Analysis of the UNCW and Duke University aerial and shipboard surveys of the Jacksonville USWTR for the period January 2009 to December 2012

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ABSTRACT

This report describes the analysis of data collected during aerial and shipboard surveys of the Jacksonville USWTR, undertaken by Duke University and the University of North Carolina at Wilmington, for the period January 2009 to November 2012. The aim of the analysis was to estimate monthly abundance of the marine mammals in the region of interest using density surface modelling methods. These estimates should be considered as minimum values because no account was taken of imperfect detection on the trackline or of animals that were below the surface and, hence, unavailable for detection. Detection functions were generated for the species groups dolphins, medium-sized cetaceans (*Grampus griseus, Globicephala* and kogiids), large cetaceans and turtles. There were sufficient detections to generate spatio-temporal abundance estimates (uncorrected for availability bias or perception bias) for *Stenella sp*. dolphins, bottlenose dolphins (*Tursiops truncatus*), medium-sized cetaceans, loggerhead turtles (*Caretta caretta*) and leatherback turtles (*Dermochelys coriacea*). Only a mean, minimum surface could be estimated for large whales.

Predicted, minimum, monthly abundance estimates of *Stenella* sp. dolphins for the time period of interest varied between 80 (95% confidence interval: 10 – 280) and 10400 animals (5300 – 25400). Predicted abundance estimates for bottlenose dolphins varied between 980 (240 – 2900) and 6500 (3300 – 15400). Predicted minimum abundance of medium-sized cetaceans varied between 5 (0 – 30) and 50 (0 – 210). Predicted monthly abundance of leatherback turtles varied between 1 (0 – 7) and 99 (39 – 160). Predicted abundance of loggerhead turtles varied between 540 (200 – 2640) and 2930 (1220 – 12420). The mean minimum surface abundance of large whales was less than one (0 - 2).

INTRODUCTION

The Jacksonville USWTR aerial and shipboard surveys for 2009 – 2012 were carried out by the University of North Carolina at Wilmington (UNCW) and Duke University, respectively. The aim of these surveys was to collect data to estimate density and abundance of marine animals in the Jacksonville USWTR region, which is off the east coast of Florida in the Atlantic (Fig. 1). Maps of estimated density were obtained using density surface modelling techniques and abundances were obtained from these maps. These techniques allowed density to vary both spatially and temporally through the explanatory variables included in the models and since data had been collected throughout the year, effects of seasonal abundance changes could be investigated.

SURVEY METHODS

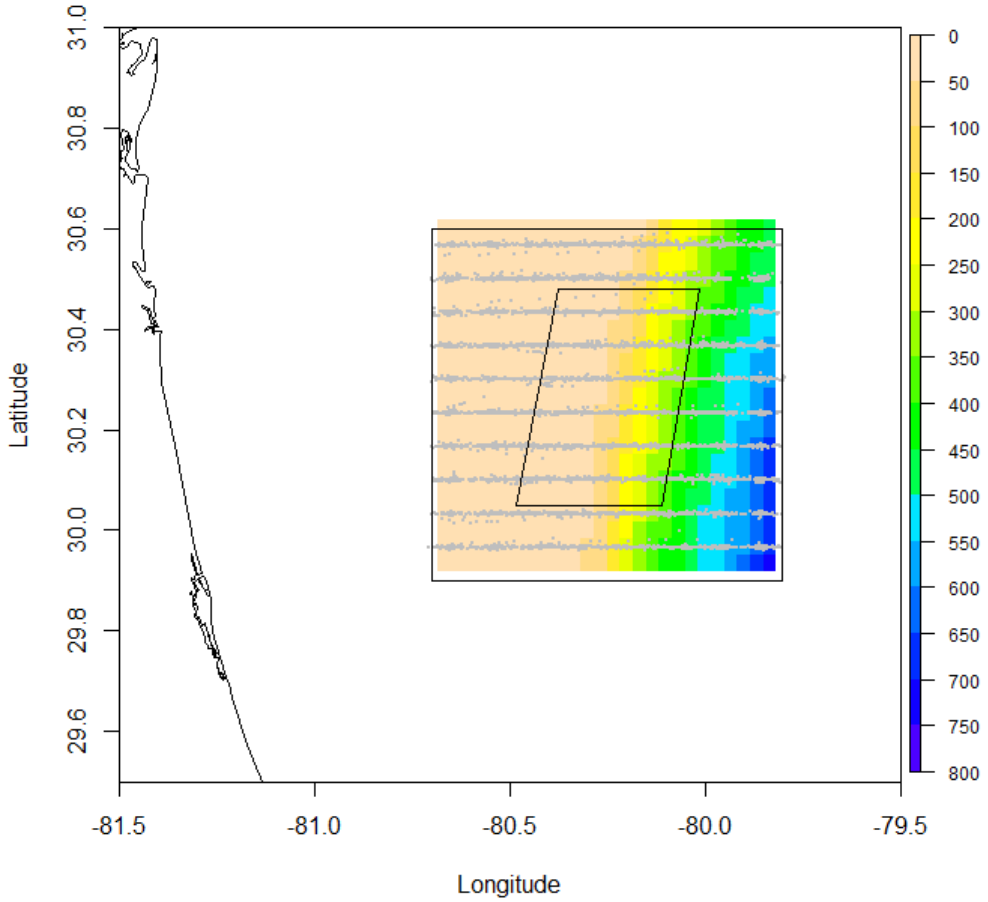
Region of interest

The Jacksonville USWTR core region of interest (hereafter "inner" region) is shown in Figure 1 with an outer survey zone (hereafter "outer") also shown. The area of the inner region is 1681km^2 and the area of the outer region (excluding inner) is 5028km^2. Abundance estimates were obtained for both the inner USWTR region and the outer region separately.

Survey effort

Ten parallel transect lines were aligned east-west across the region and both aerial and ship surveys used these transect lines (Fig. 1). Aerial surveys were conducted more or less monthly from January 2009 and generally all transect lines were covered several times during the month. Ship surveys started in July 2009 and were conducted monthly, weather permitting, until March 2011. Between one and four transect lines were surveyed during each month.

Figure 1. Jacksonville survey region with depth (m) indicated by colours. Each grid cell has dimensions 1/30 degree of latitude and 1/30 of a degree of longitude. Grey lines indicate midpoint of effort segments from all surveys. The boundaries of the outer and inner survey areas are shown by solid lines



Aerial search protocol

The plane flew at a height of 305m above sea level. Two observers (one on either side of the plane) searched for marine animals and when an animal was detected, they recorded vertical and horizontal angle to the sighting, species and group size. When a whale or dolphin was detected, search effort was stopped and the plane left the transect line to investigate the sighting in order to confirm species and group size. The search effort was resumed along the transect line after leaving the sighting. Environmental conditions were also recorded.

Estimates of perpendicular distance from the transect line to the sighting were obtained either by reference to direct estimates of distance by observers, trigonometry from the declination angle of the plane to the observed animals or for cetaceans by trigonometry from the position of the plane at first observation of the animals and subsequent location directly above the animals.

Shipboard search protocol

On detecting animals, observers recorded the species, group size, sighting angle and radial distance to the group as well as environmental conditions. Estimates of perpendicular distance were obtained from the sighting angle and radial distance.

STATISTICAL METHODS

The aim of the analysis was to estimate a density map for each species/taxa using the count method of Hedley *et al*. (2004, 1999). However, the numbers of sightings of some taxa were too few to estimate a density surface so

instead a uniform surface was assumed – this was equivalent to undertaking a conventional line transect sampling analysis (Buckland *et al*. 2001).

For each taxa, the probability of detection associated with each sighting (assuming certain detection on the trackline) was estimated and this probability was then used to estimate abundance in small segments of the trackline. These estimated densities formed the response variable in a generalized additive model (GAM) with location, habitat and temporal variables as potential explanatory variables. After model selection, the chosen models were used to estimate density for the region of interest and abundance was obtained by numerically integrating under the predicted density surface. Note that the resulting abundances are relative (rather than absolute) because they do not take into account imperfect detection on the transect line or the availability of animals at the surface.

Estimation of detection probabilities

In conventional line transect sampling, the probability of detection depends only on the perpendicular distance of the sighting to the transect (y) and at zero perpendicular distance the probability of detection is assumed to be one (denoted by $g(0)=1$). Both a hazard-rate ($1-\exp(-y/\sigma)^{-b}$) and a half-normal ($\exp(-y^2/2\sigma^2)$) form were considered as suitable forms for the detection functions (σ is the scale parameter) the most appropriate form for the relevant data (Buckland *et al*. 2001). The effects of covariates, other than perpendicular distance, were incorporated into the detection function model by setting the scale parameter in the model to be an exponential function of the covariates (Marques 2001). Thus, the probability of detection becomes a multivariate function, $g(y,\boldsymbol{v})$, representing the probability of detection at perpendicular distance y and covariates $\boldsymbol{v}$ ($\boldsymbol{v} = v_1,..,v_Q$ where Q is the number of covariates). The scale term, σ, has the form:

$$\sigma_k = \exp\left(\beta_0 + \sum_{q=1}^{Q}(\beta_q v_{kq})\right)$$

and β_0 and β_q ($q=1,\ldots,Q$) are parameters to be estimated. With this formulation, it is assumed that the covariates affect the rate at which detection probability decreases as a function of distance, but not the shape of the detection function. The covariates considered for inclusion into the aerial detection function were Beaufort sea state (BSS), group size, cloud cover, visibility, glare and species. All but the latter variable were treated as continuous variables. The covariates considered for inclusion into the ship detection function were Beaufort sea state (BSS), group size, weather and species. All but the latter variable were treated as continuous variables. A forward, stepwise selection procedure was used to decide which covariates to include in the model, with a minimum Akaike's Information Criterion (AIC) inclusion criterion. All model selection was performed using a set of customised functions (mrds v.2.0.6, Laake et al. 2013) within the statistical programming package *R* (*R* Developmental Core Team, 2002). This facilitated estimation of variance within *R* (see below).

Some of the data from Jacksonville was supplemented by additional survey data from the UNCW right whale surveys to increase sample sizes for detection function fitting. Despite this, there was a paucity of sightings for individual species and so data were amalgamated across species into groups with presumed similar detectabilities. For aerial detections, four groups were identified; all dolphin species (except Risso's dolphin), medium-sized cetaceans (Risso's dolphins, pilot whales and kogiids), large whales and turtles. For ship detections, two groups were identified; dolphins (did not include Risso's dolphins as none were seen) and turtles.

