AN UPDATE ON WORK RELATED TO SHIP STRIKE RISK TO BLUE WHALES OFF SOUTHERN SRI LANKA

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ABSTRACT

The southern coast of Sri Lanka has been identified as an area with a high risk of ship strikes due to the overlap of high densities of blue whales (*Balaenoptera musculus*) and one of the world's busiest shipping routes. The apparently high level of risk is confirmed by a large number of reported ship strikes. Visual transects perpendicular to the shipping routes and extending further offshore than the current shipping lanes were initiated in 2014. Results from these surveys coupled with observations from whale watch boats over a number of years suggested that moving the current Traffic Separation Scheme slightly further offshore would substantially reduce risk of collisions with blue whales. This paper reports on progress on recommendations from the Committee including further surveys of blue whale distribution and analysis of a year's AIS data to investigate shipping density. Results suggest a potential for over 1000 interactions annually between whales and vessels within the study area assuming no evasive response by whales or vessels. Based on survey data up until April 2015, a 15nm southward shift in shipping would reduce collision risk to blue whales by 95%. For shipping in transit to or from the Red Sea this would add around 5nm to the total transit distance.

INTRODUCTION

Ship strikes are a recognised problem for the northern Indian Ocean population of blue whales (*Balaenoptera musculus*). The area off the southern tip of Sri Lanka has been identified as particularly high risk because of the overlap between high densities of blue whales and one of the busiest shipping routes in the world. The Committee has discussed the issue for a number of years, including reports of ship strike incidents (De Vos et al., 2013a) and results from surveys to investigate the distribution patterns of blue whales in relation to ship traffic off southern Sri Lanka (Priyadarshana et al., 2014). These studies suggested that moving the current Traffic Separation Scheme slightly further offshore would substantially reduce risk of collisions with blue whales. In 2014 the Committee agreed that further surveys of blue whale distribution in the area at different times of year would provide important data. In addition, the Committee noted that there has been a dialogue between IWC and the Government of Sri Lanka on the issue, and recommended that IWC should begin to discuss possible mitigation measures with the relevant authorities and stakeholders in the area. These recommendations were endorsed by the joint IWC-SPAW Workshop to Address Collisions Between Marine Mammals and Ships held in Panama in June 2014 (IWC/65/CCRep01).

This paper reports on progress on these recommendations including further surveys of blue whale distribution and analysis of a year's AIS data to investigate shipping density. In addition, a recent analysis of 15 whale mortalities attributed to ship strikes around Sri Lanka between 2010 and 2012 found that 11 of these were blue whales. The majority of these were found as stranded carcasses on the south coast (Nanayakkara, R., pers. comm.). During the NE monsoon, winds are cross or offshore with strong, westward cross-shore surface currents making it unlikely that carcasses of whales killed in the shipping lanes would strand during these months. It can be assumed that only a very small proportion of collisions are reported or result in a whale stranding. Even so, numbers of reports are higher than for any other large whale population globallyof which we are aware.

METHODS

Blue whale Surveys

The observation methods and transects were as described in (Priyadarshana et al., 2014). Two observers using naked eye and Opticron 7x15 binoculars searched a 90^{o} sector either side of the vessel, and recorded sightings data for all marine fauna detected. The survey area was centred on the southern tip of Sri Lanka and extended 150km east-west and 50km north-south. The main objective of the surveys was to investigate blue whale distribution within the current shipping lanes and further offshore. In addition to surveys from *Raja & the Whales*, a 13m converted deep-sea fishing vessel, surveys were also conducted from *Mir*, a 35m auxiliary powered sailing research vessel.

Programme Distance (Thomas et al., 2010) was used to estimate strip widths to allow for density estimation. However, no attempt was made to estimate g(0) which was assumed to be 1. In addition to Distance analysis, transects were divided into 1km segments for the purposes of spatial modelling. The results presented here are for a simple spatial Generalized Additive Model (GAM) including possible covariates of latitude, longitude, depth, slope, sea state (Beaufort scale), and sightability. Sightability was a subjective category of how good the observers judged the conditions for seeing blue whales to be based on all factors. The response variable was the number of whales sighted in each 1km segment of survey track. Modelling was performed using the mgcv package in R (Wood, 2006; *R* Development Core Team, 2008). Depth data were taken from the Gebco_08 grid (version 20100927 www.gebco.net) at 30 arc-second (approximately 925m spacing). Since depth contours run predominantly east west across the survey area, slope was defined in just a north-south direction as the difference in depth between the closest measurement point to the north and the closest to the south of the transect segment. The east-west nature of the depth contours also results in latitude and depth being effectively collinear. Alternative models were evaluated using either latitude or depth but not both. GAMs were fitted based on a Tweedie (p=1.1) distribution to allow for the over-dispersion and disproportionate number of segments with 0 sightings compared to Poisson. The percentage of explained deviance was used as an indication of model fit.

