Harbour porpoise surveys in Rockabill to Dalkey Island SAC, 2016

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Cover image: Harbour Porpoise in Rockabill to Dalkey Island SAC, by Joanne O'Brien © DAHRRGA

Executive Summary

A visual survey of harbour porpoises (*Phocoena phocoena*) was carried out in the summer of 2016 within the Rockabill to Dalkey Island SAC, Co Dublin in order to derive local density and abundance estimates. Single platform line-transect surveys were carried out according to a standardised design on four days between June and September 2016. Distance sampling was used to produce a detection function based on the observed distribution of harbour porpoise sightings. Abundance estimates were calculated using the day as the sample and the sighting as the observation:

(i) for all survey days,
(ii) stratified by sea state and
(iii) for all surveys combined.

Surveys were carried out in favourable weather conditions (i.e., sea-state ≤2, with visibility of at least 6km) on all four survey days. A combined total of 506km of track-line was surveyed, which resulted in 152 distinct sightings totalling at least 246 individual harbour porpoises. The observed proportion of young porpoises (juveniles and calves combined) to adults was 9.8% and the proportion of calves to adults was 5.7%. No other cetacean species was recorded on any of the surveys, but a number of grey and harbour seals were sighted during on-effort periods.

Density estimates derived from each survey were relatively consistent ranging from 1.37 porpoises per km^2 to a maximum of 1.87 porpoises per km^2, with an overall pooled density of 1.55±0.17 porpoises per km^2 and a low estimated Coefficient of Variation (CV) of 0.10. Harbour porpoise abundance within the SAC site ranged from 374 individuals to 511 individuals with an overall pooled estimate of 424±46 with 95% CI of 335-536. The effect of sea-state on density estimates was investigated by running DISTANCE models on data derived from sea-state 0, sea-state 0+1 and sea-state 0+1+2. This showed that density estimates were greatest using data from sea-state 0, but the goodness-of-fit of the modelled detection function was poor. When data collected in sea-state 1 were included, it improved the goodness-of-fit but this didn't vary when data collected in sea-state 2 were also included, suggesting that it was appropriate to survey harbour porpoise at the site in sea-state ≤2.

Density estimates generated in 2016 were compared to similar surveys carried out of the Rockabill to Dalkey Island SAC in 2013 and in the same area off Co. Dublin in 2008. Density estimates in 2013 within precisely the same area were remarkably consistent with 1.44 harbour porpoise per km^2 recorded earlier compared to 1.55 porpoise per km^2 in the current study. During both studies mean estimated group size was similar though it was a little higher in 2016 (1.62) compared to 2013 (1.44). The results overall suggest that porpoise densities between the two replicate surveys are quite consistent and that the estimates of abundance represent an accurate indication of local population size for the summer period.

We recommend repeating survey track-lines using the same methodology during future surveys in order to improve the data time series within the site. The results of this survey show that provided individual survey coverage of the site are only carried out in very favourable conditions; data from four survey days can be comparable to that collected over six survey days.

Porpoise surfacing as a P&O ferry approaches.


Approaches to Dublin Port.

Introduction

The harbour porpoise (*Phocoena phocoena*) is the most widespread and abundant cetacean species in Irish waters (Berrow 2001). It has been recorded off all coasts and over the continental shelf but is thought to be most abundant off the southwest and east coasts (Wall *et al.* 2013). It is also consistently one of the most frequently recorded species stranded on the Irish coast (McGovern *et al.,* 2016; O'Connell and Berrow, 2015).

There have been a number of dedicated surveys, which have estimated absolute abundances of harbour porpoises in Irish waters. In July 1994, an abundance estimate of 36,280 harbour porpoises was calculated for the Celtic Sea as part of an international project called SCANS (Small Cetacean Abundance in the North Sea) (Hammond *et al.,* 2002). This survey was repeated in July 2005 (SCANS-II) but encompassed all Irish continental shelf waters including the Irish Sea (Hammond *et al.* 2013). Ship-based double platform line-transect surveys were carried out in the Celtic Sea and in offshore Ireland, while aircraft were used for coastal Ireland and the Irish Sea. Harbour porpoise abundance estimates were generated for three areas; Celtic Sea (80,613, CV=0.50), Irish Sea (15,230, CV=0.35) and Atlantic coastal Ireland (10,716, CV=0.37). The offshore survey area included Scotland and an estimate of 10,002 (CV=1.24) was generated for both areas combined. Hammond *et al.* (2013) reported a doubling of harbour porpoise density in the Celtic Sea between the SCANS and SCANS II survey years. An update of this survey (SCANS-III) was carried out in the summer of 2016 using similar methods, however the results and data from this project are not yet available.

The 2012 designation by the Irish Government of the Rockabill to Dalkey Island Special Area of Conservation (SAC) with harbour porpoise as a qualifying interest followed extensive consideration of relevant data and results from Ireland and neighbouring waters; this included a series of harbour porpoise surveys at eight sites throughout the country including Dublin Bay and North County Dublin (Berrow *et al.* 2008; 2014). Six single platform surveys were carried out at each of the 8 sites between July and October 2008 with density estimates calculated for each survey day and for all surveys combined (i.e., pooled estimates). These showed that density estimates were highest at the Blasket Islands SAC, off North County Dublin and in Dublin Bay. Single platform line-transect surveys using distance sampling and acoustic monitoring were carried out for Ireland's Department of Arts, Heritage and the Gaeltacht at a further six regional sites between 2010 and 2012. These sites were between 6-12 nm offshore and the surveys recorded all cetacean species encountered. Harbour porpoises were recorded at all sites but densities were highest in the Irish Sea with 1.58 ± 0.22 porpoises per km^2 recorded and with an associated CV of 0.14 (Berrow *et al*. 2011). In 2013, the Department of Arts, Heritage and the Gaeltacht commissioned a survey of the newly designated Rockabill to Dalkey Island SAC (Berrow and O'Brien, 2013). Density estimates were calculated for five of the six survey days and these ranged from 1.13 harbour porpoises per km^2 to 2.61 harbour porpoises per km^2. The overall pooled density estimate was 1.44 harbour porpoises per km^2 which delivered an abundance estimate of 391 porpoises within the SAC (Berrow and O'Brien, 2013).

Under the 1992 EU Habitats Directive Member States have been required to designate Special Areas of Conservation for species listed under Annex II of the Directive, one of which is the harbour porpoise. Ireland has designated three SACs with porpoise as a qualifying interest: The Blasket Islands SAC off County Kerry, Roaringwater Bay and Islands SAC off County Cork, and Rockabill to Dalkey Island SAC off County Dublin. In order to contribute towards the Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs' (DAHRRGA) ongoing site management and monitoring obligations, a series of visual surveys for harbour porpoise were again carried out in the latter SAC during the summer 2016. This was the second dedicated line-transect survey within this SAC since its designation, which in time will enable trends in porpoise density to be explored. The objectives of the survey in 2016 were to:

i) derive summer density and abundance estimates for harbour porpoises within the Rockabill to Dalkey Island SAC;
ii) estimate associated Coefficients of Variation and 95% Confidence Intervals;
iii) collect ancillary data during all surveys.

Methods

Survey site

The survey site off County Dublin and DAHRRGA line-transect survey design (black lines) are shown in Figure 1. The area of Rockabill to Dalkey Island SAC is an estimated 273.3 km^2. Track-line coordinates were provided by DAHRRGA, which were chosen randomly in order to provide equal coverage probability within the SAC. These track-lines were similar to those surveyed and reported on by Berrow and O'Brien in 2013 but had been repositioned entirely in order to provide an unbiased replicate sample of porpoise occurrence within the SAC.

