths of the encounters at Kerteminde, not just 1 second. We address this in the next following sections.

Animal	Start time	Stop time	Duration	w/ ATag	<2m depth	w/ clicks	p(click)
1	2010-05-19 20:07:22	2010-05-29 09:50:08	826966	137833	60082	38480	0.6405
2	2011-04-14 16:15:00	2011-04-16 18:23:00	180480	135480	41922	9935	0.2370
3	2011-05-06 17:25:15	2011-05-08 22:52:41	192446	29160	18198	11594	0.6371
4	2011-07-04 19:50:28	2011-07-07 05:43:41	208393	34800	22615	10155	0.4490
5	2011-07-15 18:52:30	2011-07-21 19:31:59	520769	86969	52313	18619	0.3559
6	2011-03-29 15:00:00	2011-04-09 17:09:56	958196	159930	72151	13464	0.1866
Total			2887250	584172	267281	102247	0.3825

Table 1: Summary of ATag data. Duration is the length of the tag deployment (in seconds), w/ Atag is the total period in which the ATag was recording (less than total duration because of duty cycling), ¡2m is the subset of this time at which the porpoise was estimated to be at greater than 2m depth, w/clicks is the number of click positive seconds. p(click) is the proportion of the seconds at which the animal was ¡2m that were click positive.

3 Estimation of probability of click at each encounter duration

Data from each porpoise was analyzed separately. As stated earlier, there were 36 encounters, ranging from 5 to 263 seconds in duration. For each of these encounter durations, the tag data was divided into chunks of this duration, and only chunks where the ATag was on for the entire duration were retained. Chunks where the porpoise was at an estimated depth < 2m for the entire duration were also discarded. For those remaining, we calculated the proportion of chunks that contained one or more click-positive seconds.

3.1 Correction for depth < 2m data

Unsurprisingly, chunks with a greater proportion of seconds where the porpoise was at < 2m depth had a lower probability of being click-positive (i.e., of having one or more seconds) – because clicks detected at depths < 2m had previously been truncated (i.e., removed). Ideally we would have excluded all chunks containing any

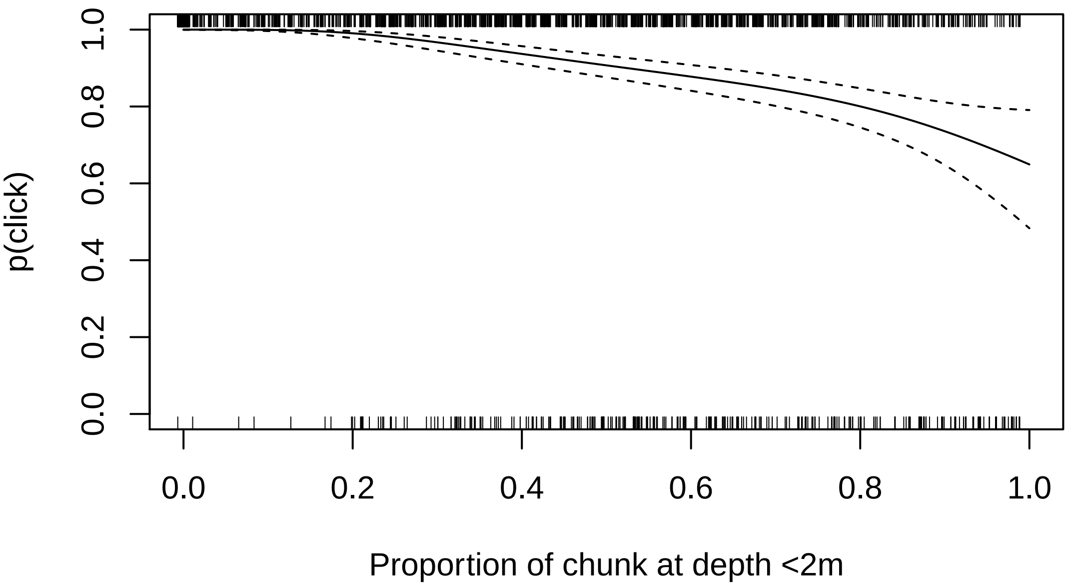

Figure 1: Estimated probability (from a monotonic binary GAM) of at least 1 click-positive second per chunk as a function of the proportion of censored data (i.e., data where the porpoise is estimated to be < 2m). This example is for animal 1, and chunk duration 56 seconds (the median encounter length). The solid line is the fitted function; dashed lines show the 95%CI on the fit. The short vertical lines at top and bottom show click-positive chunks (at top) and click-negative chunks (at bottom) (note: position on the x-axis is jittered for clarity).

data from $< 2m$ but this would have removed too much data (and also possibly caused bias if click rates are very different at deeper depths); instead we elected to use an analysis to estimate the probability a chunk is click-positive for chunks with no truncated data. We used the R package `scam` to fit a logistic regression of click positive/not click positive seconds as a function of the proportion of the chunk < 2m (i.e., truncated). Proportion < 2m was modelled using a monotonic nonincreasing smooth – in other words, we assumed that the larger the proportion of the chunk containing < 2m depths, the smaller the probability the chunk would contain a click. Examples, using the median chunk duration, are shown in Figure 1 (for the porpoise with the highest per-second probability of clicking) and Figure 2 (for the porpoise with the lowest per-second probability of clicking). We then used the fitted model to predict the probablility of being click positive for 0 proportion of the chunk at < 2m (i.e., the intercept in the above plots).

3.2 Results

Estimates of probabilitity of click for each encounter duration and for each animal are shown in Figure 3. The mean probability of a click, averaged across the 36 encounter durations are shown in Table 2.

4 Estimation of p_c across encounters and porpoises

The final estimate of p_c is a weighted mean of the p(click) values shown in Table 2, weighted by the number of seconds of data used for each animal (shown as T in that table). This value is 0.822807.

We also estimated the variance of the weighted mean, using the method described by Cochran (1977; see also Gatz and Luther 1995). This value is 0.00300591.

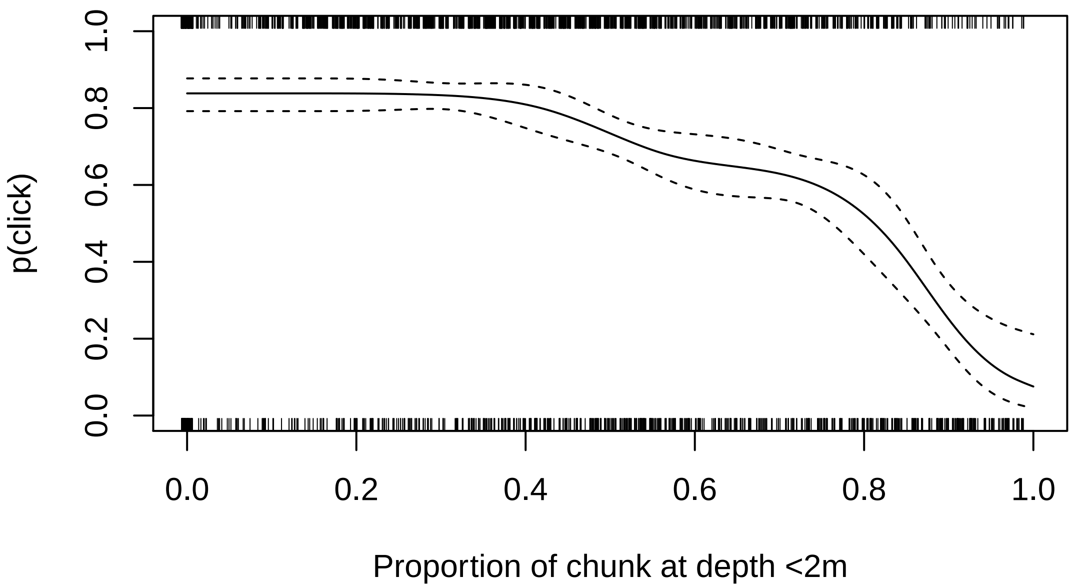

Figure 2: Same plot as previous figure, but for animal 6 (still with chunk duration 56 seconds), which showed the lowest per-second probability of clicking. Here, even after a 56 seconds with no click data censored, it is estimated that the probability of at least one click is ¡1.