Analysis of shipping density

Satellite-received AIS data (all vessels over 300GT are required to transmit AIS) were provided by MarineTraffic.com for the area 5^{o} N to 6.5^{o}N and 79.5^{o}E to 82^{o}E. Data were collected over a 320 day period from 03/07/2013 to 17/05/2014. Satellite coverage was not continuous but averaged 16.5 passes per day with each pass being treated as an instantaneous snapshot of vessels (i.e. one location was selected for each vessel from each pass). This area was subdivided into a grid of 1x1 km squares. The mean density of shipping D_S in each square expressed in km travelled per km^2 per year (i.e. $km^{-1}year^{-1}$) was estimated from;

Where P = number of satellite passes (in this case 5293)
n_i = number of vessels observed within a square on pass i
v_{ij} = the observed speed in knots of vessel j within that square on pass i
The simplest estimator of collision risk is the co-occurrence of whales and ships using the density of whales multiplied by shipping density in terms of distance travelled. This is the measure used in this study. Co-occurrence was also used in risk assessments by Redfern et al. (2013). Bezamat et al. (2014)

used a similar approach but included a term for vessel speed based on the risk-speed curve derived by Conn & Silber (2013). To estimate a crude index, *N,* of the likely number of interactions involving physical contact over a year per km^2 (assuming no response by whales or vessels), we used a modification of the approach used by Bezamat et al. (2014), giving

Where
B = The beam of the ship in m (we used an average value of 32m for a Panamax vessel)
L = Mean length of a whale in m (we used 20m)
S = Proportion of time spent at risk close to surface (we used 0.25 based on (De Vos et al., 2011))
D_S = Shipping density (km^{-1}year^{-1})
D_W = Whale density (individuals km^{-2})

The sum of potential interactions across an area (in this case the 150x50km survey area of 7500km^2) can be used an index of risk which can give an estimate of the relative risk that would be associated with different patterns of shipping.

RESULTS

Blue whale survey Results

The results of surveys between February and April 2014 were presented in (Priyadarshana et al., 2014). Since then single survey days were conducted in July, October, and December 2014, andin January 2015. These were followed by a block of surveys in March and April 2015 (Table 1). Of these all were within inter-monsoon or NE monsoon periods except the survey on 16 July. This single survey was not included in the spatial modelling analysis because the different oceanographic conditions might be expected to result in different factors influencing whale density.

Table 1. Summary of survey days at sea

Surveys from *Raja and the Whales*				
Date	Transects surveyed () indicates transect only partially completed		Total number of individual blue whales seen	Total survey effort on transect (km)
18-Feb-14	(10)	(11)	1	45
19-Feb-14	9	10	17	91
21-Feb-14	11	12	6	93
22-Feb-14	(3)	(4)	7	65
28-Feb-14	11	12	1	92
02-Mar-14	13	14	5	91
04-Mar-14	7	8	1	93
05-Mar-14	9	10	2	92
06-Mar-14	11	12	1	93
20-Mar-14	1	2	52	93
21-Mar-14	3	4	16	98
22-Mar-14	5	6	18	93
23-Mar-14	7	8	21	94
24-Mar-14	9	10	2	94
31-Mar-14	11	12	0	93
03-Apr-14	13	14	0	93
16-Jul-14	10	11	25	93

05-Oct-14	10	11	1	93
06-Dec-14	9	10	1	92
19-Dec-14	9	10	0	93
13-Jan-15	9	10	0	93
23-Mar-15	1	2	0	93
24-Mar-15	3	4	10	91
25-Mar-15	5	6	6	93
26-Mar-15	7	8	8	93
30-Mar-15	9	10	15	93
31-Mar-15	5	6	1	92
01-Apr-15	7	8	11	92
02-Apr-15	11	12	15	92
Total			**243**	**2616**
Surveys from *Mir*				
10-Mar-15	1	1	0	92
17-Mar-15		11	0	44
18-Mar-15		10	1	46
19-Mar-15	8	9	7	67
20-Mar-15	11	12	0	39
23-Mar-15	10	11	0	93
24-Mar-15	13	14	0	85
02-Apr-15	8	9	20	93
19-Apr-15	13	14	10	92
Total			**38**	**652**

The transects and blue whale sightings from this survey are shown in Figure 1. Figure 1 also shows sightings from whale watching operations in August and September 2013. These are all clustered around the 1000m contour.