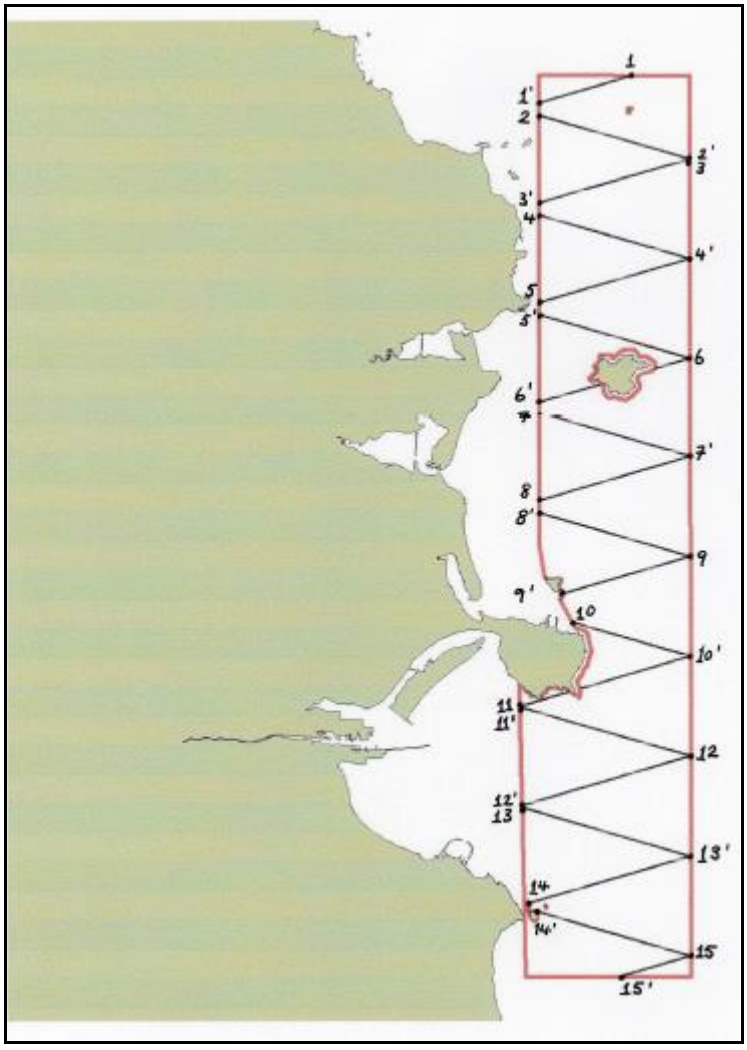


Figure 1. Rockabill to Dalkey Island SAC showing DAHRRGA track lines selected for survey coverage in 2016.

Survey platform and methodology

The same vessel was used for each survey and had been used for all previous surveys of this site. The MV Beluga is a 43'-long cruiser fitted with twin 375 hp caterpillar engines giving a maximum speed of 15 knots, and its home port is Dún Laoghaire, Co Dublin. It has a flying bridge, which provides an observation platform height of 3.1m.

Conventional single platform line-transect surveys were carried out within the boundaries of the site along the pre-determined track-lines. Transect lines were designed to try and get full coverage of the site over the study period to ensure that no potentially important porpoise concentrations were overlooked and to provide equal coverage probability. The environmental conditions prescribed by DAHRRGA in which surveys were to be

carried out included Beaufort Force/Sea state 2 or less and good light conditions with a visibility of 6km or more. Ship traffic is considerable at times within Rockabill to Dalkey Island SAC, including passenger vessels and yachts. A traffic separation zone exists in the approaches to Dublin port which resulted in small deviations from the original track-line.

Each survey was carried out at a speed of 12-16 km hr^{-1} (7-9 knots) which was 2-3 times the average speed of the target species (harbour porpoise) as recommended by Dawson *et al.* (2008). Two primary observers were positioned on the flying bridge, which provided an eye-height above sea-level of between 4-5m depending on the height of each individual observer. Primary observers watched with the naked eye from dead ahead to 90^{o} to port or starboard depending on which side of the vessel they were stationed. All sightings were recorded but sightings more than 300m were not used in the distance sampling model. This followed the recommendations of Buckland *et al.* (2001) since values beyond this truncation distance do not contribute much to the density estimate and they make it difficult to fit the detection function. Calves/juveniles were defined as porpoises ≤ half the length of the accompanying animal (adult) and in very close proximity to it. Small animals seen alone were also classified as juveniles. Sightings off-effort while transiting between track-lines or to the study site were also recorded but not included in the estimation analysis.

During each transect the position of the survey vessel was tracked continuously through a GPS receiver connected to a laptop computer while survey effort including environmental conditions (sea-state, wind strength and direction, glare, etc.) were recorded every 15 minutes using LOGGER software (© IFAW). When a sighting was made the position of the vessel was recorded immediately and the angle of the sighting from the track of the vessel and the estimated radial distance of the sighted animal(s) from the vessel were recorded. These data were communicated to the recorder in the wheelhouse via VHF radio. The angle was recorded to the nearest degree using an angle board attached to the vessel immediately in front of each observer. Accurate distance estimation is essential for distance sampling. Measuring sticks (Heinemann, 1981) were made on each vessel by each primary observer to assist in distance estimation.

Density and abundance estimation

Distance sampling was used to derive a density estimate and to calculate a corresponding abundance estimate for each individual survey where possible. The software programme DISTANCE (Version 5, University of St Andrews, Scotland) was used for calculating the detection function, which is the probability of detecting an object a certain distance from the track-line. The detection function was used to calculate the density of animals on the track-line of the vessel. During this survey we assumed that all animals on the track-line were observed, i.e., that g(0) = 1, given the strict operational and environmental conditions under which surveys took place. The DISTANCE software allows the user to select a number of models in order to identify the most appropriate for the data. It also allows truncation of sighting outliers when estimating variance in group size and testing for evasive movement prior to detection.

To calculate density, “day” was used as the sample regime with sightings used as sampling observations. Estimates of abundance and density obtained via the DISTANCE modelling process were calculated and presented for each survey day. An overall pooled abundance/density estimate was derived from all track-lines surveyed combined across all survey days. This was necessary in order to obtain sufficient sightings for a statistically robust estimate using the DISTANCE model (the minimum required is 40—60; Buckland *et al.,* 2001). In conducting this pooled analysis we assumed that there were no significant changes in distribution within the site between sample days or any immigration into or emigration out of the site.

The data were fitted to a number of models available in the DISTANCE software. The Half-Normal model with cosine adjustments was found to provide the best fit according to the Akaike Information Criterion delivered by the model. The recorded sighting data were grouped into equal distance bands of 0-30m, 30-60m, etc up to 300m. The DISTANCE model determines the influence of cluster size on variability by using a size-bias regression method with the log(n) of cluster size plotted against the corresponding estimated detection function g(x). A Chi-squared test associated with the estimation of each detection function was provided by the DISTANCE model. If found to be statistically significant it indicated that the detection function was a good fit and that the corresponding estimates were robust. The proportions of the variability accounted for by the encounter rates, detection probability and group size (cluster size) were presented with each detection

function. Variability associated with the encounter rate reflects the number of sightings on each track-line. The detection probability reflects how far the sightings were from the track-line and cluster size reflects the range of estimated group sizes recorded on each survey.

Mapping cetacean survey and encounter data

Maps of the study area and associated survey data were created in Irish Grid (TM65_Irish Grid) with ArcMap 10.2 while maps of the prescribed survey area, survey track-lines and coordinates were obtained from DAHRRGA. Data concerning transects, effort, sightings, abundance and density were stored in a single MS Access database, which were queried and processed via GIS to produce sighting distribution maps.

Results

Only four of the target six surveys were possible to carry out between June and September 2016 due to the prolonged persistence of unfavourable weather conditions. Of the four surveys carried out, environmental conditions were very favourable during all four days with only fog limiting the start time in September, when the boat had to heave to for 20-30 minutes to allow visibility to improve (Table 1).

The proportion of effort (time) surveyed in different sea-states is shown in Table 2. Sea-state 0 predominated for one survey (survey 3) and sea-state ≤1 for all four surveys. Only on survey 2 (24 August) was sea-state >1 for a significant proportion of survey effort (26%) but it still never increased to a sea-state 3.