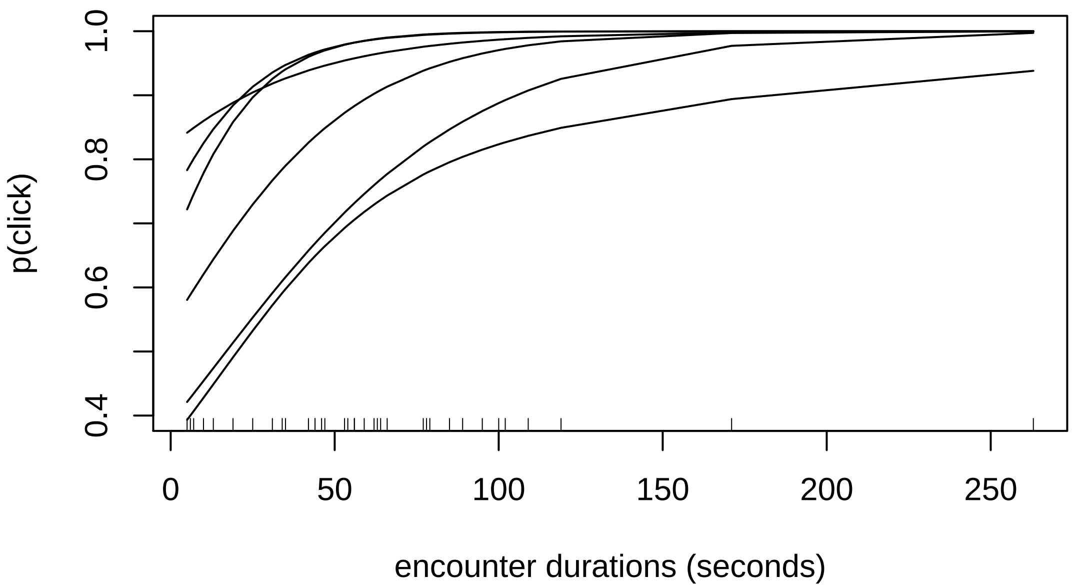

Figure 3: Estimated probability of there being one or more click (y-axis) for a range of encounter durations in seconds (x-axis) and over 6 animals (solid lines). Note that the estimates have been smoothed for clarity. The encounter durations used in the analysis are indicated by short vertical lines along the x-axis.

Animal	p(click)	T	w
1	0.954	60082	0.225
2	0.676	41922	0.157
3	0.943	18198	0.068
4	0.940	22615	0.085
5	0.851	52313	0.196
6	0.711	72151	0.270

Table 2: Mean probability of click (p(click)), averaged over the encounter durations; also shown (T) is the number of seconds in which the ATag was recording and the depth was < 2m − this is the weight used in averaging over animals; the weight standardized so it sums to 1 is shown in the last column (w).

References

- Cochran, W. G. Sampling Techniques, 3rd Edition. 3rd edn, (Wiley, 1977).
- Gatz, D. F. Luther, S. The standard error of a weighted mean concentration-I. Bootstrapping vs other methods,. Atmospheric Environment 29, 1185-1193 (1995).

SAMBAH Report 5 Version 1.1

Calibration of C-PODs

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SUMMARY

A useful measurement to account for differences between C-POD devices is the detection threshold (DT) – the level at which the device registered 50% of clicks during an experiment. However, detection thresholds were not available for all C-PODs but all have a gain setting and so the relationship between the detection threshold and gain setting was investigated.

All C-PODs are calibrated prior to deployment so that they deliver correctly calibrated sound pressure level readings – this is called the gain offset setting. The gain setting value is important because higher values may affect the sensitivity of the C-POD. The sensitivities of the C-PODs were determined by measuring the detection threshold level (DT) at which the device registered 50% of clicks. The relationship between the gain and detection threshold was analysed using regression techniques and the main factor affecting the DT seemed to be the experimental conditions under which the DT was measured (i.e. in a tank or during a playback experiment) rather than the gain setting. The DT measured in a tank was, on average, 1.8 dB lower than a DT measured during a playback experiment.

INTRODUCTION

As part of the SAMBAH project, C-PODs have been deployed throughout the Baltic Sea to record porpoise clicks in order to estimate the density and abundance of porpoise. Within the estimation process, inter-pod differences may need to be taken into account. This document explores the relationship between C-POD specific measurements.

C-PODs have specific gain offset settings; the gain setting value is a linear voltage amplification factor that is pod-specific and is set by Chelonia Ltd. prior to deployment so that each POD delivers an accurate measure of the sound pressure levels it receives. It is important because when the gain setting is high (approx. > 200) the sensitivity of the C-POD may be lower because of added electronic noise; for lower values (approx. >150) gain settings should not make a difference to the sensitivity of the C-POD (N Tregenza, pers. comm.). To measure their sensitivity, some C-PODs used as part of the SAMBAH project were tested to determine the level at which 50% of clicks were registered – called the detection threshold (DT): a device with a low detection threshold was more sensitive than a device with a high DT. These experiments were performed either in a tank under standard conditions or during playback experiments in open water. For details of a comparison of these measurement types see document 4 listed in Appendix B. The DT of C-PODS is potentially a useful measurement that could be used to account for differences between devices in the density estimation modelling process. However, DTs have not been obtained for all devices but they all have a gain setting and so the relationship between the DT and the gain is explored to determine if the gain setting could be used in the estimation process.

EXPERIMENTAL METHODS

Descriptions of the testing procedures to obtain the detection threshold levels are described in the documentation listed in Appendix B.

STATISTICAL METHODS

Regression techniques were used with DT as the response variable and the following as potential explanatory variables:

- Gain setting, g
- Type of detection threshold measurement (i.e. tank or playback experiment) fitted as a factor
- Country fitted as a factor with four levels.

Gain was included as a linear term or as a smooth function to accommodate a non-linear response between gain and DT. Interactions between gain and the factor variables were also considered. DT was assumed to be normally distributed. Models were fitted using the lm and gam (Wood 2011) functions in R version 3.0.2 (R Core Team 2013) and the model with the smallest AIC was chosen.

RESULTS

DTs for 102 C-PODs from four countries were available; DTs and gain settings for each C-POD are given in Appendix A. The gain settings ranged between 22 and 255 (units?) and the DTs ranged between 110 and 128 dB. A summary by country is shown in Table 1 and Figure 1. The correlation coefficients between the DT and gain (to measure the strength of the linear relationship) suggested that there is a moderate negative relationship for Latvian C-PODs and a strong positive relationship within Finnish C-PODs. However, the sample sizes in these two groups are relatively small; the correlation coefficient is 0.09 when all C-PODs are combined, indicating a weak relationship between the two variables.