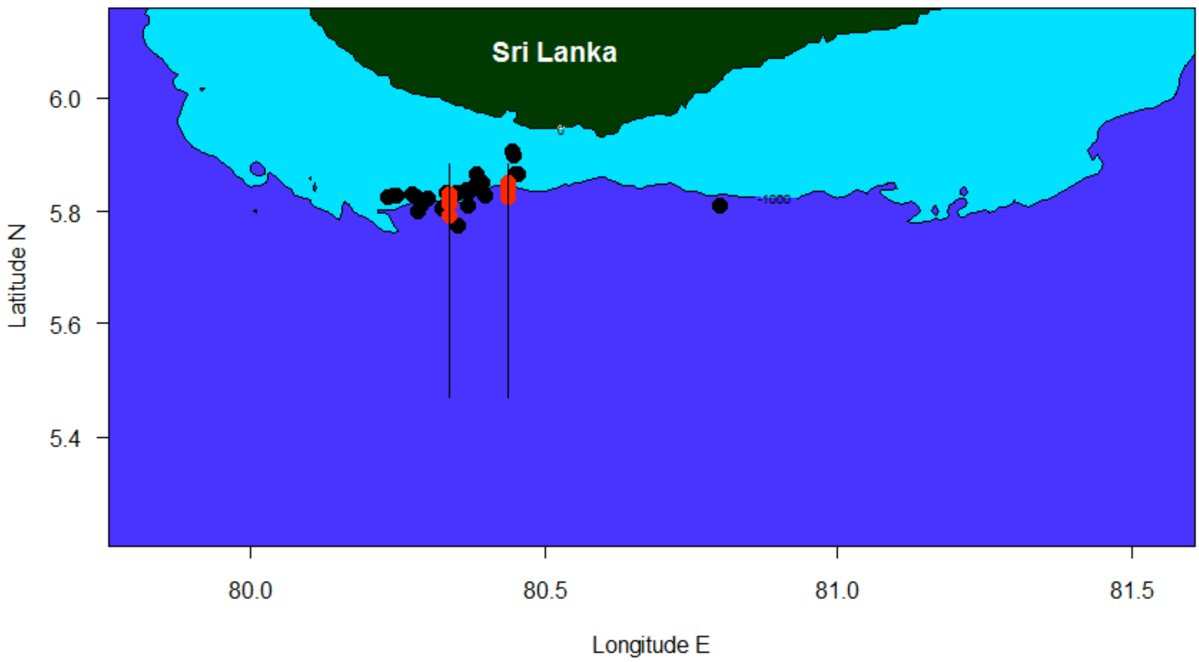

Figure 1. Data from SW monsoon. Black lines are survey tracks from 16/07/2014. Red circles indicate blue whales seen during survey. Black circles indicate blue whale sightings during whale watching in August-September 2013.

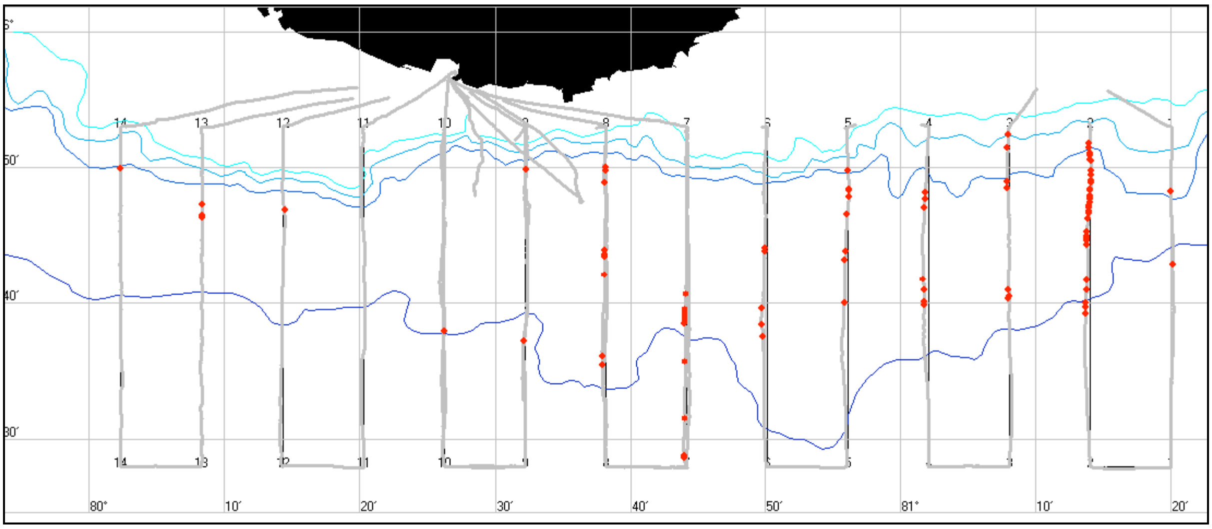

Figure 2. Vessel tracks for *Raja and the Whales* from February 2014 to April 2014 (grey lines). Blue whale sightings indicated by red dots. Transects are numbered as in Table 1.

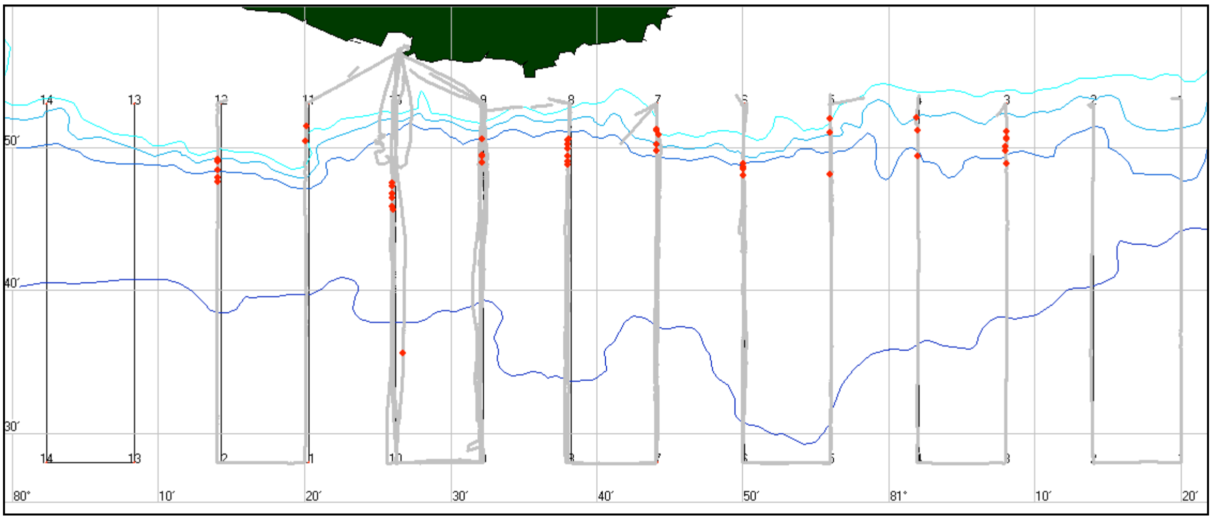

Figure 3. Vessel tracks for *Raja and the Whales* from October 2014 to April 2015 (grey lines). Blue whale sightings indicated by red dots.