Table 1. Overall environmental conditions during the surveys of Rockabill to Dalkey Island SAC in 2016.

Date	Swell (m)	Visibility (km)	Wind strength (knots)	Wind direction	Cloud cover	Precipitation
7 June	0	6-10	4	W	8/8	No
24 August	0	15-20	5	W	2/8	No
25 August	0	11-15	5	W	7/8	No
15 September	0	11-15	3	SW	4/8	No

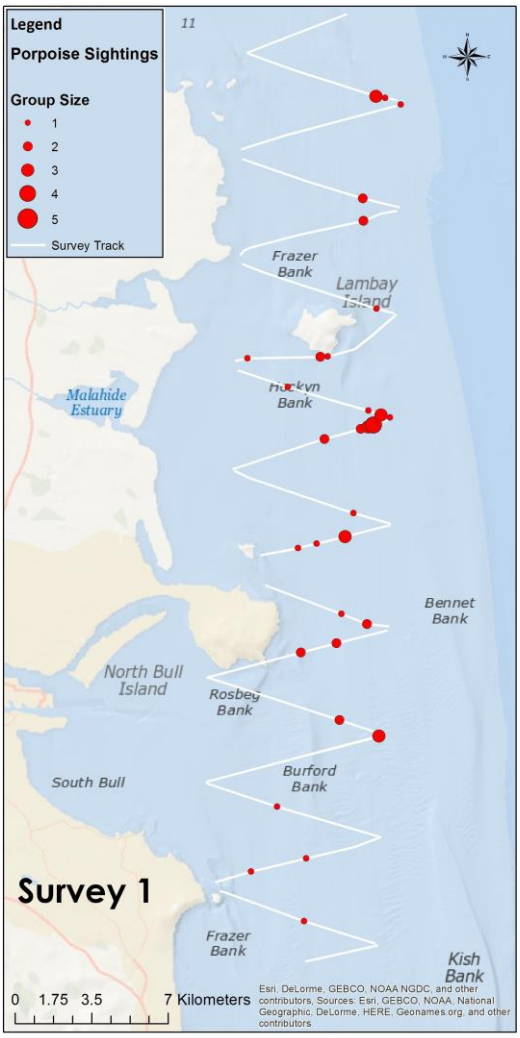
The total survey effort in Rockabill to Dalkey SAC per survey day was very consistent ranging from 126 to 127.9km per survey (Table 2). The small differences in track length were due to restrictions on line number 12-11' due to the traffic separation zone and the skipper keeping on the correct side.

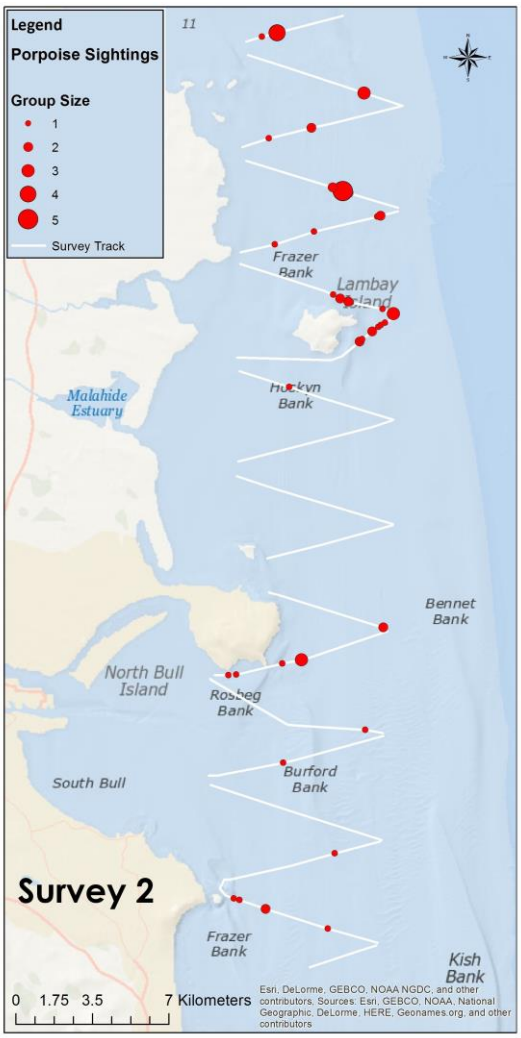
A total of 152 sightings of harbour porpoise were recorded during the four surveys, with an estimated total of 246 individual animals (Table 2). Track-lines and individual sighting locations within each survey are shown in Figures 2a-2d. Harbour porpoises were distributed throughout the study area but fewer sightings were apparent in outer Dublin Bay by comparison with adjacent waters, apart from survey 3 (25 August) where a good number of sightings were recorded over the Burford Bank. Most sightings were distributed around Lambay Island, to the south on survey 1 (June) and to the north on surveys 2 and 3 (August), with porpoises to the north and south on survey 4 (September).

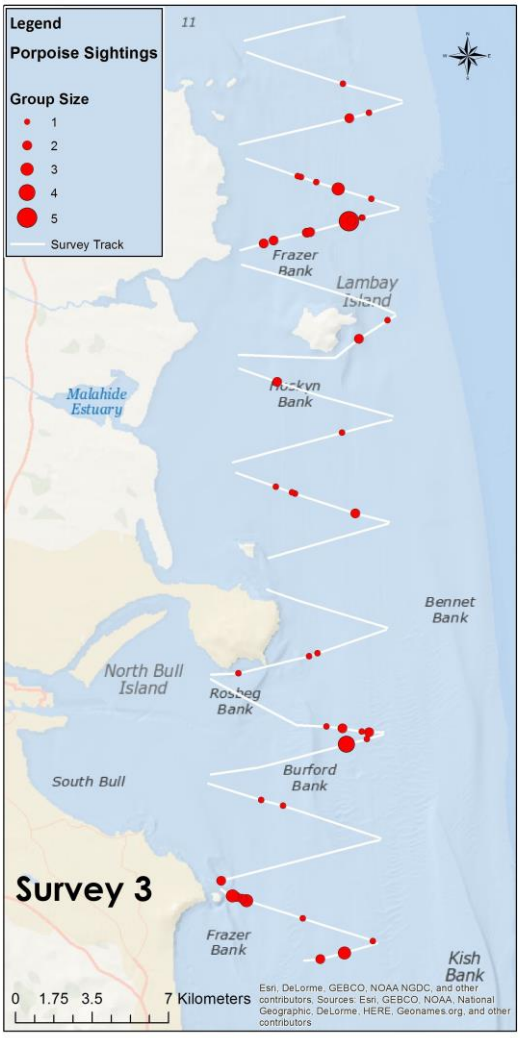
Table 2. Sea-state and on-effort sightings data for harbour porpoises recorded within Rockabill to Dalkey Island SAC.