The model with the lowest AIC included type of measurement as the only explanatory variable and the estimated values for this model are shown in Figure 2. The average DT for tank calibrations was 116 dB (SD=2.98) whereas the average DT for playback experiments was 117.9 dB (SD=1.20).

DISCUSSION

The DT does not appear to be related to the gain setting and is more dependent on how it was measured. The DT is higher, by approximately 1.8 dB, when measured during playback experiments than when measured in a tank under controlled conditions. Although relatively small, a difference between tank DT and playbacks is perhaps not surprising as there are many differences in the source and pathway before the sound is received at the C-POD and this could easily exceed the variability of the C-PODs, in terms of the gain setting (N Tregenza, pers.comm.).

The consequence of this analysis for the SAMBAH density modelling, is that gain setting should not be used as an alternative explanatory variable to detection threshold to account for inter-pod differences.

ACKNOWLEGDEMENTS

Thanks to N Tregenza and M Amundin for providing the data and also for providing useful comments on the analysis and report.

REFERENCES

R Core Team (2013) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/

Wood SN (2011) Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. Journal of the Royal Statistical Society (B) 73(1):3-36

Table 1 Average values and standard deviations (SD) of gain levels and detection thresholds for C-PODs by a) country and b) type of experiment (i.e. tank or playback).

a) By country

Country		Type	Number of C-PODs	Gain		DT	
				Average	SD	Average	SD
1	Sweden						
2	Finland	Playback	5	91.2	31.6	117.5	2.18
3	Estonia						
4	Latvia	Playback	8	179.1	22.1	118.7	1.00
5	Lithuania						
6	Poland	Playback	20	114.0	38.0	117.5	1.11
7	Germany	Tank	58	132.8	42.7	115.9	3.25
8	Denmark	Tank	16	72.0	24.0	117.0	1.26
	Total		107	121.7	46.2	116.6	2.69

b) By type

Type	Number of C-PODs	Gain		DT	
		Average	SD	Average	SD
Playback	33	126.3	45.5	117.8	1.35
Tank	74	119.6	46.7	116.1	2.96

Table 2 Pearson correlation coefficients (*r*) between the DT and the gain level by country and by type.

Country	*r*	Type	*r*
Finland	0.88	Playback	0.29
Latvia	-0.53		
Poland	-0.12		
Germany	0.17	Tank	0.04
Denmark	-0.26		
All	0.09	All	0.09

Table 3 Summary of the models fitted and AIC values. An intercept was included in all models.

Model type	Number	Model	df	AIC	Δ AIC
Linear	1	g	2	519.7	9.1
	2	type	2	510.6	0.0
	3	country	4	512.9	2.3
	4	g + type	3	512.0	1.4
	5	g + country	5	513.0	2.4
	6	type + country	4	512.9	2.3
	7	g + type + country	5	513.0	2.4
	8	g + type + g*type	4	513.7	3.1
	9	g + country + g*country	8	517.0	6.4
	10	g + type + country + g*type	6	514.7	4.1
	11	g + type + country + g*country	8	517.0	6.4
GAM	12	s(g)	3.5	519.4	8.8
	13	s(g) + type	4.6	511.3	0.7
	14	s(g) + country	6.0	513.0	2.4
	15	s(g) + type + country	6.0	513.0	2.4

Figure 1 Distributions of a) gain and b) detection threshold level for the C-PODs by country.

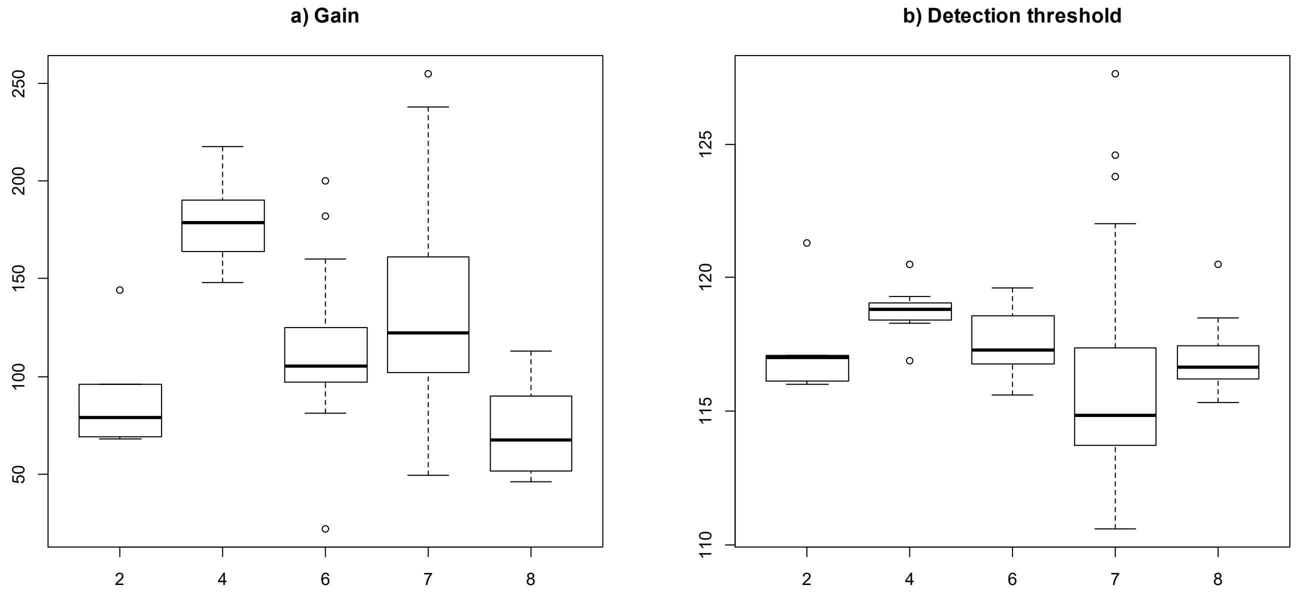
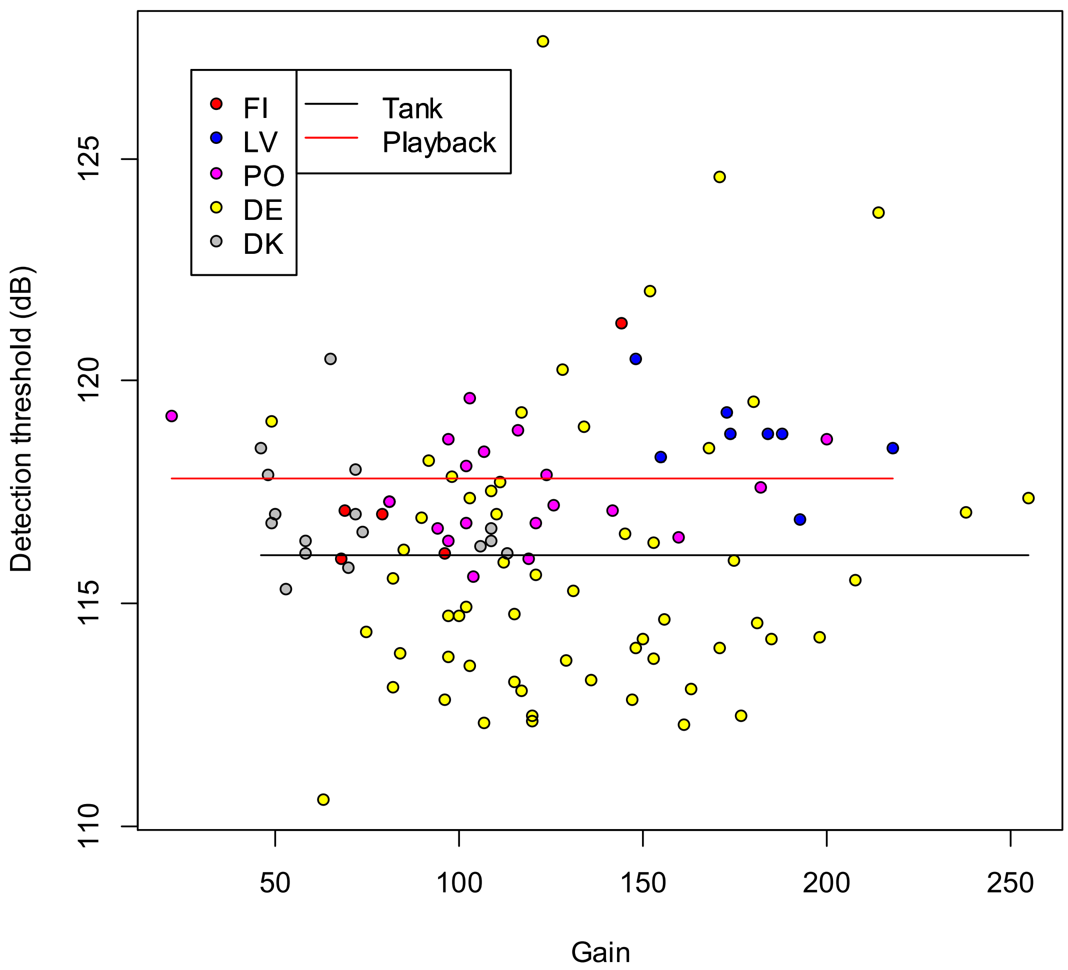