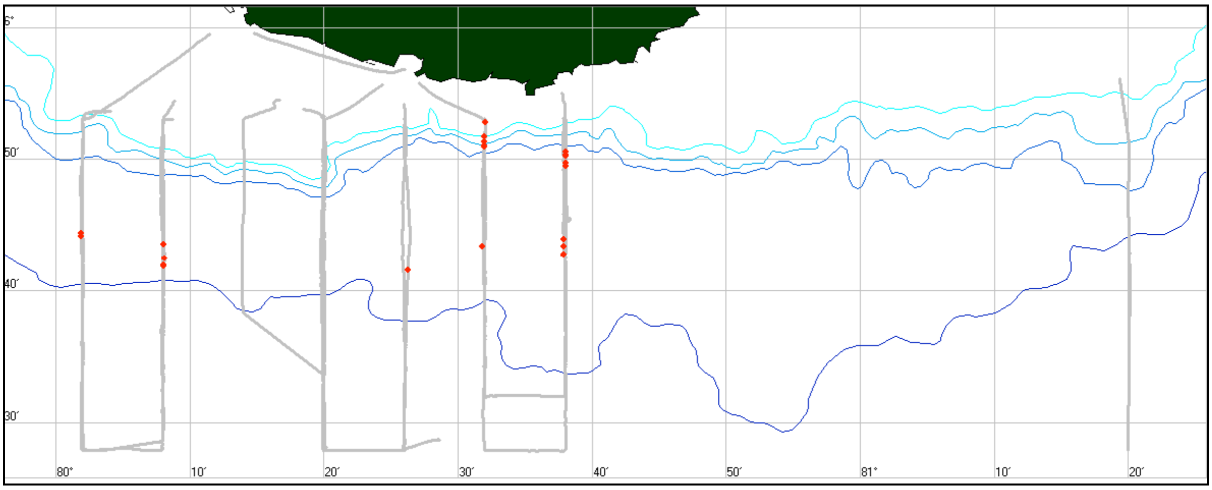

Figure 4. Vessel tracks for *Mir*, March-April 2015 (grey lines). Blue whale sightings indicated by red dots.

The survey effort achieved by both survey vessels is shown in Figures 2-4. Only effort on pre-determined transects was used for spatial modelling and density estimation.

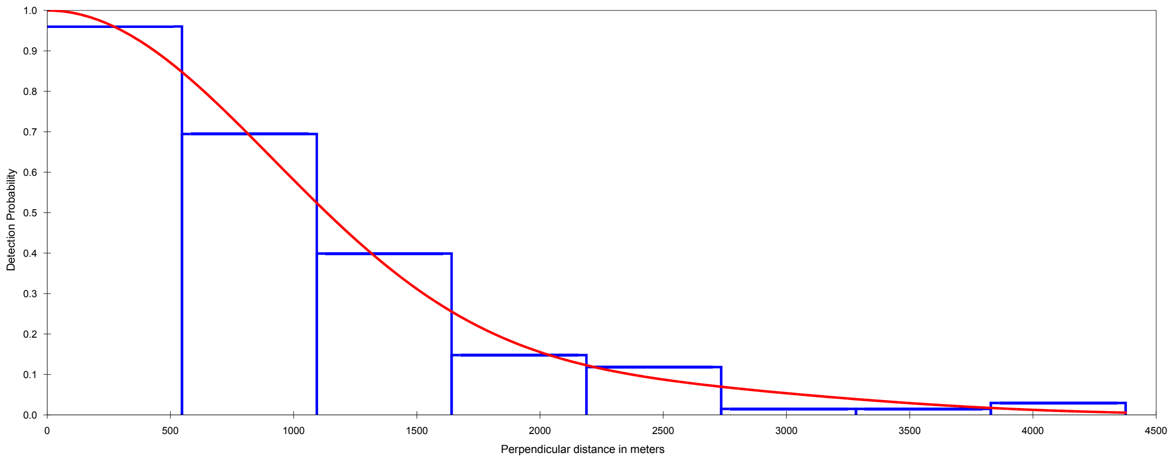

Figure 5. Detection function for all sightings of blue whale groups from *Raja and the Whales* (n=161). Data were truncated at 3000km for final fitting of the detection function.

The overall sighting rate from *Raja and the Whales* (0.06 individuals km^{-1}) for the 2015 season was similar to that from *Mir* (0.06 individuals km^{-1}). Hence although the two vessels had rather different characteristics (mean survey speed for *Mir* was 5.1knots compared to 6.3knots for *Raja and the Whales*) it was thought appropriate to pool data from both vessels in a spatial model. However, only data from *Raja and the Whales* were used to generate a detection function which was pooled across all surveys.