Estimation of density surfaces

The 'count model' of Hedley *et al*. (2004) was implemented to model the trend in spatial distribution of the different species. The response variable for this model is the estimated number of individuals in a small segment i of trackline, $\hat{N}_i$, calculated using an estimator similar to the Horvitz-Thompson estimator (Horvitz and Thompson 1952), as follows:

$$\hat{N}_i = \sum_{j=1}^{n_i} \frac{s_{ij}}{\int_o^w \hat{g}(y, v_{ij})\pi(y)dy}, \qquad i = 1, \ldots, T,$$

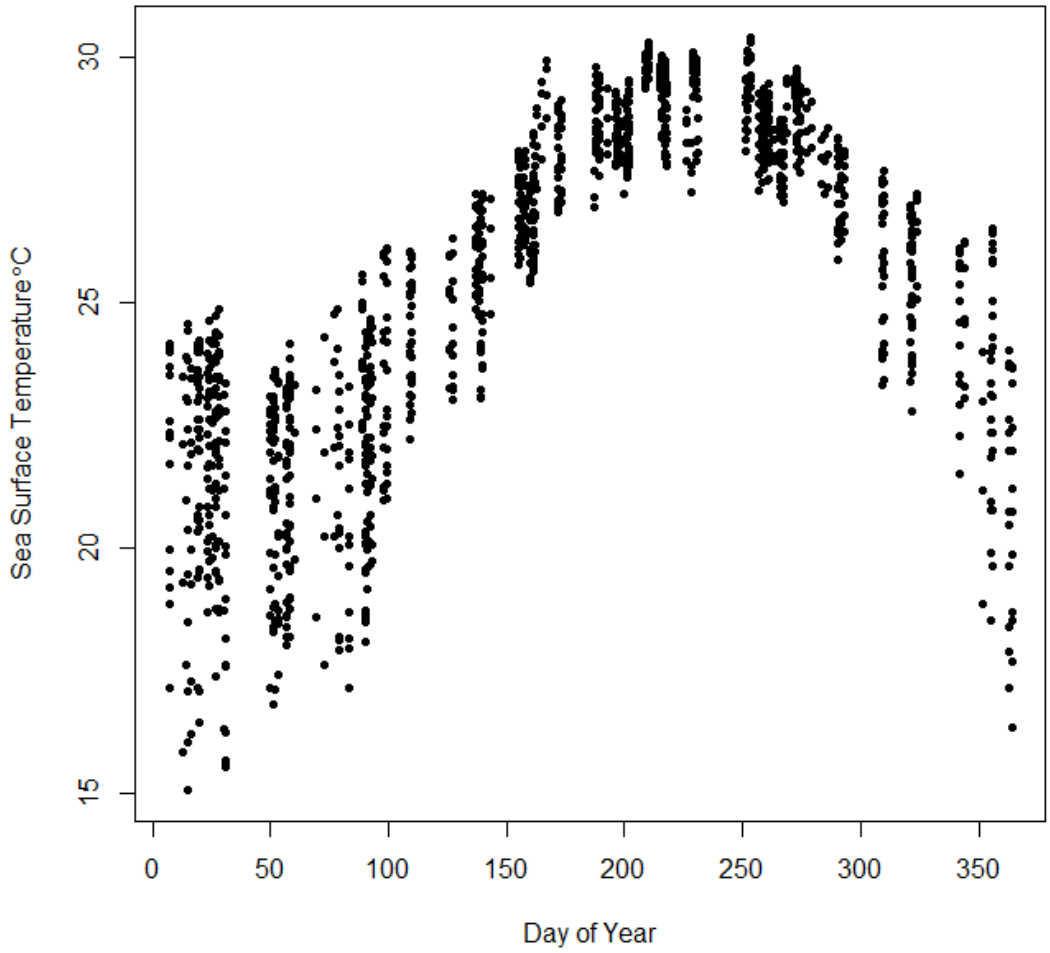
where for segment *i*, $\int_0^w \hat{g}(y, v_{ij})\pi(y)dy$ is the estimated probability of detection of the *j*th detected group, n_i is the number of detected groups in the segment and s_{ij} is the size of the *j*th group. The total number of transect segments is denoted by *T*. By assumption, $\pi(y)$, the probability density function of actual (not necessarily observed) perpendicular distances is uniform up to the truncation distance; this is satisfied by locating transects randomly or with a random start point.

Having obtained the estimated number of individuals in each segment, the density in segment *i*, $\hat{D}_i$, was estimated from $\hat{N}_i / a_i$ where a_i is the area of segment *i*. Segment area was calculated as the length of the segment multiplied by twice the truncation distance (which was decided when modelling the detection function). The realised transect lines were divided up into distinct segments based on when vessels had gone on or off effort and whether there was a change in environmental characteristics. A target segment length of 10km for the aerial survey was chosen as an appropriate compromise between maximising the ratio of non-zero to zero segments, maintaining environmental resolution and giving some measure of spatial independence, although some segments were much smaller if there had been a break in effort or change in environmental conditions. Due to the different sizes of each segment, the segment area was included as an offset (a term with a regression coefficient of one) in the subsequent model.

The main aim was to fit a model with which to predict abundance and data from both the aerial and ship surveys were combined; a covariate called *Platform* differentiated between aerial and ship segments. The environmental covariates considered for inclusion in the abundance models were longitude (*Lon*) and latitude (*Lat*), depth (*Depth*) and sea surface temperature (*SST*). Day of the year (*Dayofyear*) was fitted as a cyclic cubic spline so the smooth function for *Dayofyear* would have the same values at the start and end of the range of data values. Depths were obtained from the ETOPO1 one minute resolution relief data available from NOAA (http://www.ngdc.noaa.gov/mgg/global/global.html). Depths were associated with effort segments by finding the closest point in the bathymetry data to the midpoint of the effort segments using great circle distances. *SST* was obtained from NOAA Optimum Interpolation 1/4 Degree Daily Sea Surface Temperature data obtained from the Advanced Very High Resolution Radiometer (AVHRR) available from ftp://eclipse.ncdc.noaa.gov/pub/OI-daily-v2/NetCDF/ as described in part in Reynolds *et al*. 2007 and allocated to the appropriate segment by great circle distance and appropriate date.

Unsurprisingly, *SST* was strongly related to *Dayofyear* (Figure 2) and *Lon* and *Lat* were correlated *Depth*, thus, the inclusion of only one of these correlated variables in the final models should not be interpreted as necessarily precluding the influence of others.

Figure 2. Relationship between day of year and AVHRR-derived sea surface temperature (°C) for each segment of survey effort.



There were a large proportion of segments where no animals were detected and so, after some preliminary analysis, it was decided that the most appropriate (but nevertheless not ideal) modelling process should be a two stage process; first modelling the presence-absence of animals in segments followed by modelling the density in non-zero segments (i.e. segments where animals were detected). The two resulting surfaces were then multiplied together to obtain estimated density. Generalized cross validation implemented in the *mgcv* package (v. 1.7-13. Wood 2006) in *R* (v. 2.15.0) was used for covariate selection in both GAMs augmented with diagnostic plots, using the principles described in Wood (2001). Taking into account the low percentage of segments containing sightings, a maximum of 4 degrees of freedom (5 knots) was allowed in the selection of 1D smooths, (with the exception of year that was allowed 3 knots as there were only 4 years) and 6 knots were allowed for *Lon* and *Lat*. Some 2D and 3D smooths were also considered and were allowed a composite number of knots. Thus, the initial model considered for the presence-absence (quasibinomial) model was:

Platform + s(KmEW, KmNorth, Year, k=15) + s(Dayofyear, k=5, Year) + s(SST, k=5) + s(Depth, Year, k=8)

where *k* indicates the number of knots. In the *Dayofyear* term, *Year* was treated as a factor reflecting the fluctuating commencement of the spring plankton bloom. Backwards model selection was used to select the final model.

The initial model for the non-zero density component (assuming a Gamma error structure with a log link) was similar the above except that the *s(Dayofyear, k=5, Year)* was not included – the number of segments with sightings was small compared to the total number of segments and in the variance estimation process (see later) the full range of dates was not

necessarily generated in each iteration and these would be required for prediction if *s(Dayofyear, k=5, Year)* was included in the model.

Prediction

The selected models were used to predict density of marine animals in the inner and outer regions separately using a 2 minute resolution prediction grid. Animal abundance was estimated by numerically integrating under this predicted density surface. If survey platform was included in the model, abundance was predicted using *Platform* equal to "ship" as this was felt to reflect the best detection on the transect line (i.e. $g(0)$ from the ship was felt to be closer to one than the aerial $g(0)$) with the exception of leatherback turtles where the reverse was felt to be more likely (i.e. aerial $g(0) >$ ship $g(0)$).

Variance estimation

Variance was estimated by repeating (1000 times) the entire abundance estimation process on samples, drawn from the data, to obtain a distribution of abundance estimates. Samples were obtained by sampling transects, at random and with replacement, such that the selected effort reflected the effort in the original sample. Confidence intervals were obtained from the distribution of abundance estimates using the 2.5% and 97.5% percentiles to obtain the lower and upper limits, respectively, thus excluding the most extreme values.

Explanatory models

To explore the habitat preferences of specific taxa (bottlenose dolphins, *Stenella sp*. dolphins, leatherback turtles and loggerhead turtles) a separate set of models were fitted to the presence-absence data but excluding the covariates latitude and longitude. To reduce spatial correlation between segments, models were fitted to a subset of data, choosing segments that were far enough apart such that the estimated presence-absences were independent. The distance at which independence between segments occurred was investigated by plotting the variograms of the model residuals (where distance between segments was based on time rather than location) separately for the aerial and ship platforms. Once the time over which data points became independent was identified, these times were converted into distances given the speed of the platform. Then, based on the distance that suggested independent data points, a sequential sample of segments was taken to generate a new data set with which to explore habitat preferences.

A simplified model of the form

Platform + s(SST, k=5) + s(Depth, Year, k=8)

was fitted to the data initially and backwards model selection was performed as before.

In the case of leatherback and loggerhead turtles, a final test was performed after model selection on the presence-only component of the analysis to see if there was any evidence that turtles were missed in regions/times of high cetacean density. The adjusted sightings density for all cetaceans was introduced as a potential linear term into the final chosen model to see if turtle probability of presence decreased when cetacean numbers were high.

RESULTS

Summary of search effort and number of sightings

The aerial surveys realised 63600 km of search effort and the ship surveys realised 2413 km of search effort. The breakdown of effort by month is given in Table 1.

Table 1. Realized monthly effort (km) in the Jacksonville survey area.

Month	2009		2010		2011		2012	
	Aerial	Boat	Aerial	Boat	Aerial	Boat	Aerial	Boat
January	888	0	881	207	1692	138	1658	0
February	1706	0	2536	0	1268	0	0	0
March	431	0	1680	139	0	205	559	0
April	0	0	2047	0	1541	0	1710	0

May	0	0	811	145	1330	0	1606	0
June	1683	0	3011	309	1029	0	0	0
July	1708	166	1024	225	1690	0	1692	0
August	1696	256	1696	36	1680	0	0	0
September	3309	210	1643	0	1363	0	1279	0
October	822	137	1534	171	847	0	0	0
November	1688	0	860	0	0	0	1334	0
December	1816	0	1846	69	0	0	0	0

Aerial survey sightings

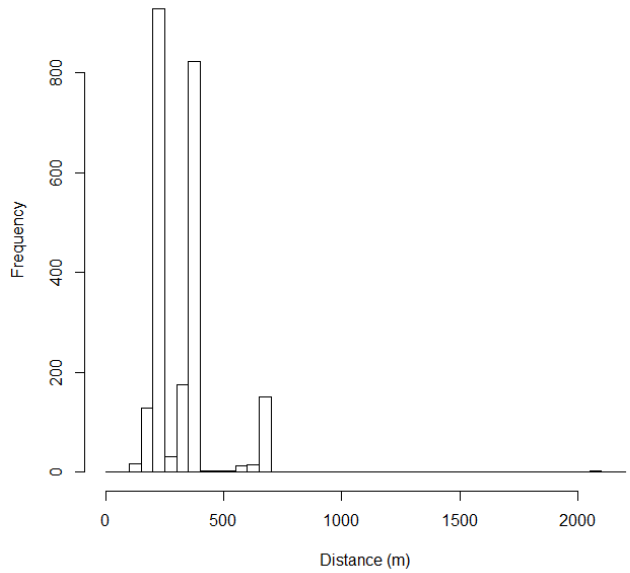
There were 521 sightings of groups of smaller dolphins within the truncation distance of 1400 m; these consisted of 250 groups of bottlenose dolphins, 217 of spotted dolphins (*Stenella frontalis*; plus one unidentified *Stenella sp*.), five of rough-toothed dolphins (*Steno bredanensis)* and 48 unidentified delphinids. Eighty percent of dolphin sightings were of animals in groups of fewer than 20, however, a group of 100 spotted dolphins was detected in January, 2009.