Figure 2 Plot of DT versus gain for C-PODs and the predicted values for each type.



Appendix A Detection threshold levels and specific gain settings for each C-POD. The column headed 'Type' indicates whether the DT level was measured in a tank or during a playback experiment.

Type	Country	C-POD ID	DT (dB)	Gain
Playback	Finland	1396	121.3	144
		1399	116.1	96
		1408	116.0	68
		1444	117.0	79
		1451	117.1	69
Playback	Latvia	1533	120.5	148
		1545	118.8	184
		1558	118.8	174
		1781	118.5	218
		1796	119.3	173
		1797	118.8	188
		1800	118.3	155
		1865	116.9	193
Playback	Poland	1128	117.6	182
		1130	117.3	81
		1131	119.2	22
		1135	116.5	160
		1141	118.9	116
		1149	116.8	121
		1154	117.9	124
		1159	119.6	103
		1162	118.7	200
		1167	118.4	107
		1168	117.1	142
		1276	116.0	119
		1280	117.3	81
		1283	116.8	102
		1284	116.7	94
		1286	118.7	97
		1288	115.6	104
		1290	118.1	102
		1291	116.4	97
		1294	117.2	126
Tank	Germany	19	116.1875	85
		466	116.9083	90
		467	119.5125	180
		469	123.7625	214
		746	118.2125	92
		750	114.1937	150
		753	114.1833	185
		802	113.7812	97
		803	113.2438	115
		804	114.7333	97
		805	117.3500	103
		806	112.2667	161
		808	112.3167	107
		809	115.5500	82
		810	114.9250	102
		811	113.8750	84
		812	117.5167	109
		813	117.8500	98
		814	115.5375	208
		815	113.6083	103
		816	115.6375	121

		817	117.3500	255
		818	112.8500	147
		819	114.3667	75
		820	117.0250	238
		821	113.7500	153
		822	113.0583	163
		824	110.6000	63
		926	112.4583	177
		927	114.5583	181
		928	119.2750	117
		929	119.1083	49
		931	117.7250	111
		1462	112.4667	120
		1463	114.6300	156
		1464	113.7000	129
		1465	120.2562	128
		1466	122.0083	152
		1467	112.8500	96
		1468	118.9750	134
		1469	115.2667	131
		1470	124.5688	171
		1471	114.7750	115
		1472	127.6250	123
		1473	114.7000	100
		1474	116.9917	110
		1475	116.3667	153
		1476	112.3500	120
		1477	115.9187	112
		1478	113.0417	117
		1479	113.1250	82
		1480	116.5500	145
		1825	113.9750	148
		1826	118.4667	168
		1827	115.9500	175
		1828	113.2917	136
		1829	114.2417	198
		1830	113.9750	171
Tank	Denmark	1053	Pending?	
		1055	118.0	72
		1056	115.8	70
		1059	118.5	46
		1061	117.9	48
		1063	116.7	109
		1064	116.1	113
		1065	117.0	50
		1066	116.6	74
		1067	116.4	109
		1070	116.4	58
		1071	116.1	58
		1072	117.0	72
		1076	116.3	106
		1078	115.3	53
		1082	120.5	65
		1083	116.8	49

Appendix B Additional documentation

The information in this report was compiled from various documents.

The specific gain settings were in a text document called 'CPOD specific settings'.

Descriptions of the calibration procedures for C-PODs were in

1. GOM-Calibration set up for C-PODs.pdf –experiments carried out by the German Oceanographic Museum
2. C-POD calibrations.docx – experiments conducted by Denmark

Detection threshold levels were in

3. 50-50 Threshold all PODs-aktualisiert.xlsx – detection threshold levels for German C-PODs
4. Swedish report on CPOD calibration using playback recordings and tank calibrations.docx – Danish, Latvian and Polish C-PODs and comparison between tank calibrations and playback recordings.
5. Calibration analysis FI overview_Final.xlsx

SAMBAH Report 7 - Version 2.2
Density and abundance estimates

Len Thomas & Louise Burt, CREEM

February 8, 2016

1 Introduction

This document contains density and abundance estimates for the SAMBAH survey, plus bootstrap estimates of uncertainty. It builds on results from previous SAMBAH reports, as outlined below.

This document was written for internal use by SAMBAH researchers. As with several other SAMBAH reports, it was written using `Knitr` package in `R version 3.2.3 (2015-12-10)`; it is therefore a "live" document in the sense that all values, tables and figures given are the direct output from `R` analyses performed as part of document compilation.

Changes since version 1 (presented at Kolmården):

- Season definitions changed. V1 "summer" was May-December; V2 summer is May-October (so that the two seasons are 6 months each, among other things)
- The presentation of the density estimator has been changed so that p_c (proportion of time clicking) is now absorbed within $\nu_{i,m,d}$ (effective detection area). (Suggestion of external reviewer.)
- The method for estimating p_c has changed, at the suggestion of an external reviewer. In V1 this was estimated for each tag deployment using the length of the average encounter at Kerteminde ≈60 seconds (and then a weighted average was calculated over all tags, weighting by deployment length). In V2, for each tag deployment, this is estimated separately for each encounter length and then averaged within tag deployment (a weighted average is then taken over tags as before). Another small change is that we now try to account for the proportion of the time the tag is at $<$ 2m depth and so clicks cannot be used, whereas before this was (more-or-less) ignored. In the event, the estimated $\hat{p}_c$ using the V2 method is only about 3% lower than the V1 estimate, although the variance is higher.