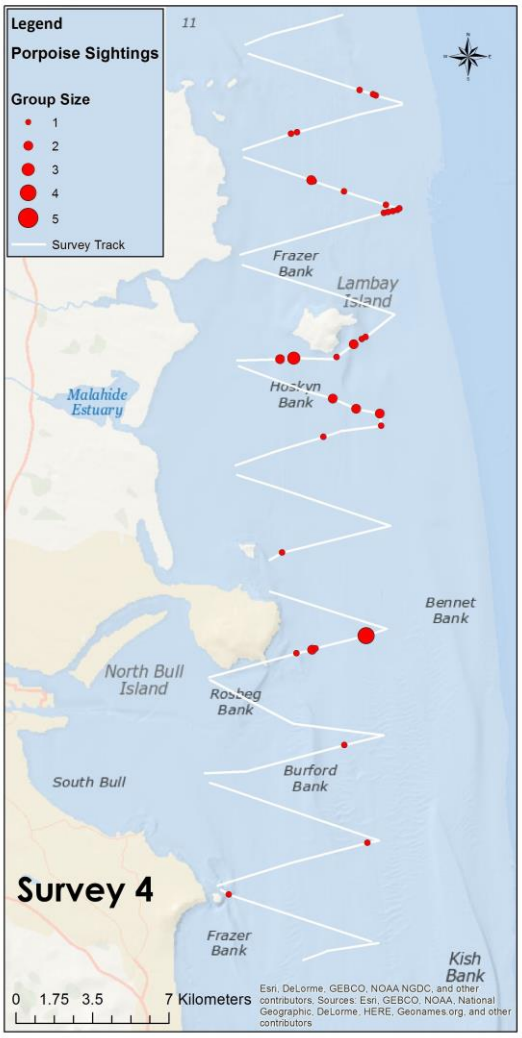
Sample Day	Date	Total effort (km) in sea-state ≤2	Sea-state (% of total survey time)			Number of sightings	Total no. of animals
			0	1	2		
1	7 June	127.9	20.0	72.0	8.0	35	60
2	24 August	126.0	49.0	25.0	26.0	38	61
3	25 August	126.0	72.4	27.6	0.0	46	80
4	15 September	126.3	3.0	79.0	18.0	33	45
Total		**506.2**				**152**	**246**

Harbour porpoises were distributed throughout the site but concentrations of sightings were evident during each survey. During survey 1 in June most sightings were recorded south of Lambay Island and on 24 August to the east and north of Lambay Island. The following day porpoises were more evenly spread between Lambay Island and Rockabill while in September they were more to the south of Lambay. There is some evidence that the tidal state had a very strong influence on local porpoise distribution within the site. On a flood tide porpoise records tended to be more northerly in distribution occurring to the north of Lambay Island while on an ebb tide records were distributed more to the south of Lambay. Elsewhere porpoises were also consistently observed in Killiney Bay and especially off Dalkey Island while on survey 3 (25 August), a cluster of sightings were recorded in the vicinity of the Burford Bank outside Dublin Bay (Figures 2a-d).









Figures 2a-d. Maps showing the locations of harbour porpoise sightings and corresponding group sizes recorded during each one-day survey of Rockabill to Dalkey Island SAC in 2016. (*note: at this resolution not all distinct sightings are visible on the map as some are overlain by others).

Density and abundance estimation

Density estimates for harbour porpoise within the SAC were calculated from sightings data obtained on each of the survey days and also for all surveys combined (i.e., pooled density estimate). A summary of the data from the DISTANCE model is shown in Table 3. The sightings dataset was truncated at 300m from the track-line. Chi-squared (i.e., Goodness-of-fit) values provided by the model were very favourable (P>0.9) for two of the surveys (surveys 1 and 4) and high for survey 3 (P=0.66), indicating that the detection functions were a good fit and the resulting estimates robust, but they were low (P=0.30) for survey 2. The detection function for survey 2 (Figure 3b) shows a higher proportion of sightings between 90-150m from the track-line than might be expected to reduce the goodness-of-fit. This is most likely due to evasive movement by porpoises as the survey vessel was approaching. The effective strip-widths surveyed were quite consistent across sample days with most variability attributed to the detection probability rather than to cluster size. Such features are typical of harbour porpoise surveys as group sizes tend to be small (i.e., in single figures) and relatively consistent in time. Mean cluster (group) size did vary between surveys from 1.39 to 1.74 (Table 3) but this was strongly influenced by relatively large group sizes of 5 and 4 individuals on 24 August (survey 2), and 5 individuals and two groups of 4 individuals on 25 August (survey 3). Two groups of 4 individuals were recorded on survey 1 (June) and one on survey 4 (September).

The detection functions for harbour porpoise in Rockabill to Dalkey Island SAC are shown graphically in Figures 3a-e. There was evidence of evasive movement by harbour porpoises on surveys 1 and 4 with a peak in sightings 30-60m from the track-line but this did not affect the goodness-of-fit (P=0.92 and 0.98; Table 3). The overall pooled data showed a goodness-of-fit of p=0.62 and a mean group size of 1.61 porpoises per sighting.

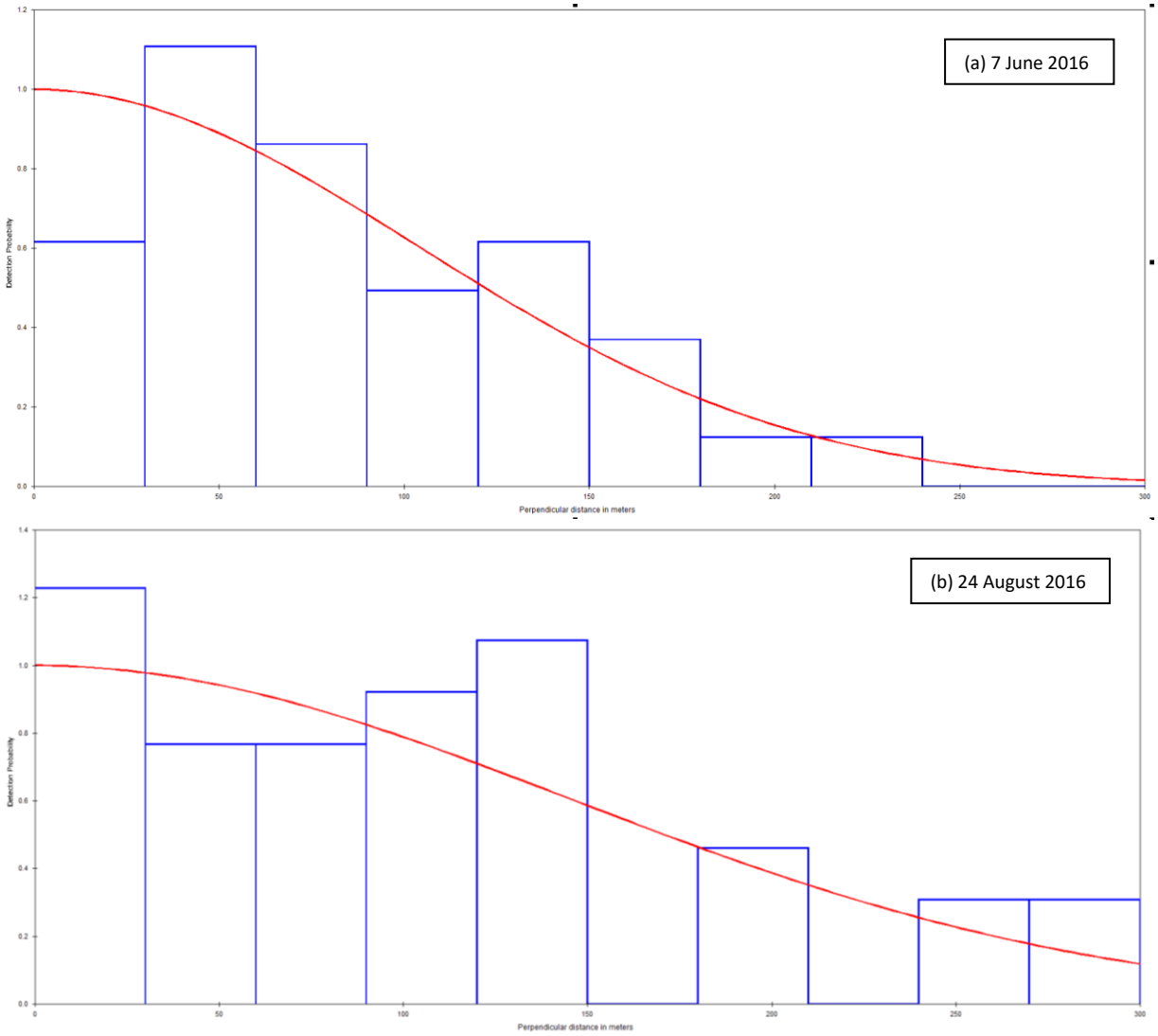
Table 3. Model data used in the harbour porpoise abundance and density estimation process for each survey of Rockabill to Dalkey Island SAC. Note: A half-normal model with cosine series adjustments and sightings data truncated at 300m was used.