The estimated effective strip half width pooling all surveys was 1301m (95% CI 1136-1491m). This strip width and the total effort of 2616km of full transect gave a mean density estimate for all surveys of 0.036 individuals km^{-1}. For the survey area of 50km by 150km, this gives an approximate mean abundance estimate of 270 blue whales (CV=0.09, 95% CI 226-322) assuming g(0)=1. This CV does not make any allowance for measurement error in angles or distances to sightings. Sea conditions generally made use of reticle binoculars challenging and so distances were judged by naked eye and must be considered very approximate. The density estimates for comparable surveys in February-April 2014 (0.042 individuals km^{-1}) and March-April 2015 (0.034 individuals km^{-1}) show slightly lower densities in 2015.

Initially separate spatial models of blue whale distribution were generated using the survey effort in Figures 2-4. Sightability and sea state did not provide consistent significant explanatory ability across these models and were thus dropped from subsequent analysis. A combination of latitude, longitude and slope as covariates gave a consistently better fit than longitude, depth and slope. However, it is likely that depth does have a strong influence over whale distribution related to coastal upwelling. To explore this, further models using just depth were generated for each of the three data sets in Figures 2-4.

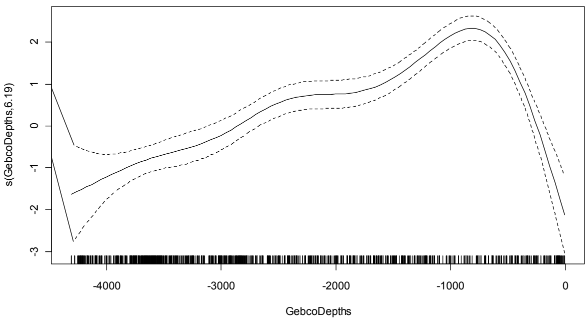

Figure 6. Smooth of depth only model using just 2014 *Raja and the Whales* survey data. Densities peak around the 800m contour. 21.2% deviance explained.

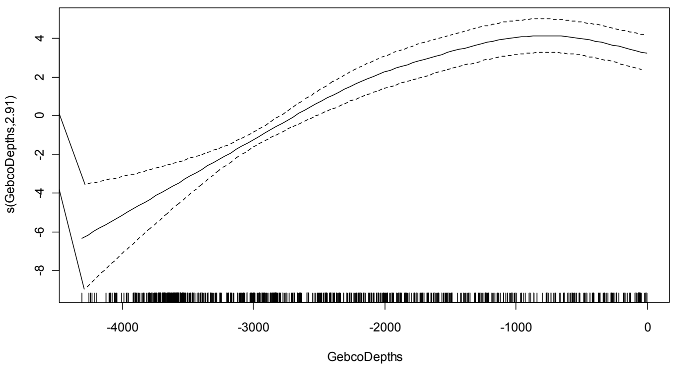

Figure 7. Smooth of depth only model using just 2015 *Raja and the Whales* survey data. Densities peak around the 800m contour. 33.3% deviance explained.

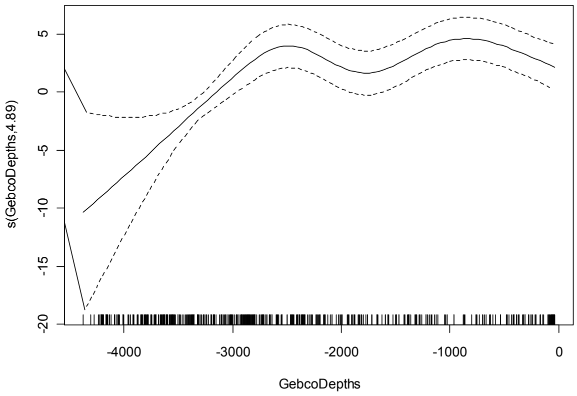

Figure 8. Smooth of depth only model using 2015 *Mir* survey data. Densities peak around the 800m contour with a lower peak around 2500m. 28.6% deviance explained.

To examine overall distribution patterns in relation to ship strike risk a model using all the data combined was generated. With latitude, longitude and slope as covariates the percentage deviance explained was 28.4%. Whale density increased with slope as shown in Figure 9.

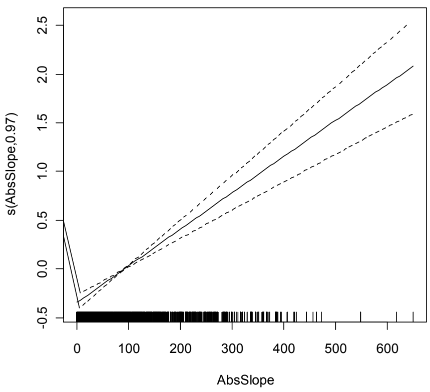

Figure 9. Smooth of blue whale density as a function of slope for full model.