2 Methods

2.1 Estimating density and abundance

Density was estimated separately for each sampling location, month and diel phase (morning, day, evening and night) using the estimator:

$$\hat{D}_{i,m,d} = \frac{n_{i,m,d}(1-\hat{c})}{T_{i,m,d}\hat{\nu}_{i,m,d}} \tag{1}$$

where

- $\hat{D}_{i,m,d}$ is estimated density at sampling location i in month m and diel phase d;
- $n_{i,m,d}$ is the number of porpoise positive seconds (PPS, i.e., seconds where one or more porpoise click is detected) at sampling location i in month m and diel phase d;
- $\hat{c}$ is the proportion of porpoise positive seconds that are false positives – this is assumed to be zero in this study;
- $T_{i,m,d}$ is the number of seconds that a C-POD was recording at sampling location i in month m and diel phase d;
- $\hat{\nu}_{i,m,d}$ is the estimated effective survey area (ESA) at sampling location i in month m and diel phase d;

We outline in subsections below how each of these components was obtained.

Density per sampling location and month was estimated using a weighted average of the diel phase-speciic estimates:

$$\hat{D}_{i,m} = \sum_{d=1}^{4} w_{i,m,d}\hat{D}_{i,m,d} \tag{2}$$

where $w_{i,m,d}$ is the proportion of month m at location i that is diel period d (where 1 is morning, 2 is day, 3 is evening and 4 is night). In practice, this proportion was approximated by taking the proportion of the middle day[1] of the month m at the location of sampling position i that was each diel period.

Estimates of density by sampling location and month, for all locations and months (including those outside the main SAMBAH survey periods) were exported to a .csv file and passed to Ida Carlen for her spatial denstiy surface analysis.

Density at higher levels of aggregation was estimated using simple averages of the location- and month-specific estimates[2]. These estimates were made using only locations and months that were inside the main SAMBAH survey period. In particular, density was estimated at the following levels of aggregation:

- Estimates by country[3] and month were produced for graphical summary only;
- Estimates by country and season were produced, where the two seasons were "winter" (November-April) and "summer" (May-October);
- Estimates by region and season were produced, as follows: for winter, all countries were combined; for summer, the study was divided into northeast and southwest strata by a line running approximately from Nogersund in Sweden to Jaroslawic in Poland[4].

Abundance was estimated as density multiplied by the relevant survey area.

2.2 Estimating encounter rate (n and T)

A description of the methods used to obtain the number of porpoise-positive seconds n and the monitoring time T is given in SAMBAH Report 1. That document also contains an analysis of encounter rate by diel phase, justifying the requirement to model detectability by diel phase. Note that the 1-second period is also called a "snapshot."

2.3 Estimating effective detection area, ν

The effective detection area (EDA) for each sampling location, month and diel phase was estimated using the equation:

$$\hat{\nu}_{i,m,d} = \frac{\hat{\nu}^*_d \hat{p}_c \hat{\xi}_{i,m}}{\hat{\xi}^*} \tag{3}$$

where

[1] Need to double check this is strictly correct.

[2] We could have used effort-weighted averaging, where we weighted by the amount of survey effort at each location – this may have increased precision, but at the cost of introducing possible bias if survey effort was more likely to be missing in low density sites.

[3] Denmark mainland and Denmark Borholm were treated separately in all cases where "country" is mentioned

[4] Would be good to have a more rigerous definition of this, and possibly a picture

- $\hat{\nu}_d^*$ is the estimated EDA for porpoises in diel phase d estimated at the Kerteminde experimental site, using acoustic encounters with porpoises that were clicking (hence the need for p_c,below);
- $\hat{p}_c$ is the estimated probability that porpoises at the Kerteminde experimental site produced one or more click during the time period of an acoustic encounter;
- $\hat{\xi}^*$ is the estimated EDA for an artificial click at the Kerteminde experimental site;
- $\hat{\xi}_{i,m}$ is the predicted EDA for an artificial click at sampling location i and month m, estimated from the playback study in the SAMBAH area.

Details of the methods and results for obtaining $\hat{\nu}_d^*$, the porpoise EDA at Kerteminde, is given in SAMBAH Reports 2 and 2a; for $\hat{p}_c$ is given in SAMBAH Reports 4 and 4a; for $\hat{\xi}^*$, the playback EDA at Kerteminde is in SAMBAH Reports 3 and 3a; for $\hat{\xi}_{i,m}$, the playback EDA in the SAMBAH area is in SAMBAH Reports 3 and 3b.

2.4 Variance estimation

The distribution of density estimates was estimated by using a bootstrap procedure, where each component of the density estimate was generated from an independent bootstrap, as follows:

- Encounter rate (n and T). A non-parametric bootstrap was used, resampling sampling locations within countries within regions (NW or SE).
- EDA for porpoises at Kerteminde (ν^*). A non-parametric bootstrap was used, resampling porpoise encounters within diel phase. Details are given in SAMBAH Report 2a.
- EDA for playbacks at Kerteminde (ξ^*). A parametric bootstrap was used, resampling from the fitted detection function model. Details are given in SAMBAH Report 3a.
- EDA for playbacks in the SAMBAH area (ξ). A non-parametric bootstrap was used, resampling playback sessions (i.e., a set of playbacks performed at the same sampling location and date). Details are given in SAMBAH Report 3b.
- Proportion of time clicking (p_c). A parametric bootstrap was used, because there were not enough tags for a nonparametric bootstrap. The observed mean and variance from SAMBAH Report 4a was fitted to a beta distribution, by matching the moment. This distribution was then sampled from to produce a bootstrap realizations of p_c. (For the record, since it is not recorded elsewhere, the random seed used for this parametric bootstrap was 7049681.)

In all cases, 1000 bootstrap resamples were generated. For each bootstrap replicate, porpoise density at each site and month was then estimated, using equations 1, 2 and 3; these site and month estimates were combined as described in section 2.1 to produce 1000 bootstrap replicate estimates of density and abundance at the level of season and region. Estimates of variance in density and abundance were derived from the bootstrap replicates using the usual estimator, and confidence intervals were derived using the percentile method.

2.5 Assumptions

In deriving density from these data, we make the following assumptions:

- At most one individual porpoise is detected in each one-second snapshot at each site.
- There are no false positive detections.
- Sampling locations are representative of the study area (despite some secondary positions being used).
- Missing data is missing at random (e.g., there is no relationship between proportion of missing dat and density)[5].

[5]Using unweighted mean density over sites provides some robustness against this assumption, at least within site and month.

- Tagged animals have vocal behaviour representative of the average animal within the SAMBAH region and survey period.
- Tag records analyzed are representative of animal vocal behaviour (for example, depths < 2m could not be used).
- In the Kerteminde trial, only the trial animals were picked up on the test C-PODs; these animals were accurately localized; encounter length was 1 minute.
- Detection probability of porpoises in the SAMBAH area is equal to detection probability of the Kerteminde trial animals multiplied by the ratio of the playback probabilities.
- The statistical models used to describe detection probablity of porpoise at Kerteminde, and of playbacks at Kerteminde and in the SAMBAH area, produce unbiased estimates.

An additional requirement (although not strictly an assumption) is that adequate sample sizes exist of encounter data, tag data, Kerteminde trials and playbacks.

In deriving estimates of uncertainty, we make the following further assumptions:

- Encounter rate: The SAMBAH locations are randomly located by country within region.
- EDA for porpoises at Kerteminde: encounters are independent.
- EDA for playbacks at Kerteminde: the fitted model accurately represents uncertainty.
- EDA for playbacks in the SAMBAH area: playback sessions are independent.
- Proportion of time clicking: the fitted beta distribution accurately represents the uncertainty on this parameter.