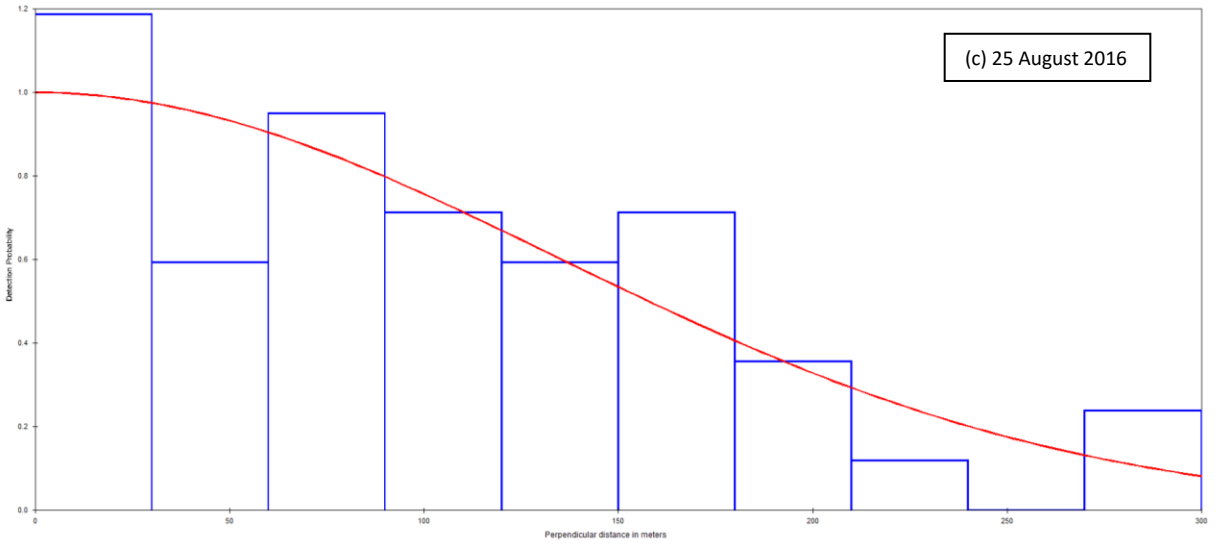
Sample Day	Chi^2 P value	Effective Strip Half-Width (m)	Mean Cluster Size ±SE	Variability (D)	
				Detection	Cluster
1	0.908	129.2	1.71±0.16	65.9	34.1
2	0.300	174.9	1.63±0.15	72.6	27.4
3	0.656	163.8	1.74±0.14	71.1	28.9
4	0.982	101.4	1.39±0.12	73.6	26.4
OVERALL	**0.617**	**145.0**	**1.61±0.07**		

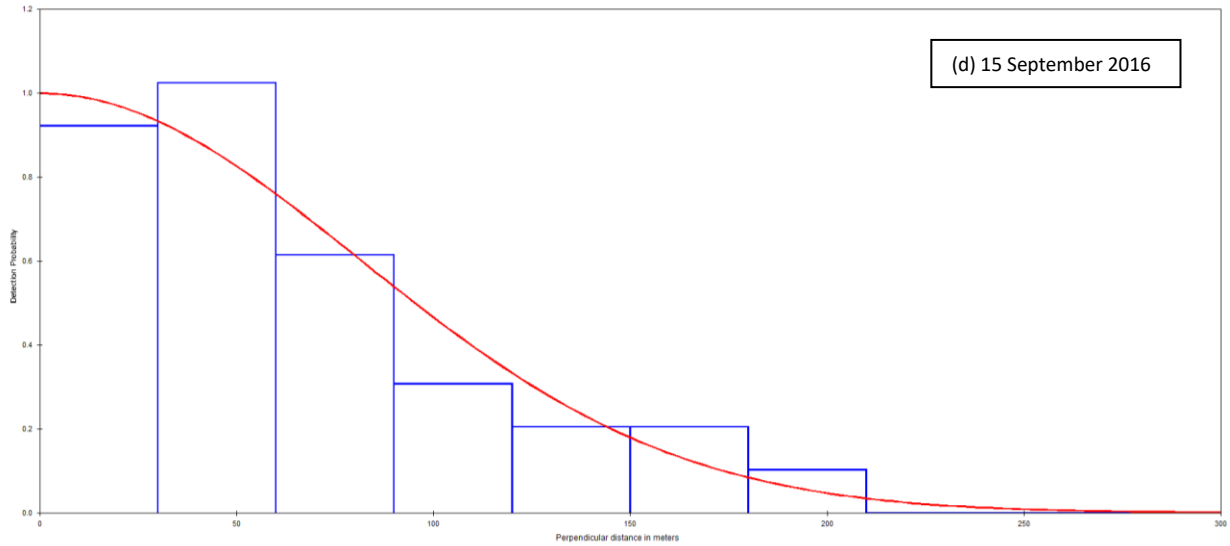
Density and abundance estimates for harbour porpoise in Rockabill to Dalkey Island SAC are shown in Table 4. Density estimates ranged from 1.37 animals per km^2 on 24 August to 1.87 animals per km^2 on 25 August, but were very consistent between surveys. The coefficients of variation (CV) were also very consistent and low (CV=0.14-16) with an overall pooled estimate CV of 0.10 which is very low. The overall pooled density estimate from all survey days combined was 1.55 porpoises per km^2 which gave an abundance estimate of 424±45 (95% Confidence Intervals [CI] = 355-536). Abundance estimates delivered by each survey ranged from 374 to 511 porpoises (Table 4), which were also comparatively consistent across each replicate survey of the SAC. Mean group size varied somewhat between surveys (Table 4) with slight peaks in June and late August but some variability but some variability between individual survey replicates is to be expected.

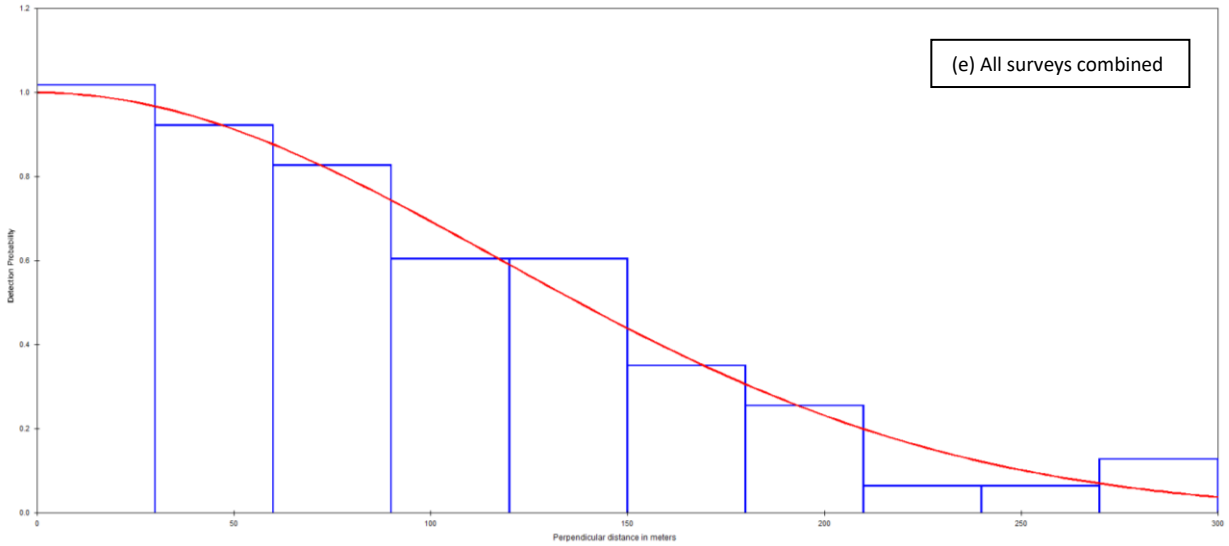
Table 4. Estimated density, abundance (N) and group sizes of harbour porpoise recorded during each survey of Rockabill to Dalkey Island SAC in 2016.