Sixty-four medium-sized cetacean groups were detected within the truncation distance (50 Risso's dolphins, 12 pilot whales and 2 sightings of kogiids).

Eleven groups of baleen whale were detected; minke (8 groups), unidentified baleen whale (1), North Atlantic right whale (1) and humpback (1). An additional 5 sightings, from the UNCW right whale aerial surveys, were included to increase the sample size in the large whale group.

Turtles were the most numerous taxa detected (2107 groups within the truncation distance) with loggerhead turtles the most detected species of turtle (1657 groups). The other turtle species detected were leatherback (95 groups) and Kemp's ridley (3 groups) along with 352 groups of turtles that were detected but the species could not be identified. The majority (80%) of turtle detections were of single animals but groups of up to eight turtles were detected. The distribution of calculated perpendicular distances shows distinct grouping reflecting the recorded values for the "angle down" bins (Figure 3) and does not conform to the expected shape which would confirm the assumption of monotonically declining detection probability with increasing distance. The reasons for the unusual distribution are not known and worthy of further investigation but it may have been caused in part by rounding of distances; a substantial number of sightings had a perpendicular distance around 210m and 370m. Due to this odd distribution, the data were left truncated at 100m (i.e. all sightings with a perpendicular distance of 100m were excluded from analyses and 100m was subtracted from all remaining perpendicular distances) and then right truncated at 500m and the distances binned into 200m bins. Unknown turtles were allocated on a pro-rata basis to the 3 known categories based on their proportions to each other. Fitting the Kemp's ridley turtles proved difficult so they were omitted form the data.

Figure 3. Histograms of actual perpendicular distances of aerial turtle sightings prior to truncation.



Shipboard survey sightings

Sixty-one groups of dolphins were detected made up of spotted (36), bottlenose (24) and one group of unidentified delphinid. The majority of dolphins were in groups of between one and ten animals. The maximum group size was 55 spotted dolphins recorded in October, 2010.

Sixty-six groups of turtles were detected within the truncation distance, made up of loggerhead (56) and leatherback (10) turtles. A group of two loggerhead turtles was detected otherwise all other sightings of turtles were of single animals.

Only one medium-sized cetacean group (a Risso's dolphin group) and no large cetaceans were detected during the ship surveys.

Detection functions

The (scaled) histograms of perpendicular distances (after truncation) and the fitted detection functions are shown in Figures 4 & 5 with details provided in Table 2. Perpendicular distances were binned into intervals for model fitting and to avoid a long tail in the detection function (Buckland *et al*. 2001), typically between 5 -10% of the longest distances were truncated.

Table 2. Summary of detection function models; number of detected groups (n) within the given truncation distances, detection function (DF) form (half normal HN or hazard rate HR), covariates added in addition to perpendicular distance and detection probability within the truncation distance.

Species	Platform	*n*	Truncation distance (m)	DF form	Additional Covariates	Detection probability (se)
Dolphin	Aerial	521	1400	HN	Visibility	0.508 (0.018)
	Ship	61	250	HR	BSS + Weather	0.201 (0.091)

Turtles	Aerial	2104	400*	HN	BSS + Group Size	0.886 (0.0431)
	Ship	66	80	HN	-	0.583 (0.059)
Medium cetaceans	Aerial	50	1200	HN	-	0.626 (0.073)
	Ship	1	1000	Strip	-	1 (0)
Large whales	Aerial	15	1200	HN	-	0.645 (0.126)
	Ship	0	-	-	-	-

*with left truncation at 100 m.

Figure 4. Aerial detections: fitted detection functions overlaid onto scaled perpendicular distance distributions (data binned into 200 m distance intervals); a., dolphins, b. turtles, c. medium-sized cetaceans and d. large whales. The points are individual detections.

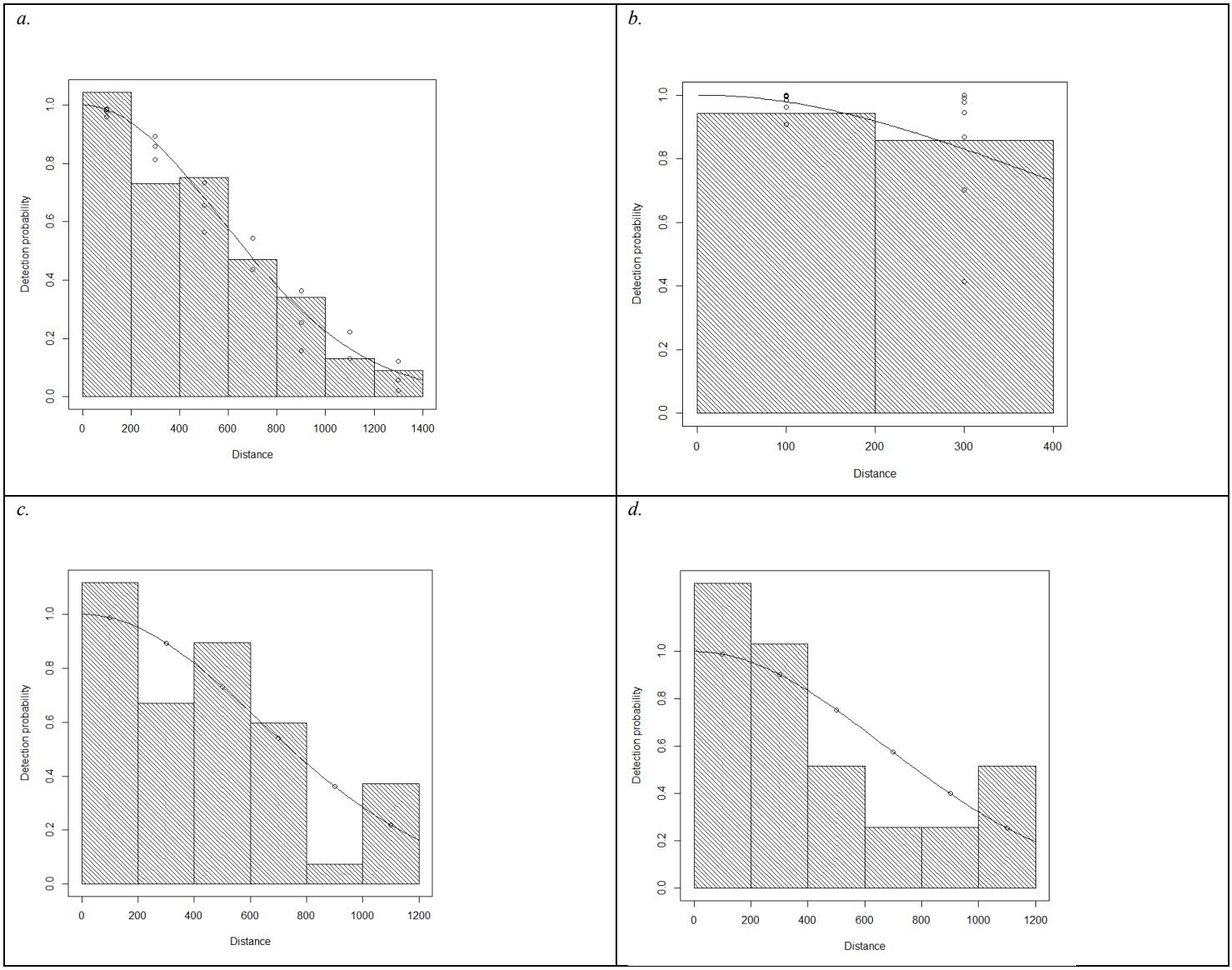
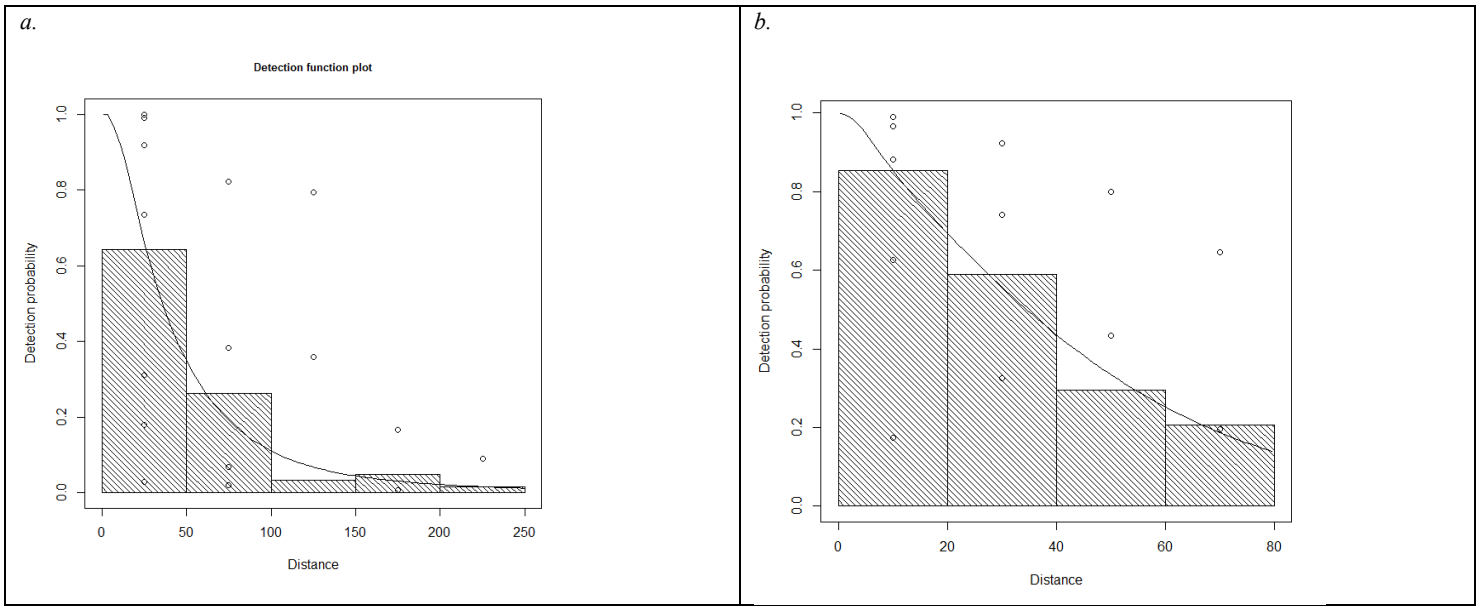


Figure 5. Ship detections: fitted detection functions overlaid onto scaled perpendicular distance distributions; a. dolphins (data binned into 50m sections), b. turtles (data binned into 20m sections).