3 Results

3.1 Encounter rate

Mean encounter rates by country and month are shown in Figure 1.

3.2 Effective detection area

Mean effective detection area by country and month, calculated from equation 3 is shown in Figure 2.

Here we also report results for p_c, the probability of clicking during an encounter. The mean proportion encounter intervals when animals were found not to have been silent, over the 6 tagged animals (weighted by record length), was 0.8228 with variance 0.003006. This was fitted to a beta distribution, which yielded beta parameters α =40.49, β =9.406; this distribution is in Figure 3.

3.3 Density and abundance

Density and abundance estimates by country and month are shown in Figures 4 and 5. The estimates were aggregated by country within region and season; these are shown in Tables 1 and 2.

The estimated total number of porpoises for the winter season is 11111, of which 74% are estimated to be in Danish mainland, with 2931 in the remaining Baltic waters.

The estimated total number of porpoises for the summer season is 497 in the NE and 21390 in the SW.

3.4 Variance

Bootstrap results are presented as the bootstrap mean, 95% confidence limits (labelled LCL and UCL), and coefficient of variation (CV, the square root of the estimated variance divided by the original estimate, not the mean of the bootstrap estimate).

Tables 3, 4 and 5 give bootstrap results for density, abundance, and summed over the countries for winter; Tables 6, 7 and 8 give the estimates for summer north-east stratum, and Tables 9, 10 and 11 give them for summer south-west stratum.

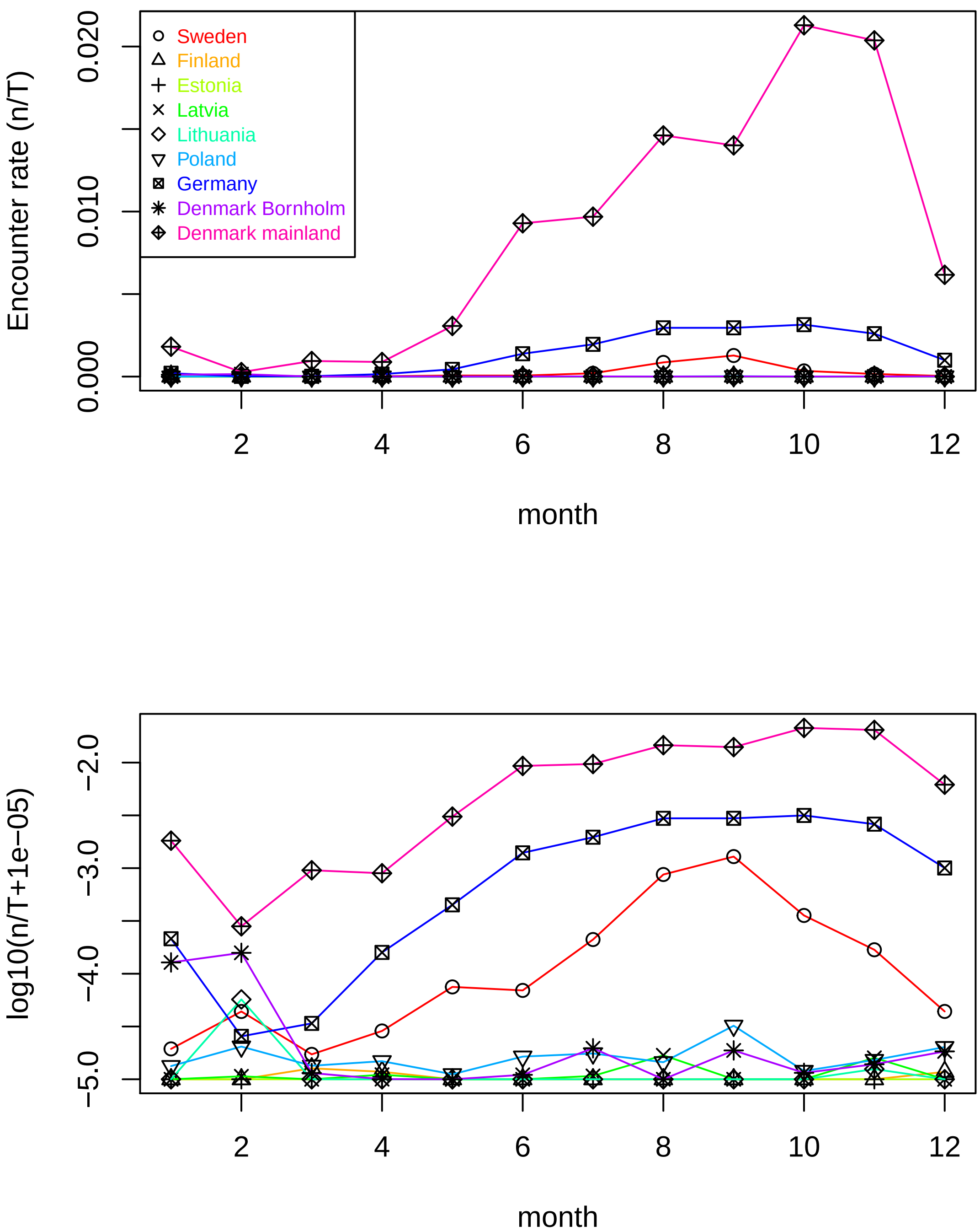


Figure 1: Average encounter rate by month, by country. Bottom plot is on the log10 scale, to show patterns in low density countries.

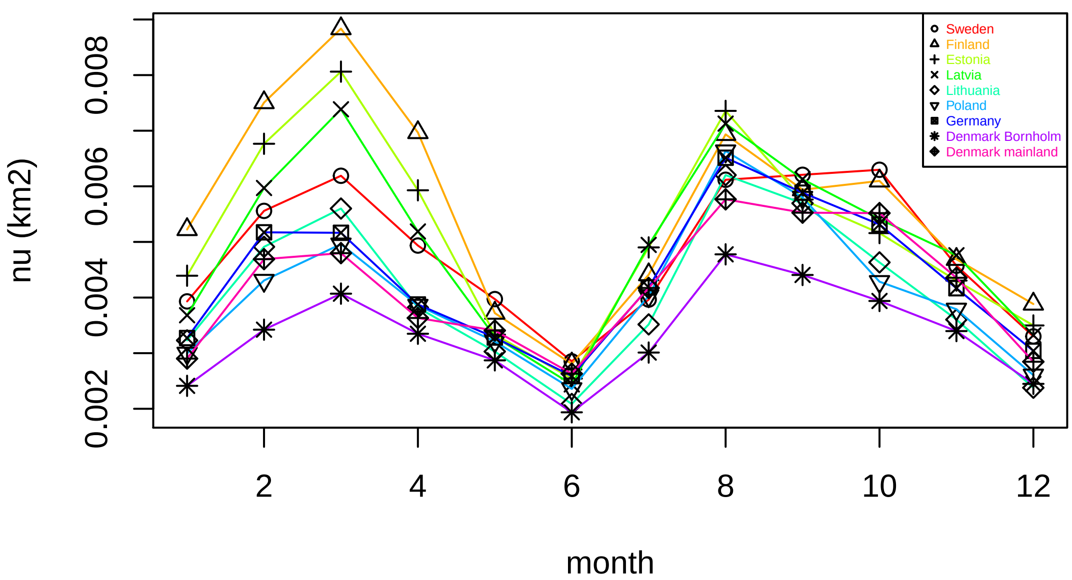


Figure 2: Average effective detection area by month, by country.