Sample Day	N (95% CI)	SE	CV	Density (per km^2)	Mean group size (95% CI)
1	457 (335-624)	71.6	0.16	1.67	1.71 (1.42-2.06)
2	374 (271-517)	60.6	0.16	1.37	1.63 (1.35-1.97)
3	511 (384-680)	73.6	0.14	1.87	1.74 (1.48-2.05)
4	479 (358-641)	70.1	0.15	1.75	1.39 (1.16-1.67)
Overall	**424 (335-536)**	**45.5**	**0.10**	**1.55**	**1.62 (1.48-1.76)**









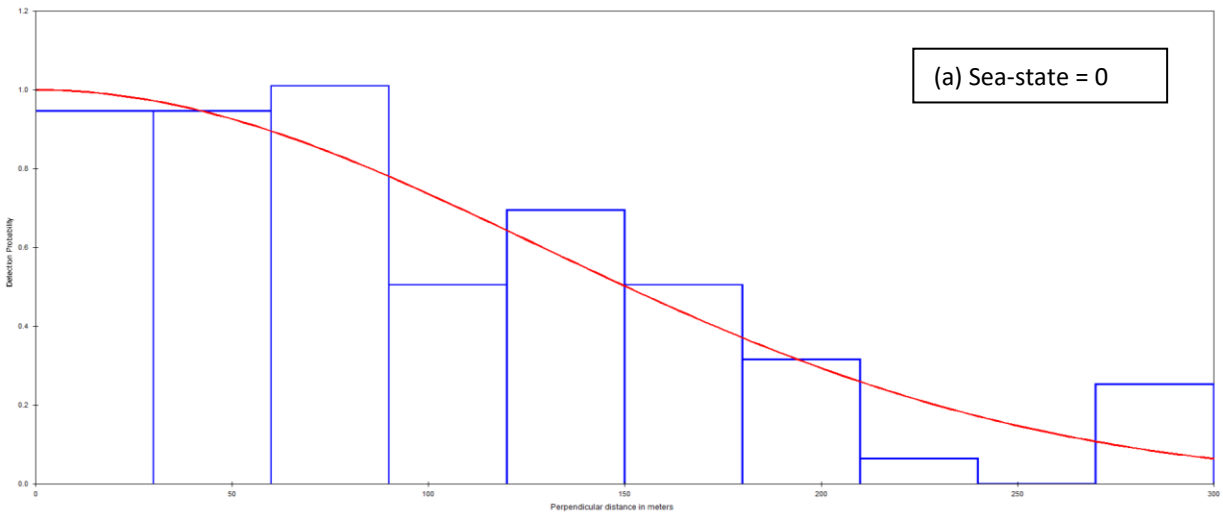
Figures 3a-e. Detection function plots for each survey of harbour porpoises in Rockabill to Dalkey Island SAC and for all survey data pooled together. Data used in this exercise were truncated in advance to within 300m perpendicular distance from the vessel's trackline.

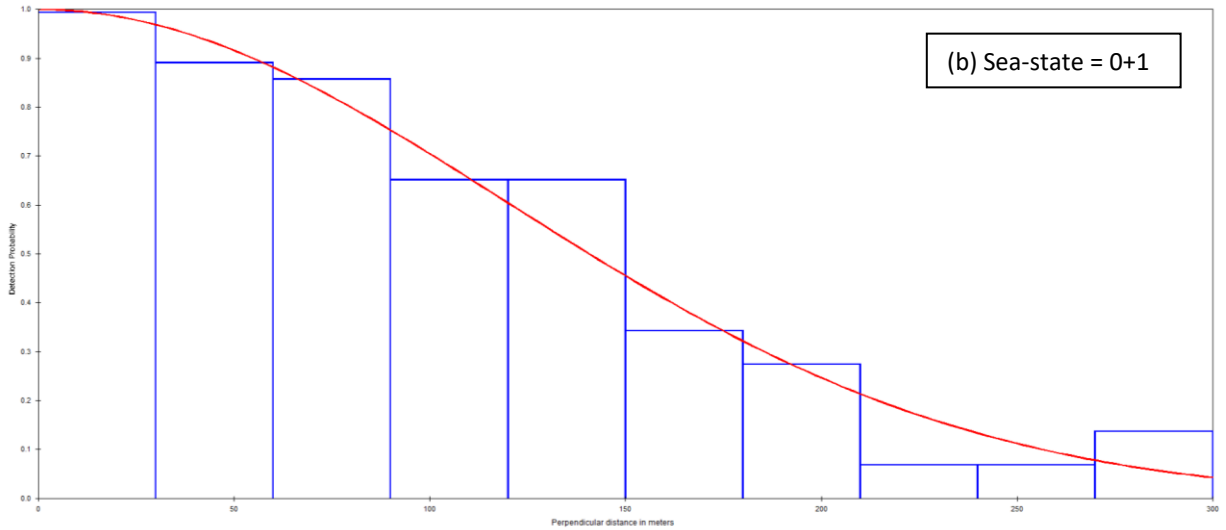
Density and abundance estimates in different sea-states

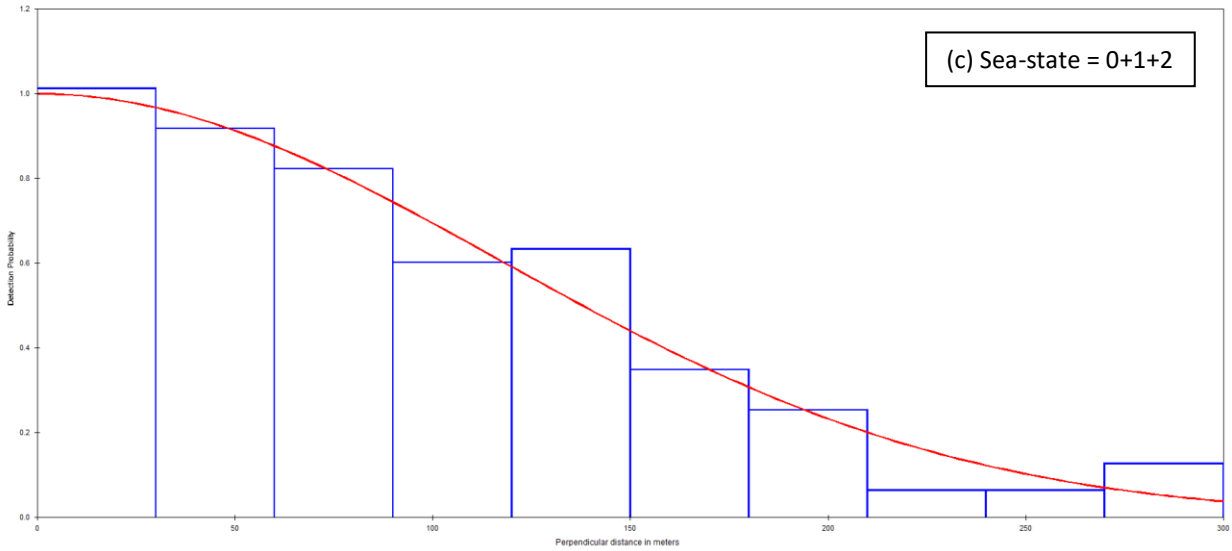
In order to determine whether sea-state had a significant influence on the density estimates produced by the modelling process the data for all surveys were pooled and detection functions were calculated for increasing sea-state (i.e., sea-state 0, sea-state 0+1, sea-state 0+1+2; Figure 4a-c). Total sighting effort (in km) was calculated for each sea-state class and subsequently used in the distance analysis (Table 5). The model's best fit was generated from data collected in sea-state 0+1 (P=0.62) but the highest density of porpoises and lowest CV around the estimate were recorded in sea-state 0 (Table 5). There was little change in either density estimate when data collected in sea-state 2 was compared to data from sea-state 0+1+2, with a consistent CV. This suggested that although the highest density was recorded in sea-state 0 the goodness-of-fit was poor (p=0.18) and the more accurate estimates are those using data from sea-state 0+1 or sea-state 0+1+2. This is also reflected in the narrower 95% Confidence Intervals around the abundance estimates generated from those data (Table 5).