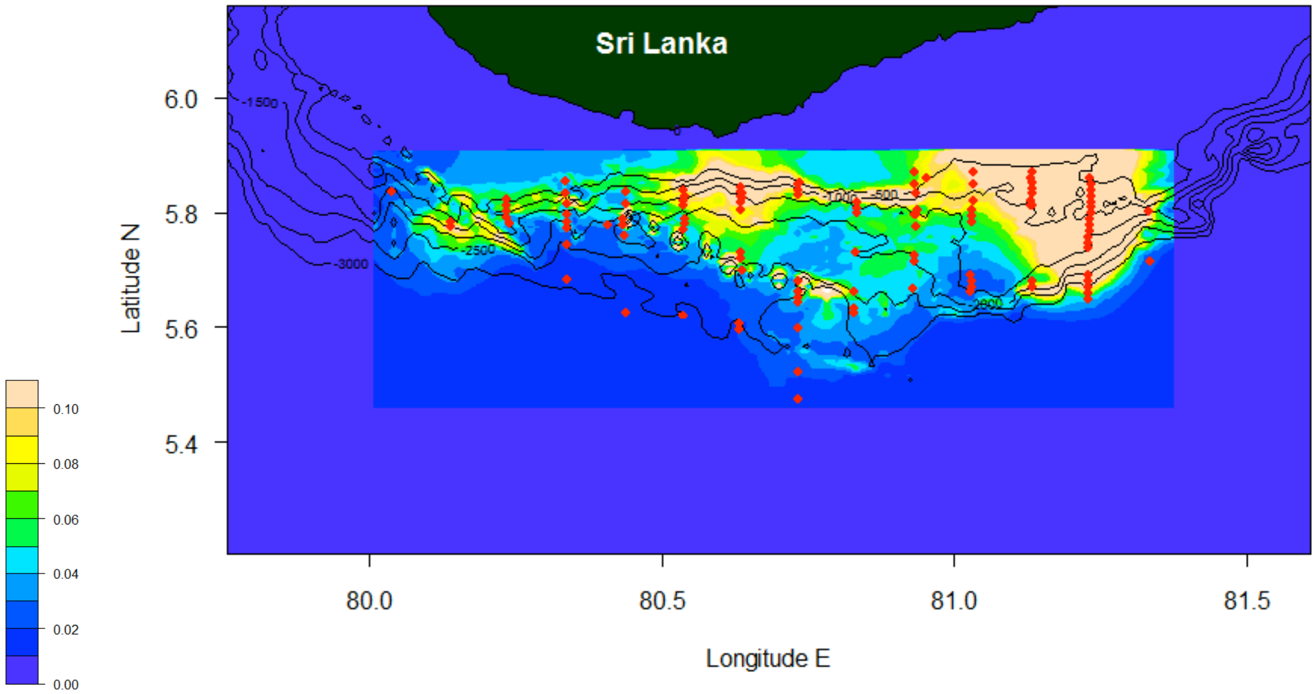

Figure 10. Predicted whale density based on the full model using latitude, longitude and slope as covariates. Red circles indicate sightings on which model is based. Predictions are only given for the surveyed area. Scale is whale density as individuals km^{-2}.

Shipping density results

Shipping densities by 1km square varied from 0 to 2200 $km^{-1}year^{-1}$. As expected the highest values were in the main east-west shipping lanes close to the Traffic Separation Scheme (TSS) off Dondra Head (Figure 11). East of the TSS, shipping remained concentrated whereas there was more dispersal further west. When averaged across longitudes between 80.5°E and 81°E the peak mean density in the westbound lane was 1090 $km^{-1}year^{-1}$ and in the eastbound lane 810 $km^{-1}year^{-1}$. These densities reflect the slightly greater total volume of westbound traffic overall. These can be compared to an estimate from 2007 of 280 $km^{-1}year^{-1}$ for the main route across the eastern Mediterranean basin between the Strait of Sicily and the Suez Canal (Leaper & Panigada, 2011), and highlights that this is one of the densest areas of open ocean shipping anywhere in the world.