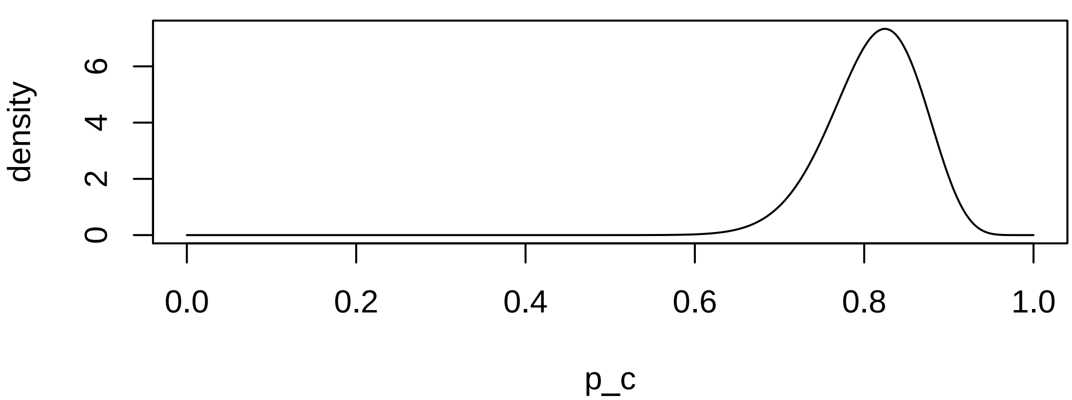


Figure 3: Beta density used to generate samples for p_c from tag data.

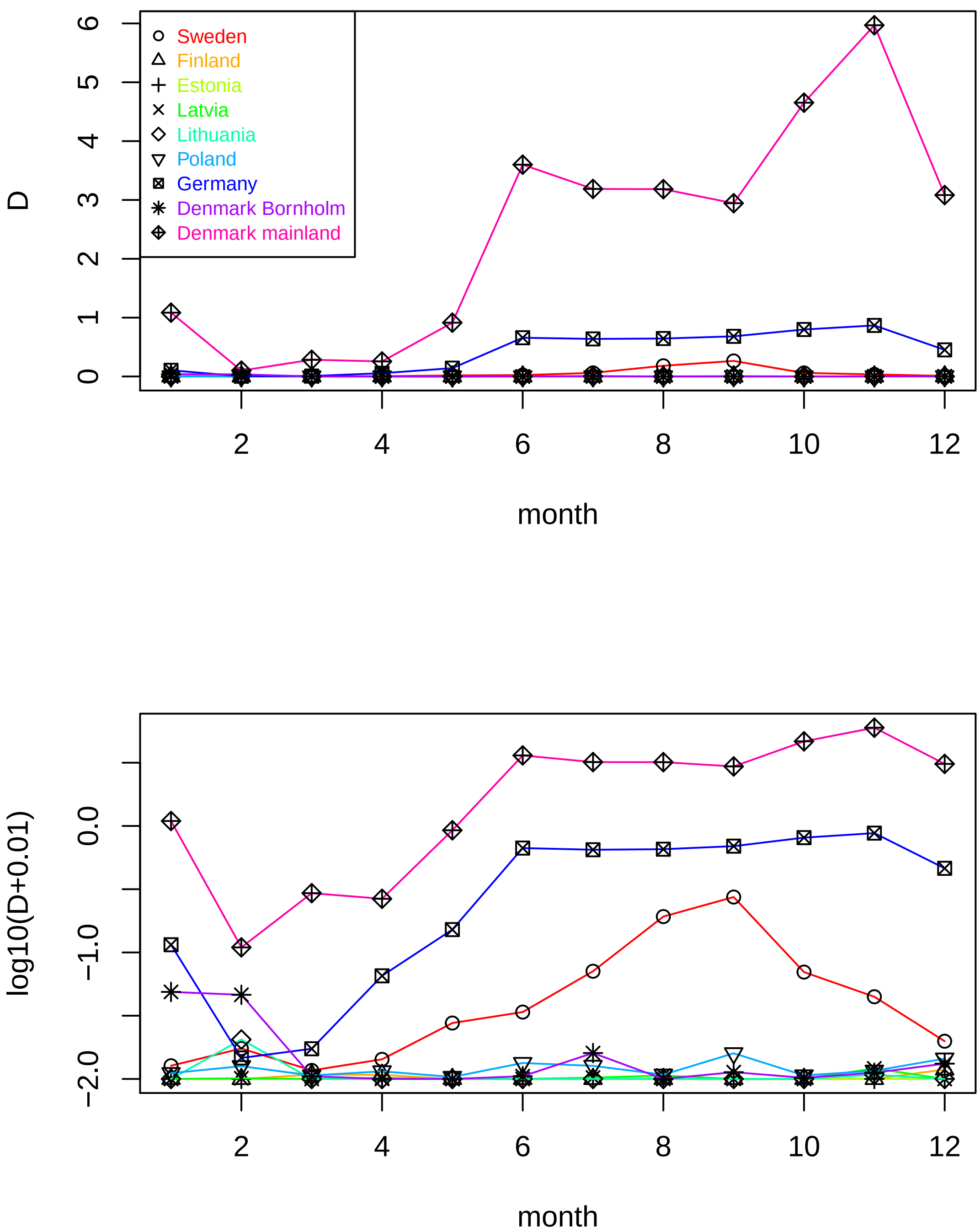


Figure 4: Average density by month, by country. Bottom plot is on the log10 scale, to show patterns in low density countries.