Table 5. Density, abundance (N) and group size estimates of harbour porpoise in Rockabill to Dalkey Island SAC across different sea-state classes.

Sea-state class	Effort (km)	Chi^2 P value	Mean group size ± SE	Density (per km^2)	SE	CV	N (95% CI)
0	222.1	0.18	1.63±0.10	1.92	0.26	0.14	524 (393-700)
0+1	475.3	0.62	1.62±0.07	1.57	0.12	0.18	428 (329-558)
0+1+2	506.2	0.58	1.61±0.07	1.57	0.09	0.17	430 (340-544)







Figures 4a-c. Detection function plots for harbour porpoise surveys of Rockabill to Dalkey Islands SAC according to different sea-state classes. Data used in this exercise were truncated in advance to within 300m perpendicular distance from the vessel's trackline.

Proportion of young porpoises to adults

The numbers and proportions of young porpoises and calves to all porpoises (including adults), for each survey and for all surveys combined are shown in Table 6. The proportion of young harbour porpoises (i.e., juveniles + calves) recorded on individual survey days was very consistent and ranged from c. 8-11% of all animals seen, and it was c. 10% overall using the combined sighting dataset. The proportion of calves recorded on each survey ranged from 4 to 9% of all animals seen and it was 5.7% overall using the combined dataset.

Table 6. The numbers and proportions of adult harbour porpoises, juveniles and calves recorded during individual surveys of Rockabill to Dalkey Island SAC in 2016

Survey	Number of Sightings	Number of Individuals	Adults	Juveniles	Calves	% young	% calves
1	35	60	51	2	4	10.0	6.7
2	38	61	55	4	3	11.4	4.9
3	46	80	74	4	3	8.8	3.8
4	33	45	41	0	4	8.7	8.7
Overall	**152**	**246**	**221**	**10**	**14**	**9.8**	**5.7**

Additional sightings

Seals were the only other marine mammal species recorded while observers were on-effort with grey seals (n=10) being much more frequently recorded than harbour seals (n=2) (Table 7).

Table 7. Sighting records of seals that were obtained in Rockabill to Dalkey Island SAC during surveys in 2016

Species	Date	Total number of sightings	Total number of individuals
Grey seal	7 June	3	3
	24 August	1	1
	25 August	4	4
	15 September	2	2
Harbour seal	7 June	1	1
	24 August	1	1

Discussion

This is the second dedicated series of line-transect surveys for harbour porpoises in Rockabill to Dalkey Island SAC since it was first designated in 2012. The similar single platform surveys carried out in 2013 and 2016 now provide some measures that are useful for inter-annual comparison; for example in the density, distribution and status of the species at this site. The survey carried out in 2016 was successful in that sea conditions were favourable and fit for purpose throughout all four surveys conducted, and porpoises were recorded on all surveys. Due to the large area of the SAC, it is very difficult to get suitable weather conditions to persist for the entire survey day. Despite constant weather watching in 2016, only four of the six surveys were achieved. However, given the results from the present study, it is possible to compare results from four surveys with past years once surveys are carried out in excellent conditions, although this can lead to a higher CV.

As in preceding surveys for harbour porpoise within designated sites in Ireland (see below), distance sampling was used to derive density and abundance estimates within the Rockabill to Dalkey SAC in 2016. Statistical inference using distance sampling rests on the validity of several assumptions (Buckland *et al.,* 2001). These include the assumption that objects are spatially distributed according to some stochastic process. If transect lines are randomly placed within the study area, we can safely assume that objects are uniformly distributed

with respect to the perpendicular distance from the track-line in any given direction. Another assumption is that objects on the track-line are always detected (i.e., g(0)=1) and are detected at their initial location prior to any movement in response to the survey vessel. Finally, if objects occurring on or near to the track-line are not detected the resulting density estimate will be an underestimate. To minimise the effect of animal movement on the detection rate and detection function, it is recommended that the speed of the observation platform is at least twice the speed of the target object. If this is the case, then movement of the object causes few problems in line-transect sampling (Buckland *et al.,* 2001).

Typically for broad-scale surveys of harbour porpoise g(0)= 0.30-0.40 (Hammond *et al.* 2002) or even as low as 0.21 (Hammond *et al.* 2013) i.e., fewer than half of the animals available for detection on the track-line are actually detected by observers. If this was the case with the present survey, then we could perhaps double the density estimates derived from the sighting and effort data. Without a double-platform line-transect methodology (e.g., Hammond *et al*. 2002) it is not possible to accurately determine the number of porpoise detections missed on the track-line. The detection functions derived in the current analysis also suggest that there was some evasive movement from the survey boat which caused a poor fit to the DISTANCE model on a few occasions. Such factors will tend to lower the density estimates delivered via the modelling process. However, these sources of variability were consistent throughout the 2013 and 2016 surveys of Rockabill to Dalkey SAC. Furthermore, the single platform line-transect methods used in 2013 and 2016 were consistent with those used by Berrow *et al.* (2007; 2008; 2012) and Ryan *et al.* (2010) which facilitates a comparison between these surveys.

The ability to visually detect harbour porpoises at sea, and thus the accuracy of density and abundance estimates, is extremely dependent on sea-state. During the present study all transect lines were contracted by DAHRRGA to be carried out in sea-state 2 or less since the ability to detect harbour porpoises decreases significantly in sea-states ≥3 (Teilmann, 2003). In the present study, when the data were stratified by sea-state there was little difference in the density estimates obtained for each SAC when data collected in sea-state 2 were included, compared to using data collected only in sea-states 0 and 1. This finding supports the methodological decision to survey within these sites in conditions up to and including sea-state 2.

Rockabill to Dalkey Island SAC

Rockabill to Dalkey Island Special Area of Conservation was designated as a candidate SAC in 2012 with harbour porpoise as one of its qualifying features. Porpoise density and abundance estimates were obtained in 2013 (Berrow O'Brien, 2013) and again in 2016 using a DAHRRGA survey design comprising 19 randomly set zig-zag transect lines. During 2016, the number of sightings of harbour porpoise per survey was comparatively high and quite consistent, apart from the 15 September survey which recorded slightly lower numbers despite favourable sea conditions and which was attributed to smaller group sizes recorded on the day.

Porpoises were distributed throughout the SAC survey area in 2016 but significant changes occurred in their spatial distribution between individual surveys with abundance higher in the northern section of the SAC during the second half of the survey period. Harbour porpoise sightings in the outer Dublin Bay area also varied between surveys but were generally low compared to other sites surveyed within the SAC. This could be a consequence of heavy vessel traffic when ferries and cargo ships approach and leave Dublin Port. Such activity might cause harbour porpoises, or indeed their prey resources, to alter their distribution during periods of higher vessel activity.