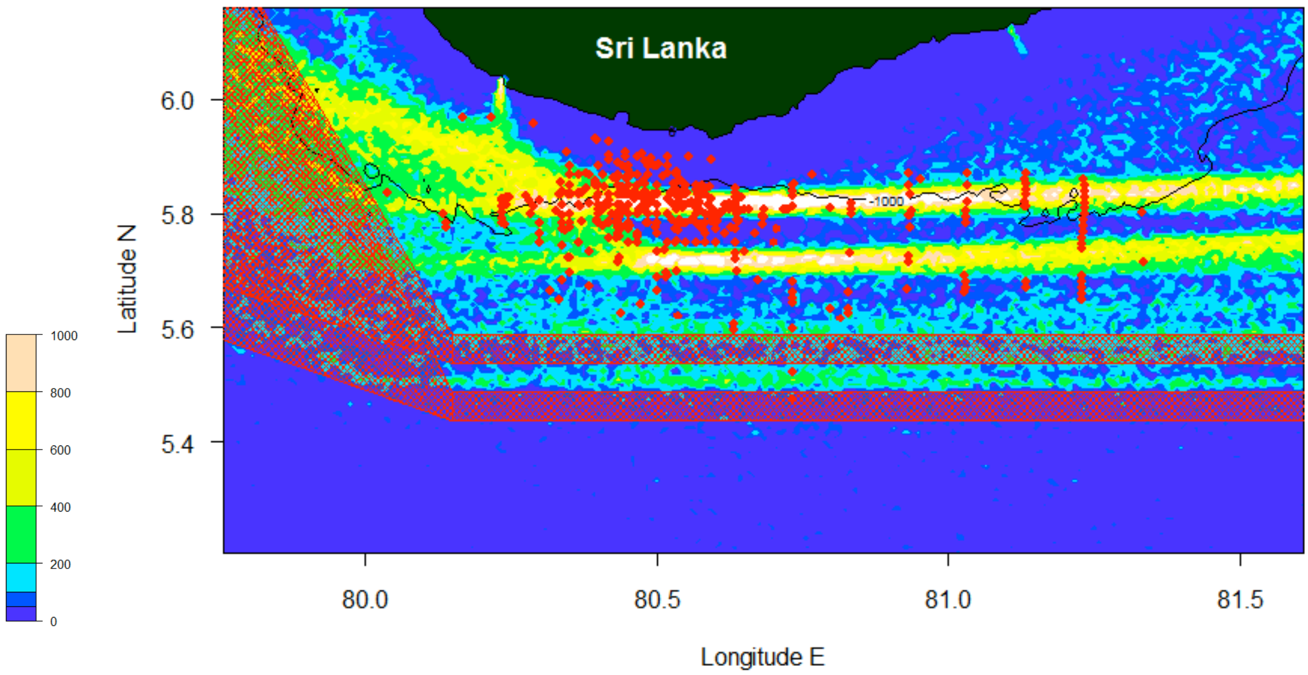

Figure 11. Shipping density according to scale measured as km^{-1} $year^{-1}$. Red circles indicate all blue whale sightings from surveys and whale watch observations by *Raja and the Whales*. Red shaded area indicates possible alternative shipping route 15nm to the south of the current Traffic Separation Scheme.

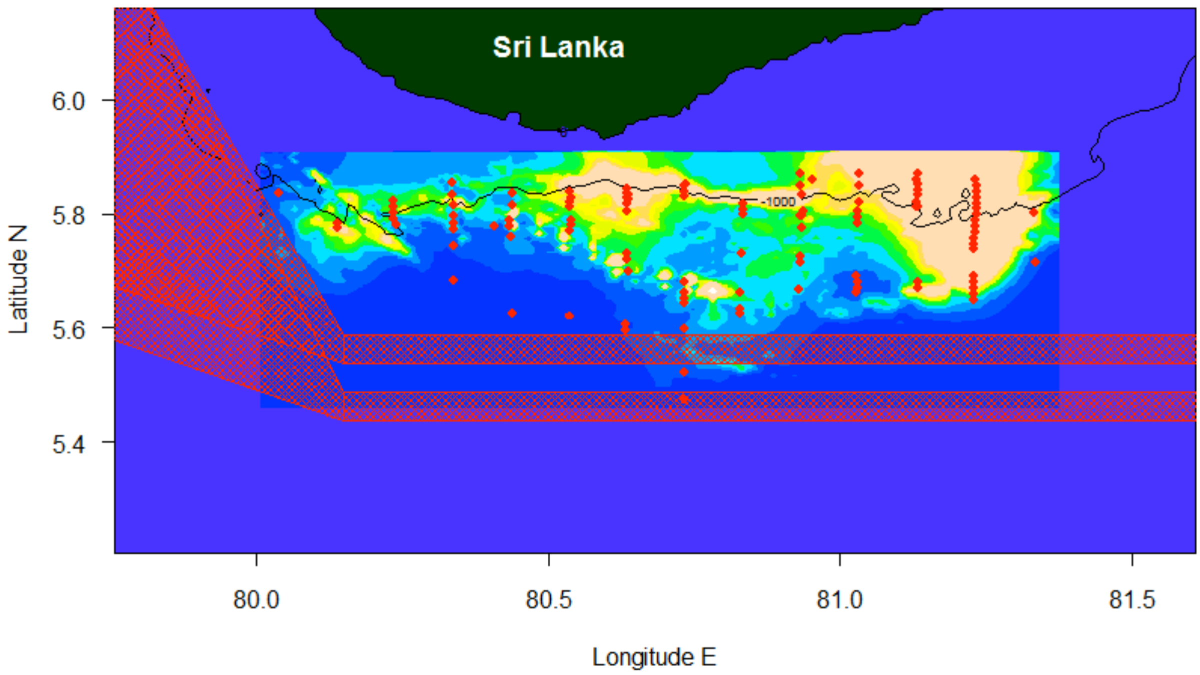

Figure 12. Predicted blue whale densities from model (see scale on Figure 10) overlayed with possible alternative shipping route.

Collision risk assessment

The estimate of the total number of interactions within the survey area of $7500km^2$ based on the modelled whale density across all the surveys, assuming no evasive response from whales or vessels, was 1016 per annum. This is an order of magnitude greater than even the most pessimistic estimates of the number of collisions occurring. Hence it is likely that the majority of situations that could result in a collision do not result in mortality. In addition, there are many months of the year for which whale density has not been reliably estimated. Nevertheless, the number of potential interactions gives an indication of the relative risk and can be used to evaluate the implications of changes in shipping patterns.

Based on the predicted whale densities in the full model (Figure 10), the alternative shipping route in Figure 12 would reduce collision risk to blue whales by 95%.

Other whale species
Other large whale species that regularly occur south of Sri Lanka are Bryde's and sperm whales. Both species are known to be vulnerable to ship strikes but occur in much lower densities than blue whales.