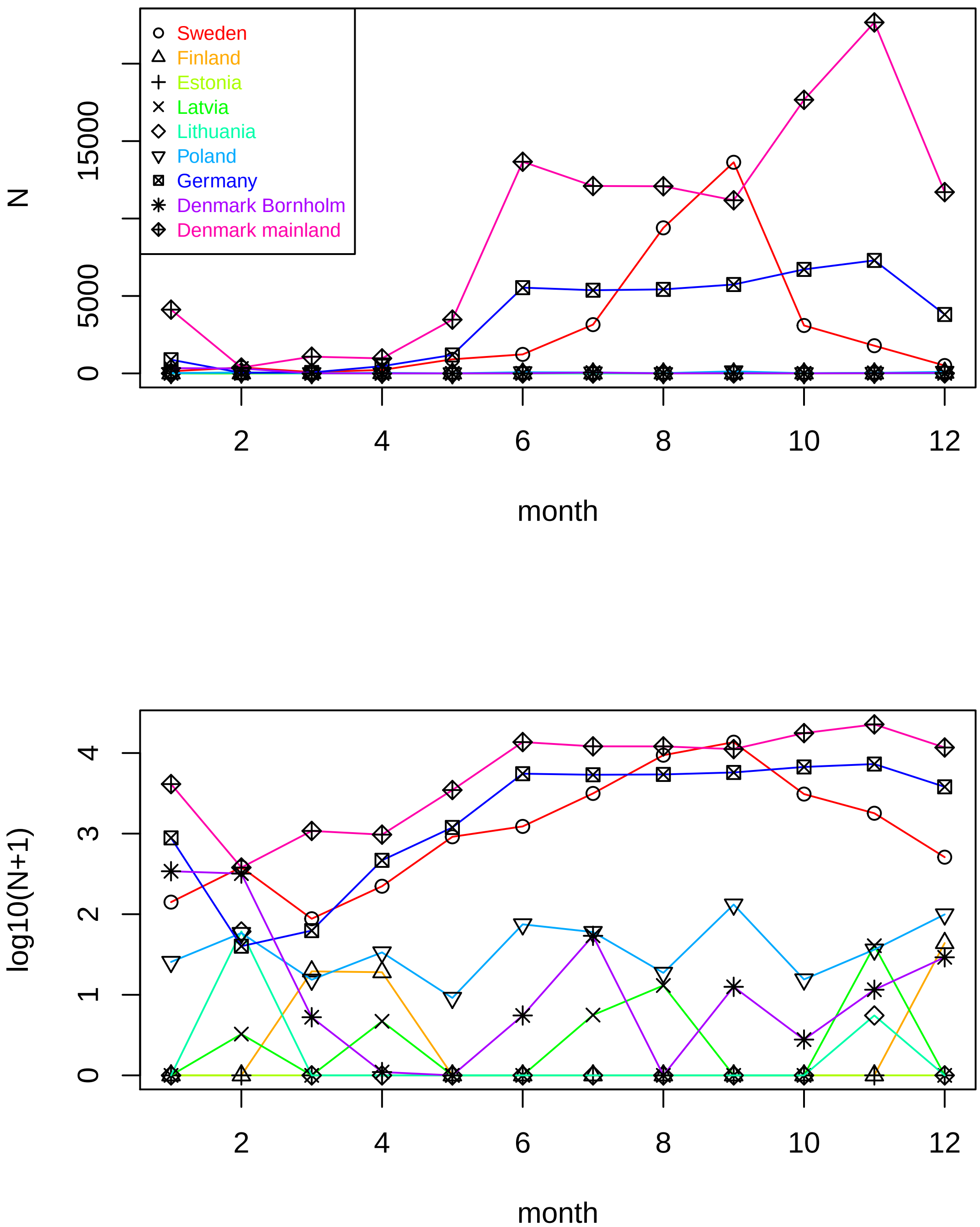


Figure 5: Average abundance by month, by country. Bottom plot is on log10 scale.

	name	country	D	n.stations	A	N
1	Sweden	1	0.01041	97	51609.57	537
2	Finland	2	0.00055	45	23004.63	13
3	Estonia	3	0.00000	30	24587.97	0
4	Latvia	4	0.00050	27	18734.87	9
5	Lithuania	5	0.00146	8	5719.03	8
6	Poland	6	0.00183	37	21941.17	40
7	Germany	7	0.26159	16	8411.58	2200
8	Denmark Bornholm	8	0.00944	12	8779.80	83
9	Denmark mainland	8	2.12468	8	3796.63	8067

Table 1: Estimates of density and abundance for winter

	region	name	country	D	n.stations	A	N
1	NE	Sweden	1	0.01073	87	44859.85	481
2	NE	Finland	2	0.00000	46	23004.63	0
3	NE	Estonia	3	0.00000	34	24587.97	0
4	NE	Latvia	4	0.00010	32	18734.87	2
5	NE	Lithuania	5	0.00000	8	5719.03	0
6	NE	Poland	6	0.00048	25	14849.22	7
7	NE	Denmark Bornholm	8	0.00000	1	847.51	0
8	SW	Sweden	1	0.67312	12	6749.73	4543
9	SW	Poland	6	0.00517	14	7091.95	37
10	SW	Germany	7	0.59211	16	8411.58	4981
11	SW	Denmark Bornholm	8	0.00162	11	7932.30	13
12	SW	Denmark mainland	8	3.03492	8	3796.63	11522

Table 2: Estimates of density and abudance for summer

	name	country	A	D	mean.D	lcl.D	ucl.D	cv.D
1	Sweden	1	51610	0.0104	0.0118	0.0042	0.0215	0.43
2	Finland	2	23005	0.0005	0.0007	0.0001	0.0021	1.20
3	Estonia	3	24588	0.0000	0.0000	0.0000	0.0000	
4	Latvia	4	18735	0.0005	0.0006	0.0000	0.0019	1.14
5	Lithuania	5	5719	0.0015	0.0015	0.0001	0.0039	0.78
6	Poland	6	21941	0.0018	0.0021	0.0009	0.0041	0.47
7	Germany	7	8412	0.2616	0.3076	0.1028	0.6021	0.49
8	Denmark Bornholm	8	8780	0.0094	0.0107	0.0011	0.0268	0.76
9	Denmark mainland	8	3797	2.1247	2.4617	0.8909	4.8910	0.51

Table 3: Winter density bootstrap results

	name	country	N	lcl.N	ucl.N
1	Sweden	1	537	218	1112
2	Finland	2	13	3	49
3	Estonia	3	0	0	0
4	Latvia	4	9	0	36
5	Lithuania	5	8	0	22
6	Poland	6	40	19	89
7	Germany	7	2200	865	5065
8	Denmark Bornholm	8	83	10	235
9	Denmark mainland	8	8067	3383	18569

Table 4: Winter abundance bootstrap results

	D	mean.D	lcl.D	ucl.D	cv.D	N	mean.N	lcl.N	ucl.N
1	0.06578	0.07634	0.03323	0.14353	0.4285	10958	12718	5535	23910

Table 5: Winter total

	name	country	A	D	mean.D	lcl.D	ucl.D	cv.D
1	Sweden	1	44860	0.0109	0.0117	0.0016	0.0241	0.67
2	Finland	2	23005	0.0000	0.0000	0.0000	0.0000	
3	Estonia	3	24588	0.0000	0.0000	0.0000	0.0000	
4	Latvia	4	18735	0.0001	0.0001	0.0000	0.0002	0.68
5	Lithuania	5	5719	0.0000	0.0000	0.0000	0.0000	
6	Poland	6	14849	0.0005	0.0005	0.0001	0.0010	0.53
7	Denmark Bornholm	8	848	0.0000	0.0000	0.0000	0.0000	

Table 6: Summer NE density bootstrap results

	name	country	N	lcl.N	ucl.N
1	Sweden	1	488	73	1081
2	Finland	2	0	0	0
3	Estonia	3	0	0	0
4	Latvia	4	2	0	4
5	Lithuania	5	0	0	0
6	Poland	6	7	1	14
7	Denmark Bornholm	8	0	0	0

Table 7: Summer NE abundance bootstrap results

	D	mean.D	lcl.D	ucl.D	cv.D	N	mean.N	lcl.N	ucl.N
1	0.00375	0.00402	0.00060	0.00823	0.6551	497	533	80	1091

Table 8: Summer NE total

	name	country	A	D	mean.D	lcl.D	ucl.D	cv.D
1	Sweden	1	6750	0.6825	0.7525	0.1150	1.6906	0.62
2	Poland	6	7092	0.0052	0.0057	0.0007	0.0109	0.51
3	Germany	7	8412	0.6004	0.6467	0.2788	1.1277	0.37
4	Denmark Bornholm	8	7932	0.0016	0.0018	0.0002	0.0041	0.67
5	Denmark mainland	8	3797	3.0773	3.3570	1.5559	5.7315	0.34

Table 9: Summer SW density bootstrap results

	name	country	N	lcl.N	ucl.N
1	Sweden	1	4607	776	11411
2	Poland	6	37	5	77
3	Germany	7	5050	2345	9486
4	Denmark Bornholm	8	13	2	32
5	Denmark mainland	8	11683	5907	21760

Table 10: Summer SW abundance bootstrap results

	D	mean.D	lcl.D	ucl.D	cv.D	N	mean.N	lcl.N	ucl.N
1	0.62946	0.68618	0.39613	1.11894	0.3029	21390	23318	13461	38024

Table 11: Summer SW total