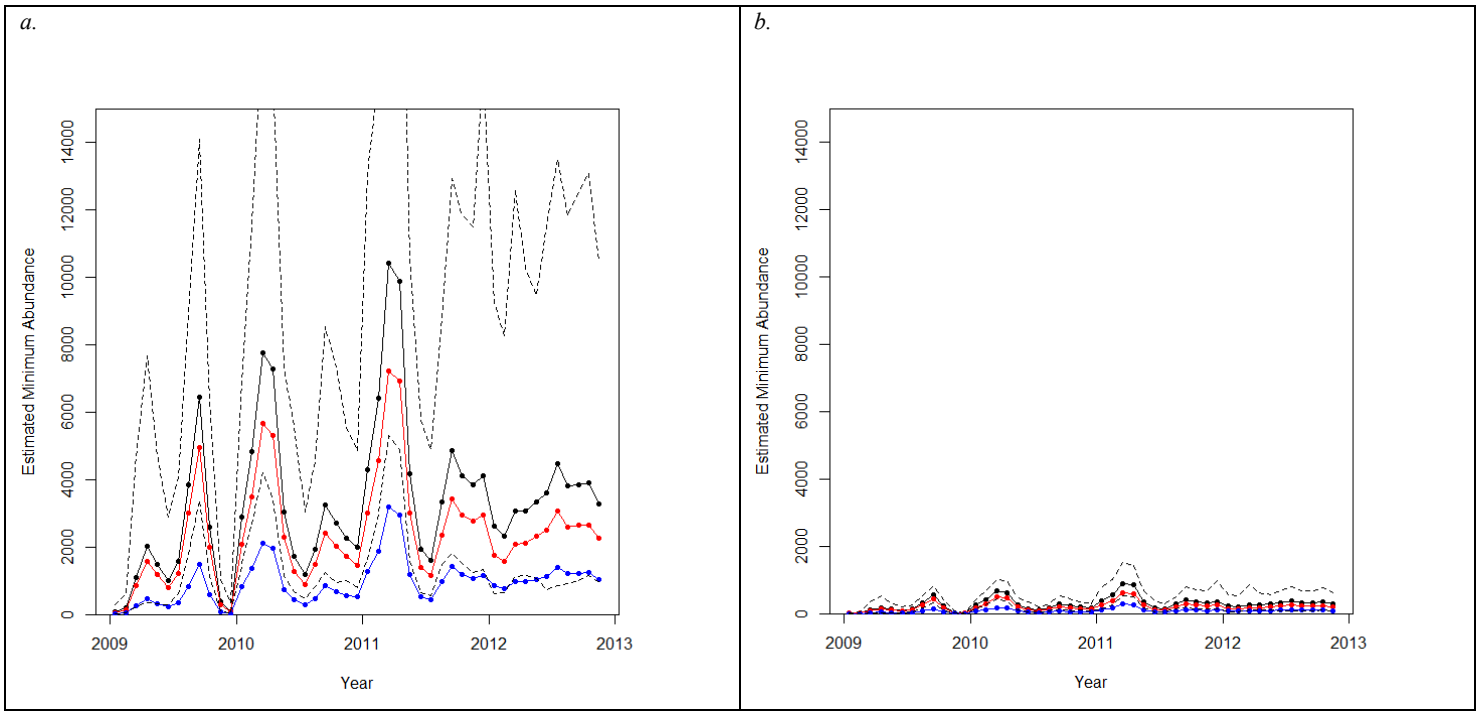
Density surface models for abundance

The aerial search effort was divided into 6452 segments with a mean length 9.39km (SE=0.03km). The ship effort was divided into 600 segments with a mean length of 4.02km (SE= 0.14km). Summaries of the fitted models are given in Table 3. Predicted density surfaces for the last month of survey data (November 2012) are given for each of the species.

Table 3. Summary of density surface models used for abundance estimation: selected model (where s(var) indicates a smooth function of var) and percentage of deviance explained by the model. The total number of segments was 7052 and n is the number of segments containing detections.

Species	**Presence-absence model**		**Non-zero presence model**		
	Selected model	**Explained deviance %**	***n***	**Selected model**	**Explained deviance %**
Stenella sp.	*Platform + s(Lon, Lat, Year, k=15) + s(Dayofyear, k=4,Year)+s(SST,k=5) + s(Depth, Year, k=6)*	21.9	259	*Platform + s(Lon,k=5) +* s(*Depth, Year, k=2)*	26.3
Bottlenose dolphins	*s(Lon, Lat, k=12) + s(Dayofyear, k=4, Year) + s(SST, k=5) + s(Depth, k=5) + s(Year, k=3)*	5.5	274	*Platform + s(Lon, k=6) + s(Lat, k=6) + SST*	23.6
Medium-sized cetaceans	*Platform + s(Lon, Lat, Year, k = 15) + s(SST, k=5) + s(Depth, Year, k=8)*	18.5	50	*SST + Year*	19.3
Loggerhead turtles	*Platform +s(Lon, Lat, Year, k=15) +s(Dayofyear, k=5, Year) + s(SST, k=5) + s(Depth,k=5)*	24.4	1272	*Platform + s(Lon, Lat, k=12) + s(SST, k=5) + s(Depth, k=5) + s(Year, k=3)*	18.0
Leatherback turtles	*Platform + s(Lon, Lat, Year, k=15) + s(Dayofyear, k=4,Year) + s(SST,k=5) + s(Depth, Year, k=6)*	19.9	92	*s(Lon, k=5) + s(SST,k=5) + s(Year, k=3)*	28.9

Figure 6. Predicted minimum abundance of Stenella sp. dolphins. Black indicates abundance estimates for the whole region and red and blue represents the abundance estimates for the inner and outer areas, respectively. Dashed lines represent the upper and lower 95% confidence bounds for the abundance estimates for the whole region. a. estimates assuming assuming a ship platform, b estimates assuming an aerial platform.



Stenella sp. dolphins

No obvious seasonal pattern of abundance was apparent (Figure 6) although two peaks in abundance are noticeable for every year except 2012. There were estimated to be substantially more *Stenella* dolphins in 2013 then at the beginning of 2009. *Stenella sp.* dolphins appear to avoid the deeper waters offshore (Figure 7). Predictions were made both assuming a ship platform and an aircraft platform. *Stenella* dolphins are generally more detectable from boats than from the air (Figure 6).

Figure 7. Predicted minimum abundance of Stenella sp. dolphins in November 2012. Colours indicate the density of surface animals per km^2. Grey points indicate the midpoints of effort segments and the red circles indicate the location of detections. The size of the red circle is proportional to the adjusted density of observed animals per km^2.

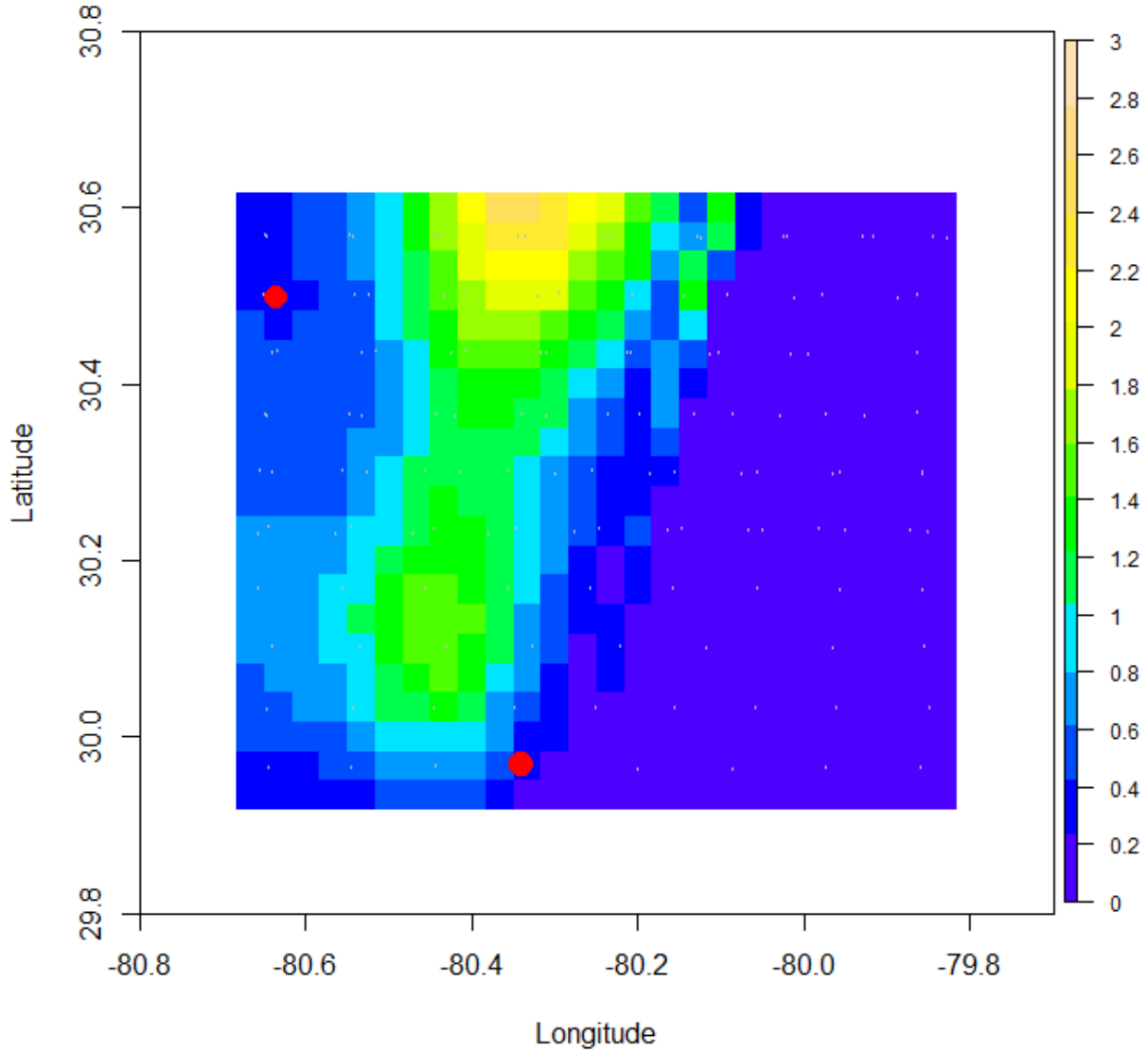
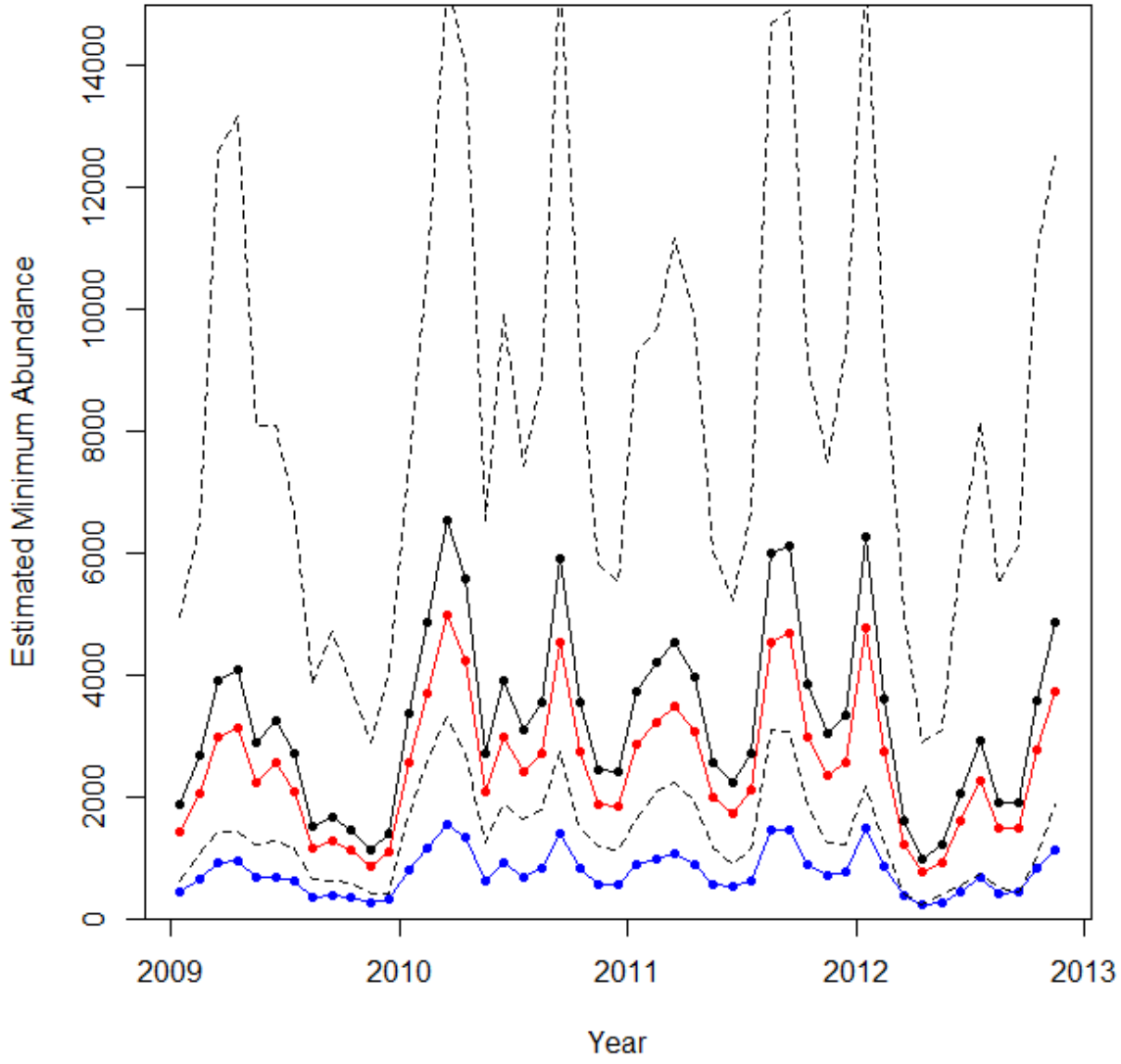