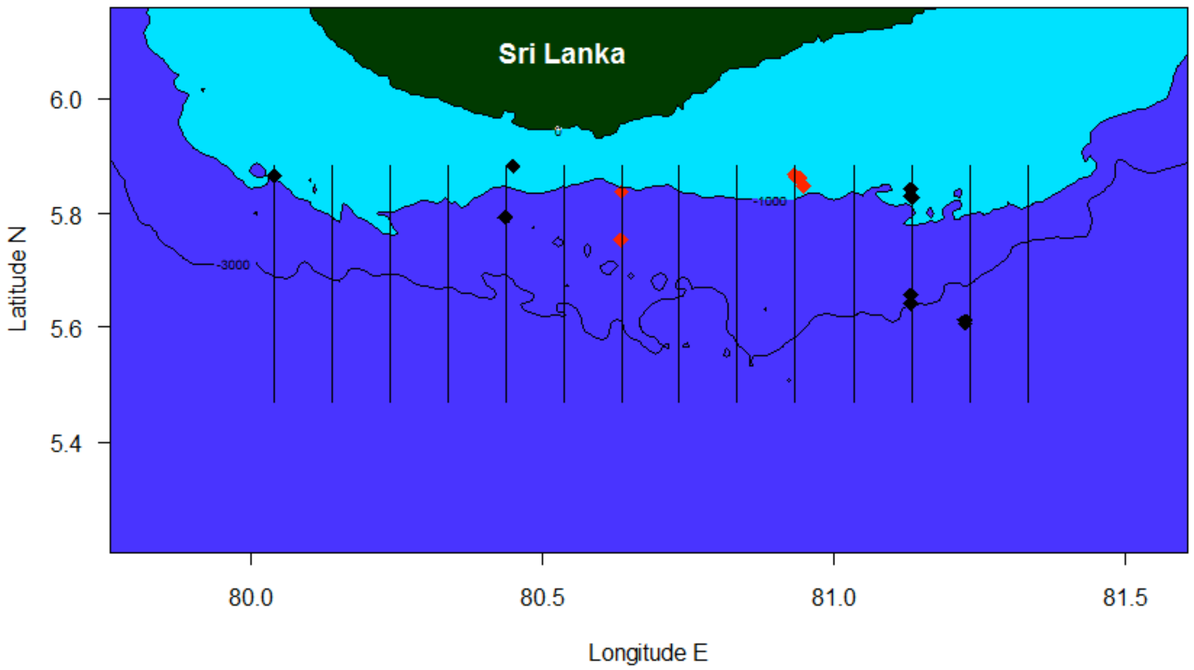

Figure 13. Sightings of sperm whales (red diamonds) and Bryde's whales (black diamonds) on survey transects (black lines).

Sperm whales are associated with the 1000m depth contour in other areas. Two large groups of sperm whales were seen, in both cases close to the 1000m depth contour. There were 11 sightings of Bryde's whales during this study and all these were north of 5° 36'N. Whale watch data also suggest a more coastal distribution for Bryde's whales compared to blue whales. The possible alternative shipping routes in Figure 12 would also be expected to reduce risks for sperm and Bryde's whales.

Calves
Calves and juveniles appear to be more vulnerable to ship strikes than adults, possibly due to a lack of awareness or a greater proportion of time spent at the surface (Laist et al., 2001). During March-April 2015 two mother-calf pairs of blue whales were observed on the survey transects; the calves were very small. Other small blue whale calves were also seen when not on transect and small calves are frequently reported by whale watch operators. Small sperm whales calves were also observed. This suggests that south of Sri Lanka is a nursery area for these species and that shipping may pose an even greater risk because of this.

DISCUSSION

The distribution patterns of blue whales in March-April 2015 were similar to those observed in 2014 and consistent with observations from whale watching operations over the last few years. Data from other months also show similar patterns. However, data from the SW monsoon period are still limited.

The predictable pattern of blue whale distribution indicates the potential for measures to keep ships and whales apart. These predictable patterns are also consistent with the oceanography. The southern coast of Sri Lanka has a narrow continental shelf and steep continental slope leading to an abyssal plain of 3-4000m. Coastal upwelling driven by monsoon winds has been identified as the physical mechanism causing nutrient enrichment in the surface layer close to the southern coast. This upwelling is caused by converging coastal currents that generate an offshore flow creating a divergence at the coastline which maintains productivity during both monsoon periods (De Vos et al., 2013b). It seems likely that routing measures to reduce risks to blue whales would also reduce risks for sperm and Bryde's whales.

Any measures will need to take account of economic considerations for vessels visiting ports in Sri Lanka, in addition to traffic on passage across the Indian Ocean. Further, measures to reduce ship strike risk to blue whales should improve maritime safety for whale watch operators and coastal fishing vessels (Priyadarshana et al. *submitted*). In addition, the current situation results in some shipping apparently being concentrated in unofficial shipping lanes to the south of the TSS (Figure 11). These concentrations of traffic have two-way flow, and safety could be enhanced by a routing scheme in these areas. For shipping in transit to or from the Red Sea, the additional distance of transiting through a TSS established 15nm to the south of the current scheme as in Figure 11 would add around 5nm to the total distance, 9nm for traffic from west coast of India and Arabian Gulf, or 12nm from Colombo.

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