Figure 8. Predicted minimum abundance of bottlenose dolphins. Black indicates abundance estimates for the whole region and red and blue represent the abundance estimates for the inner and outer areas respectively. Dashed line is the 95% confidence interval for the total region.



Bottlenose dolphins

As in the case of *Stenella sp.* there was no consistent pattern of seasonality in estimated minimum abundance except elevated numbers in the early part of the year (Figure 8). The distribution of bottlenose dolphins was heterogenous in space with most animals in deeper water (Figure 9).

Figure 9. Predicted minimum abundance of bottlenose dolphins in November 2012. Colours indicate the density of surface animals per km^2. Grey point indicate the midpoints of effort segments and the area of the red circles is proportional to the adjusted observed density of animals per km^2.

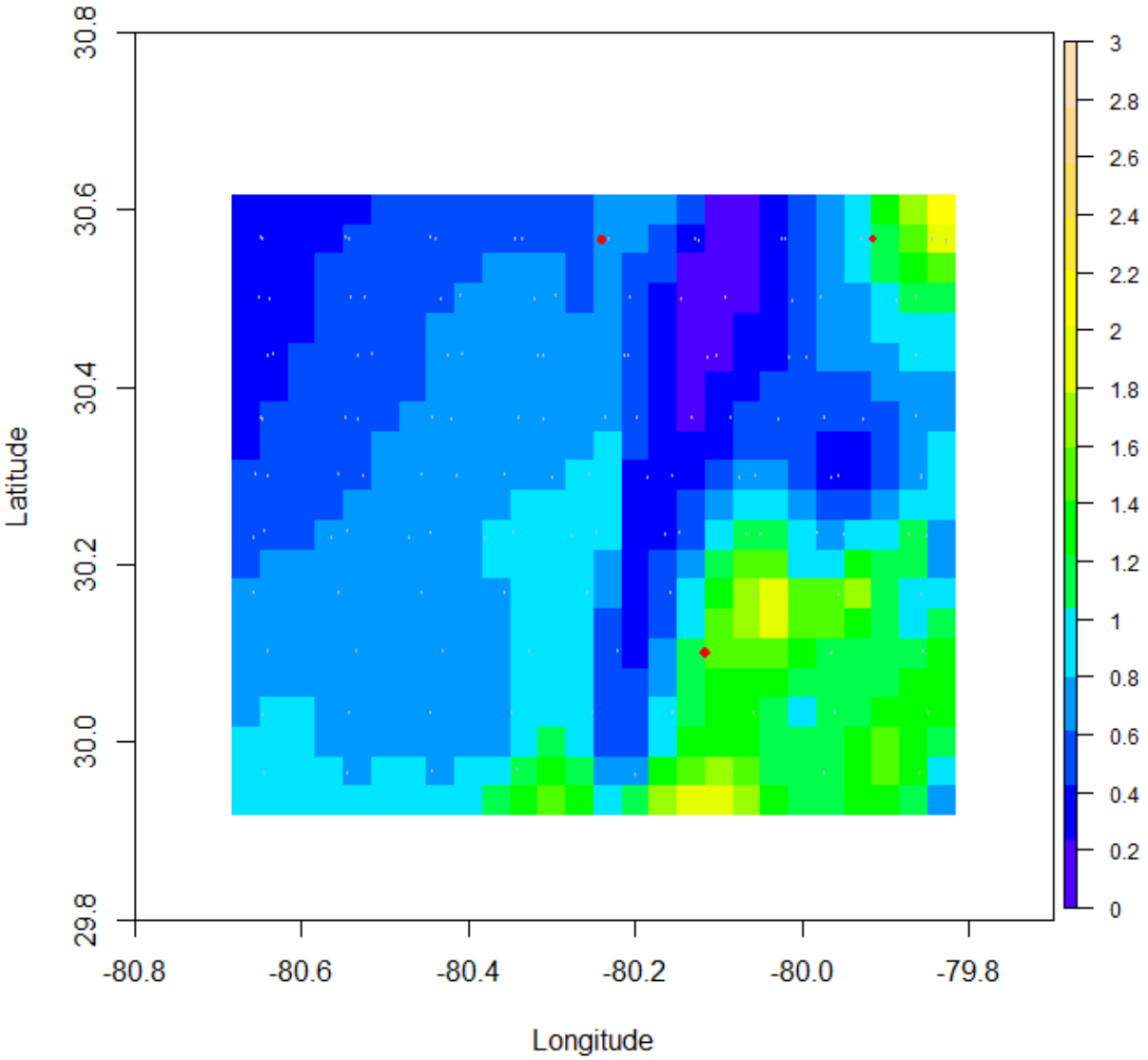
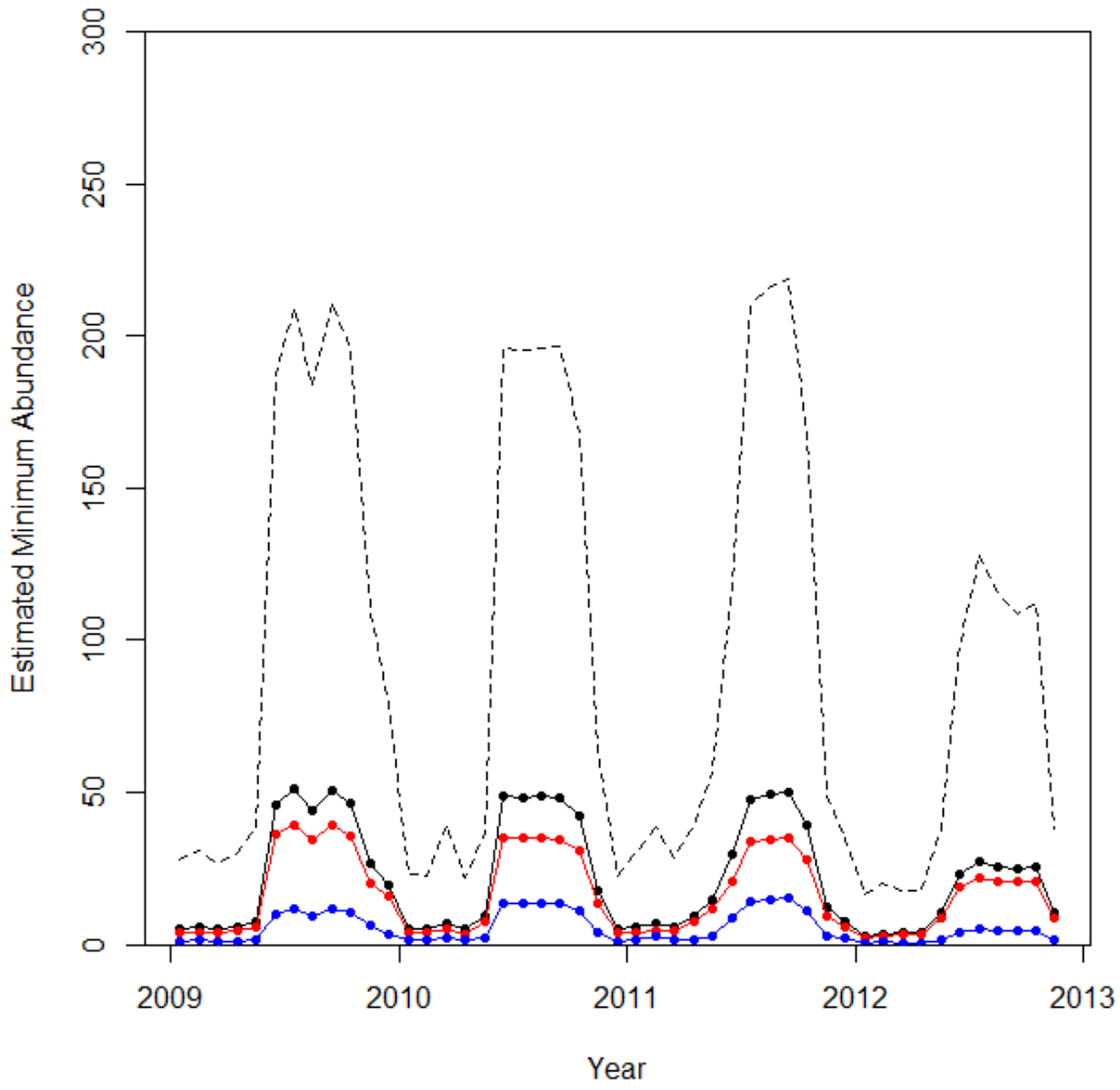


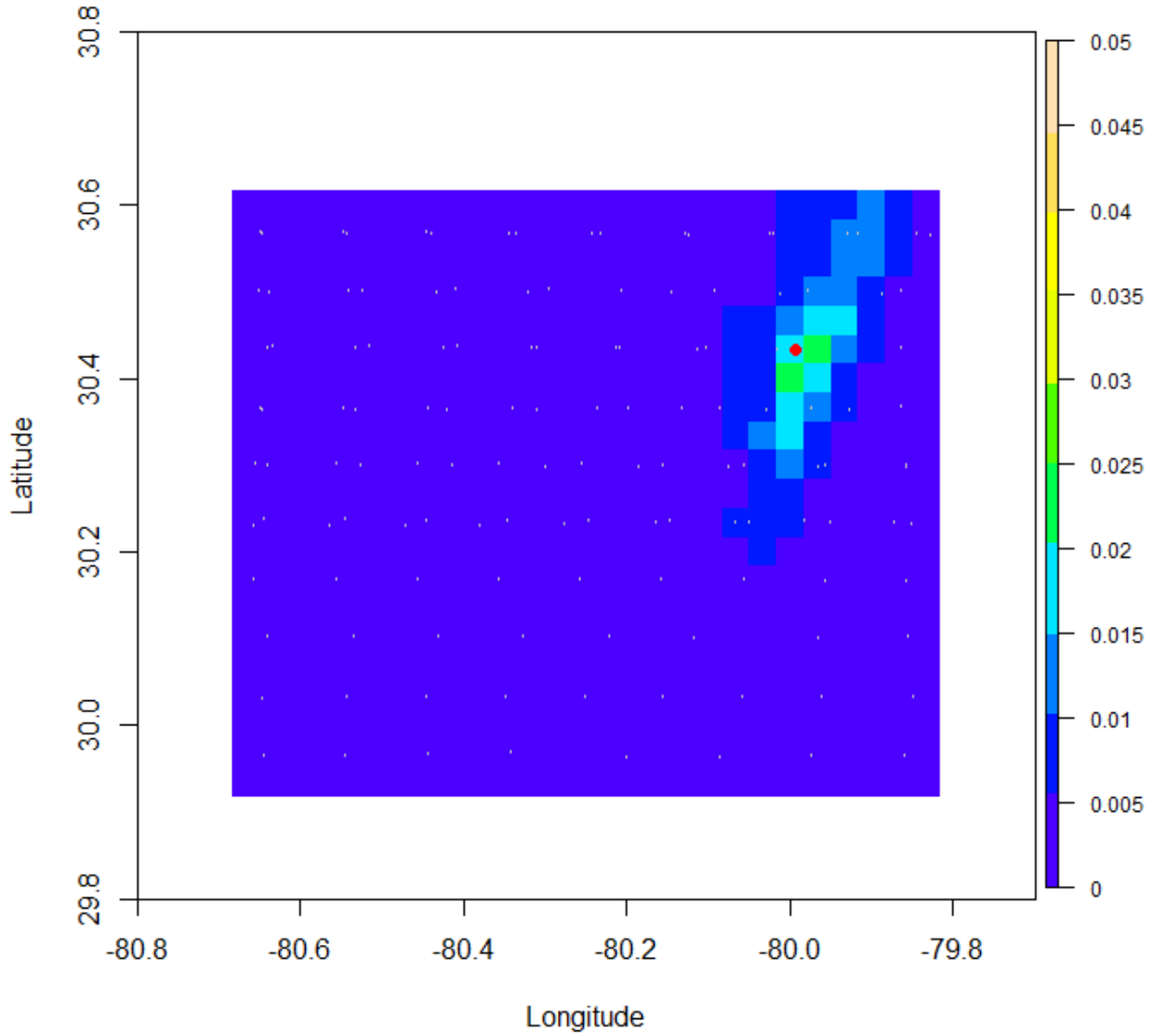
Figure 10. Predicted abundance of medium-sized cetaceans (Risso's dolphins, long-finned pilot whales and kogiids). Black indicates abundance estimates for the whole region and red and blue represent the abundance estimates for the inner and outer areas respectively. Only the upper bound of the confidence interval for the total area is shown (dashed line), the lower bound is consistently zero.



Medium-sized cetacenas (Risso's dolphins, pilot whales and kogiids)

Medium-sized cetacean groups were only detected in 50 segments out of 7052 and so initially a simpler model was fitted - no *Dayofyear/Year* interaction was included. The final model is given in Table 3 and the time series of predicted abundances are shown in Figure 10. Predicted numbers are persistently highest in the late summer and early autumn. Animals were seen in deeper water (Figure 11).

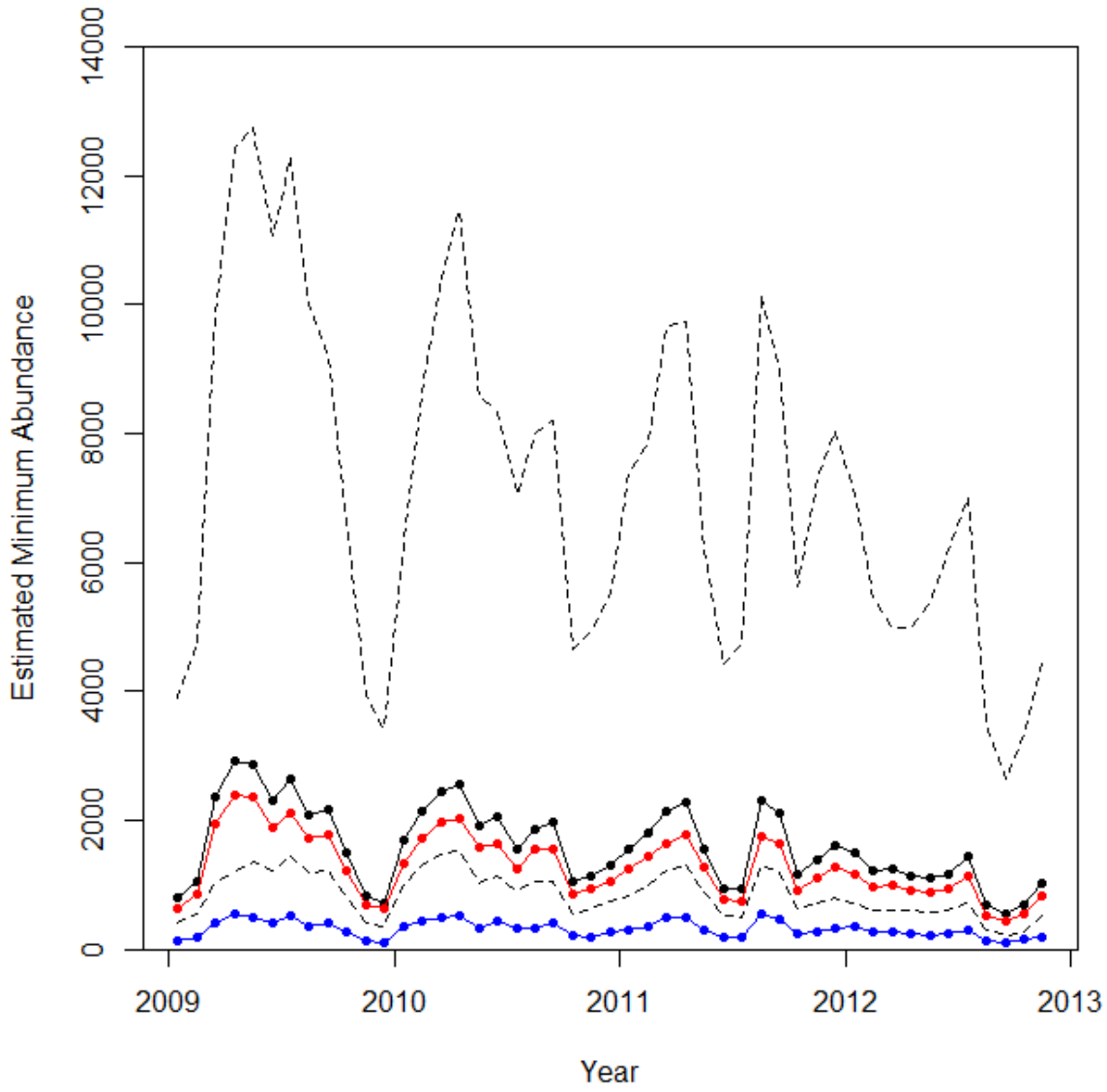
Figure 11. Predicted minimum abundance of medium-sized cetaceans in November 2012. Colours indicate the density of surface animals per km^2. Grey point indicate the midpoints of effort segments and the area of the red circles is proportional to the adjusted density of animals per km^2.



Large whales

Large whales were detected in only 10 segments and so no attempt was made to fit models to these data. The estimated abundance was less than one in both the inner and outer regions (C.I. whole area: 0 - 2)

Figure 12. Predicted minimum abundance of loggerhead turtles. Black indicates abundance estimates for the whole region and red and blue represent the abundance estimates for the inner and outer areas, respectively. Dashed line is the 95% confidence interval for the total region.



Loggerhead turtles

Loggerhead turtles were found in a relatively large proportion of effort segments (16%) compared to the other species but density was still modelled as a two stage process. The final selected models are given in Table 3. The abundance estimates have very high uncertainty (Figure 12) caused, in part, by high uncertainty in the spatial model. High abundances are never predicted for the eastern part of the survey region (Figure 13). Although there appears to be a steady decline in numbers, it is not yet significant although *Year* does appear in the final models. There was no evidence that whale densities influenced the probability of presence of loggerhead turtles.

Figure 13. Predicted minimum abundance of loggerhead turtles in November 2012. Colours indicate the density of surface animals per km^2. Grey point indicate the midpoints of effort segments and the area of the red circles is proportional to the adjusted density of observed animals per km^2.

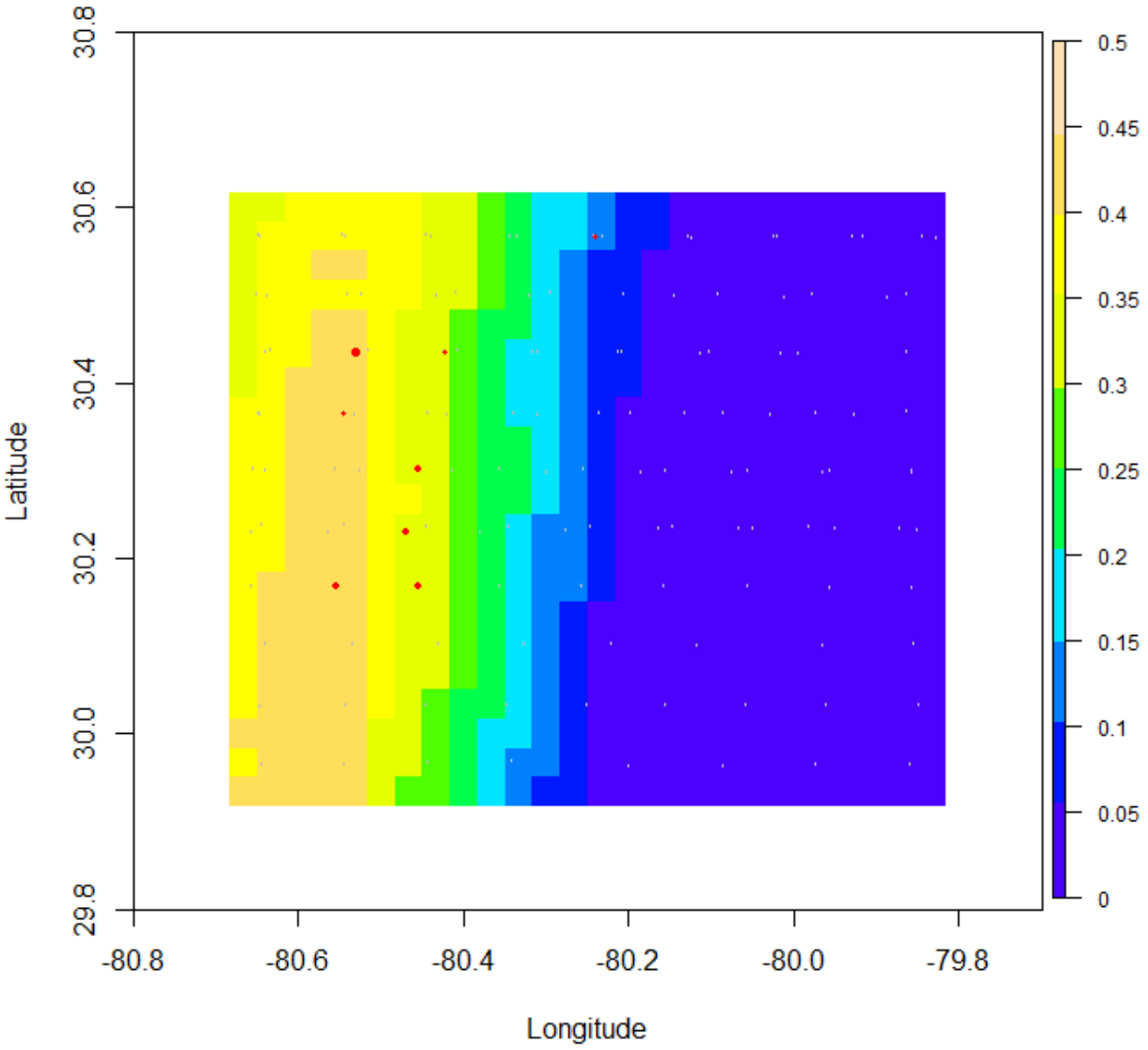
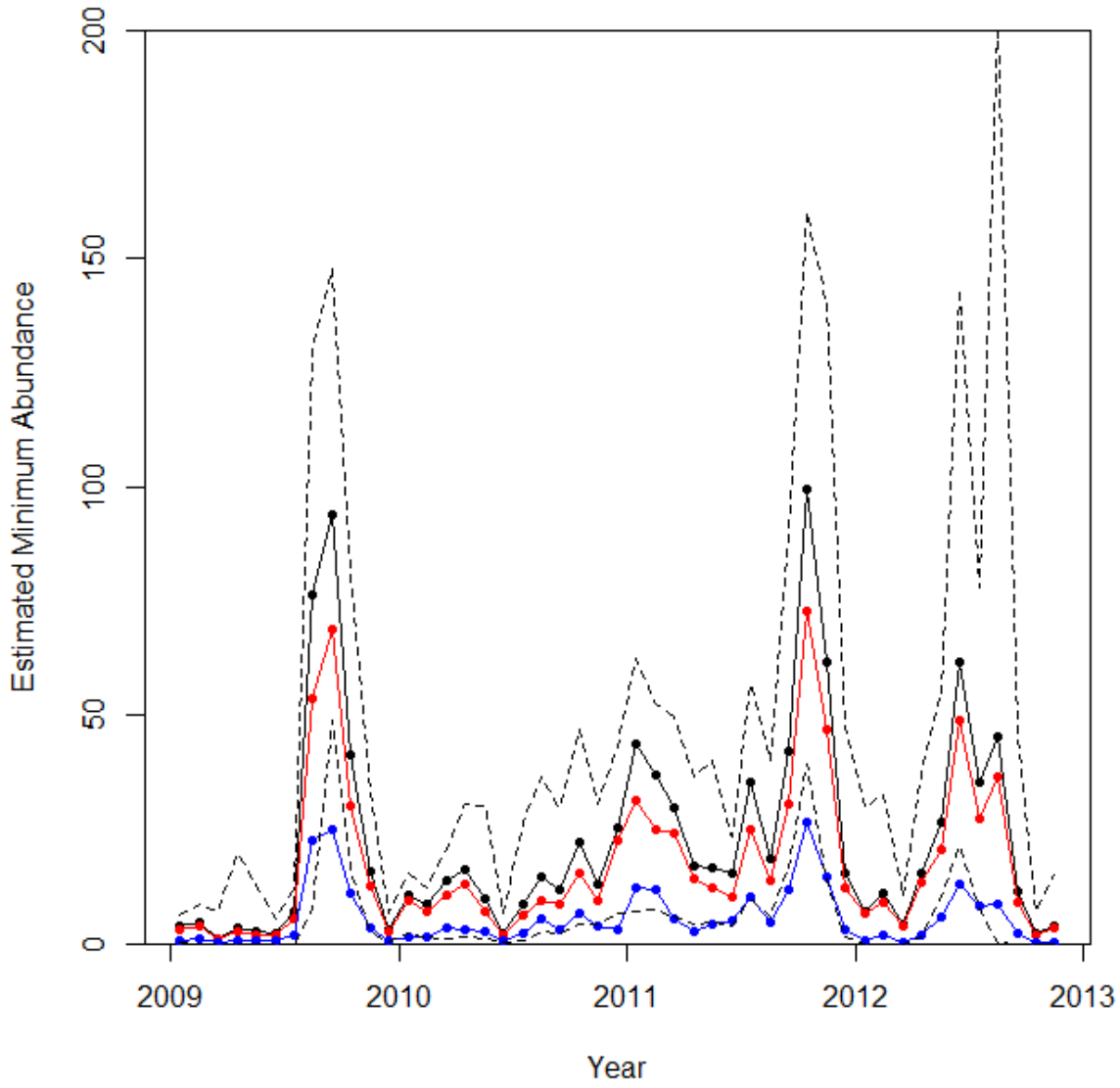


Figure 14. Predicted abundance of leatherback turtles. Black indicates abundance estimates for the whole region and red and blue represent the abundance estimates for the inner and outer areas respectively. Only the upper bound of the confidence interval for the total area is shown (dashed line), the lower bound is consistently zero.



Leatherback turtles

No terms were excluded from the initial model for presence-absence (Table 3). The non-zero density data were described by *Lon, Lat* and *Year.* The estimated abundance showed evidence of seasonality with the majority of leatherback turtles normally appearing in late summer and early autumn. Leatherbacks are mainly predicted in shallower waters. There was evidence (lower gcv score) that the detected probability of presence declined with greater adjusted numbers of sighted cetaceans.

Figure 15. Predicted minimum abundance of leatherback turtles in November 2012. Colours indicate the density of surface animals per km^2. Grey point indicate the midpoints of effort segments and the area of the red circles is proportional to the adjusted density of observed animals per km^2.

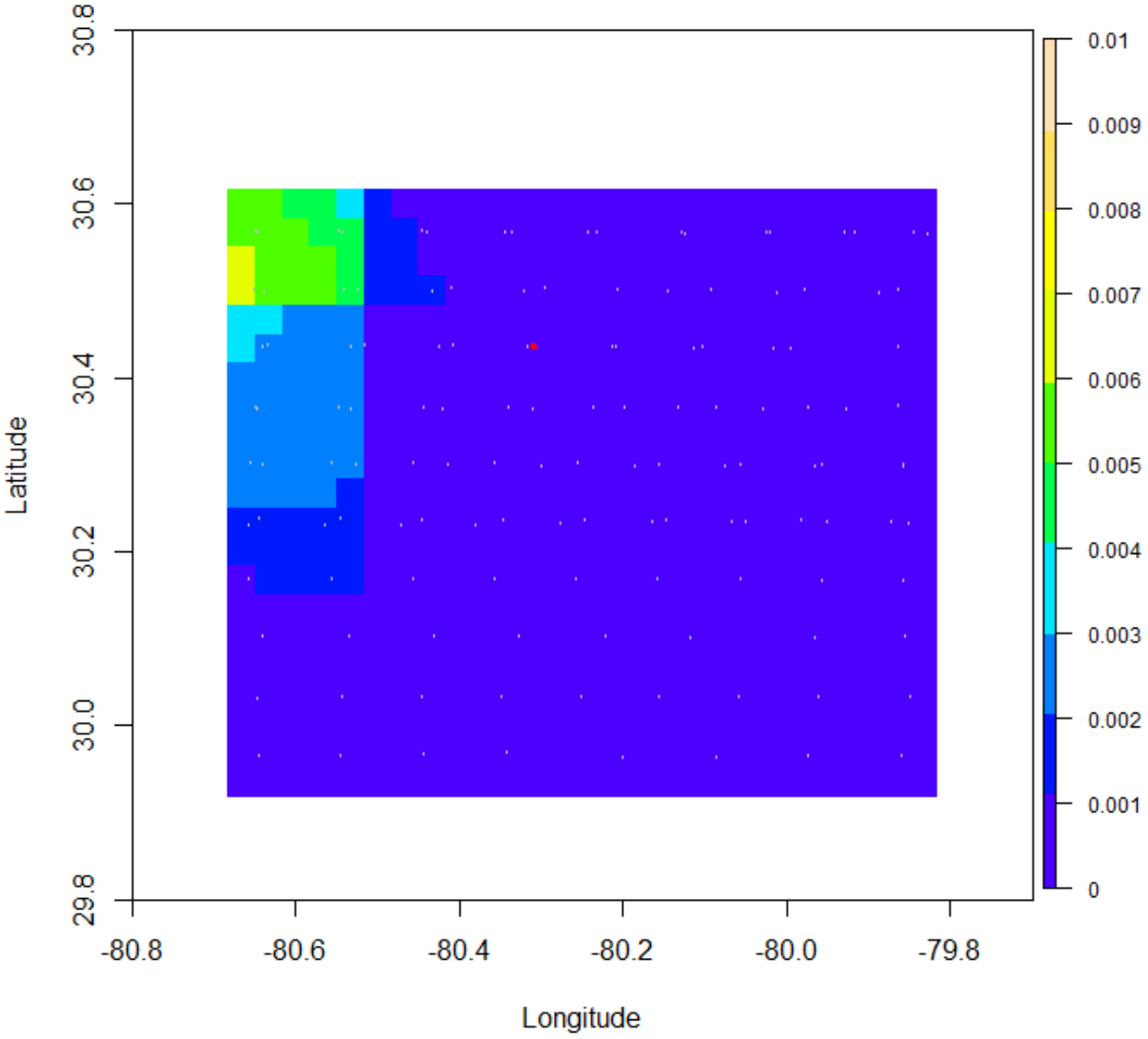
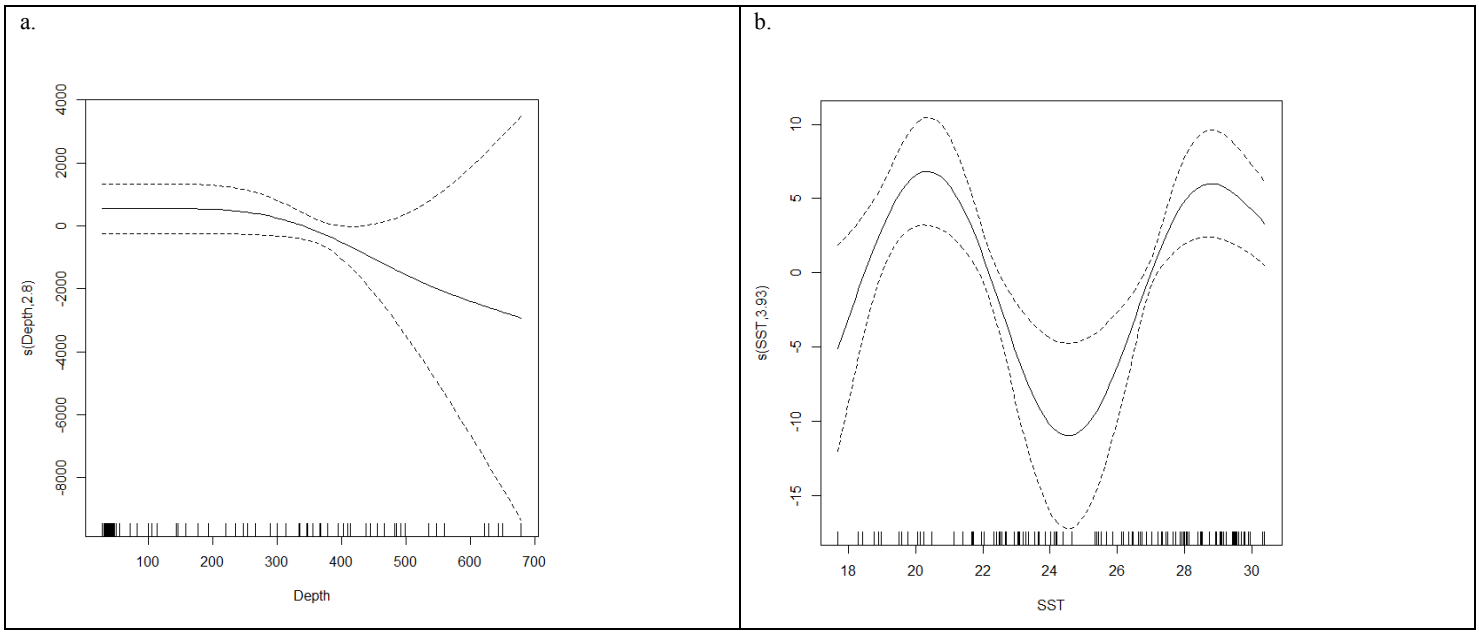


Table 4. Explanatory models for presence-absence based on independent segments.

Taxa	Model	n	Explained deviance
Stenella sp.	*Platform + s(SST, k=5) + s(Depth, k=4) + Year*	115	47.1%
Tursiops truncatus	*s(Dayofyear,k=5) + s(SST,k=5) + s(Depth, k=5) + s(Year,k=3)*	173	42.4%
Caretta caretta	*Depth + Year*	86	32.2%

Figure 16. Responses of Stenella sp. to a. Depth and b. SST. N.B. Response of SST is rescaled and has a small range compared to Depth.

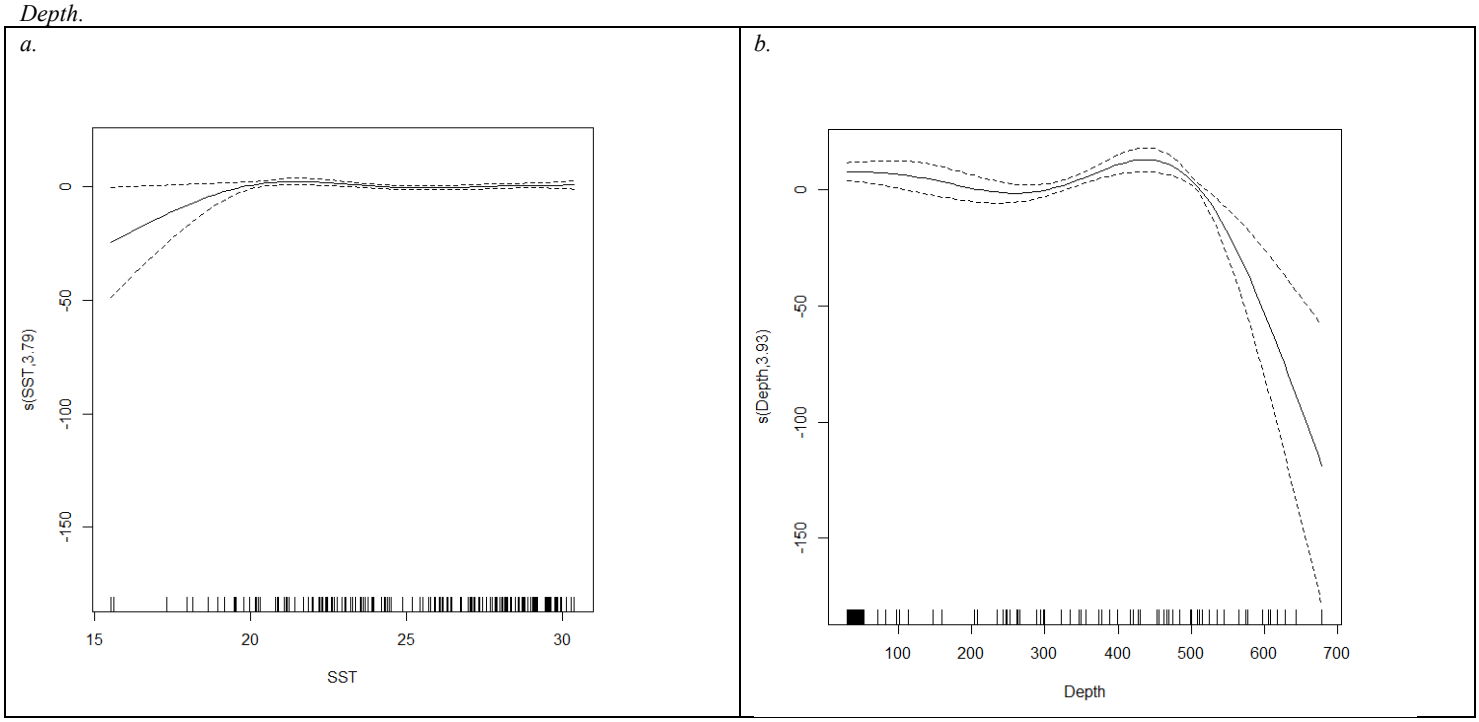


Explanatory density surface models

In the case of *Stenella* sp. aerial segments were conservatively interpreted apparently independent at a huge distance of 553 km whereas there was no clear evidence for correlations in adjacent ship segments. The data should really correlated over the same distances in both surveys. This discrepancy was probably due to the irregular nature of the relevant ship variogram and so 553 km distance was used. After reduction of the original data set there were only 115 datums. The final explanatory model is given in Table 4 and shown in Figure 16. The bimodal distribution for *Stenella* may show a seasonal entry into the Jacksonville waters. Note that despite the presence of SST in the final model by far the most variation in probability of presence is associated with depth.

Similarly in the case of *Tursiops truncatus*, aerial segments were conservatively interpreted to be independent at a distance of approximately 369 km whereas the distance at which ship segments were unclear, so 369 km was taken as the point of independence. After reduction of the original data set there were only 173 datums. The final explanatory model is given in Table 4 and shown in Figure 17. Variation in presence is dominated by depth with a low probability of animals greater than 550 m. There is also a suggestion of an inshore and offshore preference also shown in the density surface (Figure 9). The response to SST suggests seasonality in the appearance of the animals in Jacksonville waters although this is not shown in the time series of abundance (Figure 8). In comparison to *Depth* the effect is slight.

Figure 17. Probability of presence of Tursiops truncatus with respect to the various predictors. All figures on the same log (p/(1-p)) scale. a. SST, b. Depth.



In the case of *Caretta caretta*, the variogram was conservatively interpreted to be independent at 733 km. This gave a new data set of size of 86. A declining linear (on the logit scale, not illustrated) response to depth was found.

In the case of *Dermochelys coriacea* the variogram was conservatively interpreted to be independent at 733 km. This gave a new data set of size of 86. However this data set contained no leatherback turtle presences so an explanatory model for leatherback turtle presence was not pursued.

DISCUSSION

Detection functions could be readily fitted to the estimated perpendicular distances although further consideration should be given to the distribution of turtle distances.

The abundance estimates should be regarded as a minimum because they do not take into account perception bias on the trackline (i.e. not all animals may be detected by the observers) and availability bias (i.e. not all animals may be at the surface to be detected). In the case of turtles, the random allocation of unidentified turtles to species probably lessened the bias associated with the estimates, at the cost of making the models less precise.

The density surface models have indicated both spatial and temporal fluctuations for all of the species under consideration with some taxa (e.g. *Stenella sp*., medium-sized cetaceans and leatherback turtles) showing a consistent seasonal pattern. Increased abundance of turtles at lower water temperatures may be an artefact of a tendency of turtles to surface more at lower temperatures (Hochscheid *et al*. 2010). Temperature was measured at a greater spatial (1/4 degree) and temporal (1 day) resolution than in previous reports on this data.

The method of identifying independent points here somewhat conservative so some Depth was an important explanatory variable in the models and suggests that both *Stenella* dolphins and loggerhead turtles preferred the shallower waters. Bottlenose dolphins may have distinct inshore and offshore distribution. It is however clear from the density surfaces that leatherback turtles are also avoiding deeper waters.

For all species except leatherback turtles prediction was made assuming a ship survey. However no such surveys have been undertaken since 2011 rendering more recent predictions problematic. In the case of *Stenella* sp. the patterns of abundance are different for 2012 compared to previous years. This may be due to the lack of ship-based calibration.

There was evidence that the probability of presence of (observed) leatherback turtles declined when the adjusted density of cetaceans increased. This could reflect a difference in preferred habitat or aversive behaviour on the part of one or both parties but could also reflect observers concentrating on cetaceans in regions of high cetacean density at the cost of missing leatherbacks. However such an effect would be expected to influence both species of turtle.

Recommendations for the future

Assuming the Jacksonville survey work is on-going, issues of potential interest in the future work might include:

1. Investigation of the strange pattern of reported distances for turtles during the aerial surveys.
2. Investigation of whether dolphins are being attracted to the ship before detection.
3. Investigation of reliable methods for estimating $g(0)$ without double-observer survey. Options include cue-based methods and use of appropriate availability correction methods based on data on availability patterns for each species.
4. Further elucidation of the environmental drivers of cetacean density in the area of interest, perhaps by the use of additional variables.
5. Records of water opaqueness may be a useful explanatory variable to include in the detection functions for turtles.

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