Prior to the designation of Rockabill to Dalkey Island SAC, harbour porpoise density estimates were generated for two areas off the County Dublin coast in 2008. A comparison of key results from these 2008 surveys and the 2013 and 2016 surveys are presented in Table 8. "North County Dublin" was within the northern sector of Rockabill to Dalkey Island SAC and "Dublin Bay" was within the southern sector. Density estimates in North County Dublin in 2008 varied very significantly with the highest density of porpoises recorded at any site in Ireland thus far (i.e., 6.93 porpoises per km^2) recorded in August 2008. However, individual estimates from other surveys during 2008 were much lower, so this one survey had a strong influence on the overall pooled density estimate of 2.03 animals per km^2. Densities in Dublin Bay in 2008 were also comparatively high with three surveys recording 1.49, 1.51 and 2.05 porpoises per km^2 respectively. However, density recorded at this site was also as low as 0.48 porpoises per km^2 on one survey. These estimates gave an overall pooled density

estimate of 1.19 porpoises per km^2 for Dublin Bay. If we take the average of the overall pooled density estimates for the two sites in 2008 it equates to 1.61 which is quite similar to the 1.55 porpoises per km^2 derived from the present survey. The CV of the 2013 density estimate for Rockabill to Dalkey Island SAC was very low (CV=0.06) and considerably lower than those derived in 2008, indicating that the density/abundance estimation was robust and that the survey design and methods used within the site were effective. A previous wider-scale line-transect survey in the north Irish Sea, to the east and north of the current SAC, delivered a density estimate of 1.59±0.22 porpoises per km^2 (Berrow *et al.* 2011). This was also of a similar magnitude to that derived from surveys in 2013 and the present study.

Table 8. Density, abundance and group size estimates for harbour porpoise within Rockabill to Dalkey Island SAC during 2008, 2013 and 2016

Location	Year	Area (km^2)	Mean group size	Density (per km^2)	Abundance ± SE (95% CI)	CV	Reference
Rockabill to Dalkey Island SAC	2016	273	1.62	1.55	424±45 (335-536)	0.10	This study
Rockabill to Dalkey Island SAC	2013	273	1.47	1.44	391±25 (344-445)	0.06	Berrow and O'Brien (2013)
North County Dublin	2008	104	1.41	2.03	211±47 (137-327)	0.23	Berrow *et al.* (2008)
Dublin Bay	2008	116	1.19	1.19	138±33 (86-221)	0.24	Berrow *et al.* (2008)

Proportion of young to adult harbour porpoise

The proportion of young porpoises (both to juveniles and calves, and just calves) within the study area across the survey years is presented below. These values are consistent across years, ranging from 6 to 9.8% of all individuals recorded. Sonntag *et al*. (1999) suggested that the proportion of calves off the Isle of Sylt in Germany (measuring 9.6-17.9%) indicated that it was a preferred calving ground for harbour porpoise in the southern North Sea. Our proportions of adults to calves certainly show this SAC is a significant "calving site" or perhaps more fittingly a site in which calves are recorded in the company of other animals. However, the proportion is relatively consistent with other studies at around 3-5% (Hammond *et al.,* 2002; Evans and Hammond, 2004). Very little is known about the actual process of calving and initial calf-rearing by individual adults or groups of harbour porpoise (e.g., the nature and timing of calving events, locations of birthing, behavioural ecology around calving and calf rearing) and, in an Atlantic context at least, this is an area requiring further scientific research.

Table 9. The numbers and proportions of adult harbour porpoises, juveniles and calves recorded during surveys in Rockabill to Dalkey Island SAC during 2008, 2013 and 2016.
([1]North County Dublin and [2] Dublin Bay)

Year	Number of sightings	Number of Individuals	Adults	Juveniles	Calves	% young	% calves
2016	152	246	221	10	14	9.8	5.7
2013	201	292	272	14	6	6.8	2.0
2008[1]	82	111	102	1	8	8	7.2
2008[2]	56	69	65	1	3	6	4.6

Trends in density estimates for harbour porpoise in the Rockabill to Dalkey SAC and other SACs around Ireland

The results from the present survey show a slight increase in density compared with 2013 (Figure 5, Table 8). This increase is small and not significant and may be associated with only four surveys being completed in 2016, compared to six in 2013. Similar methodologies were employed in 2013 and 2016 due to implementation by DAHRRGA of a standardised design for the site. This more recent design and methods are different to those implemented in 2008, which saw the overall survey area split into two parts and surveyed on different days, and which may be reflected in the higher estimates.

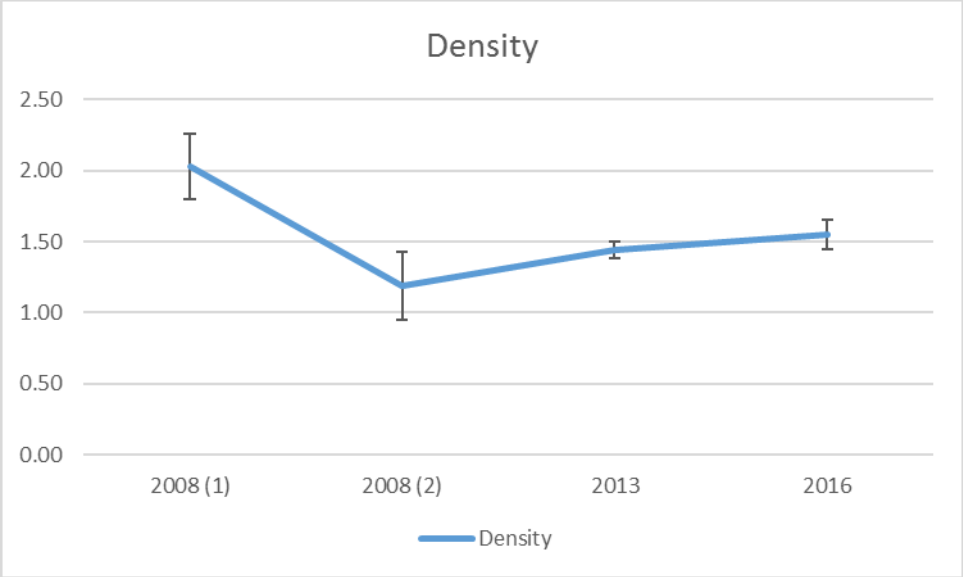


Figure 5. Changes in the recorded density of harbour porpoises in Rockabill to Dalkey SAC between years. The data shown are the pooled estimates from multiple surveys carried out in each year. ([1]North County Dublin and [2]Dublin Bay from 2008)

The CV of the 2016 pooled density estimate (0.10) is slightly higher than the 2013 estimate (0.06) but both the 2013 and 2016 figures were much lower than the 2008 estimates (0.23 and 0.24; Table 8). The data collection in 2016 and 2013 were very similar with the entire SAC surveyed in a single day and similar track-line lengths distributed randomly but in a standard ziz-zag arrangement within the site. In comparison, in 2008 the County Dublin area was divided and the north and south parts were surveyed on different days. Furthermore, track-lines undertaken in 2008 were not consistent in each survey and were not distributed evenly within study areas. Both factors, and also differing research objectives at the time, may thus explain some of the difference in the derived results and estimate precision.

Overall when the results from 2016 are compared with the most recent estimates from the two other harbour porpoise SACs (Table 10),Rockabill to Dalkey Island SAC recorded the second highest pooled density estimate after Roaringwater Bay and Islands SAC in Cork (2.02; O'Brien and Berrow, 2015) and over double that recorded from the Blasket Islands SAC in 2013 (0.64; O'Brien and Berrow, 2014). This east coast SAC has demonstrated the highest abundance estimates for an Irish site (424±25) in comparison to Roaringwater Bay and Islands SAC (289±80), and the Blasket Island SAC (146±53). This could be as a consequence of its greater area but further replicated surveys will inform this picture.

The process of building robust baseline data on the abundance, density and distribution of harbour porpoises at individual sites in Ireland is in its early stages, therefore appropriate caution must be taken when carrying out inter-site and inter-annual comparisons. In the case of all three SACs, effective long-term monitoring of these important sites for harbour porpoise will allow for trends in porpoise occurrence and density to be assessed, and establish whether the estimates are consistent or whether they increase or decrease over time.

Table 10. Density and abundance estimates for harbour porpoise within SACs designated for the species in Ireland. The data shown are derived from pooled estimates across multiple surveys.

Location	Year	Area (km^2)	Mean group size	% young	Density (per km^2)	Abundance ± SE (95% CI)	CV	No. of surveys	Reference
Rockabill to Dalkey Island SAC	2016	273	1.62	9.8	1.55	424±45(335-536)	0.10	4	This study
	2013	273	1.47	5	1.44	391±25 (344-445)	0.09	5	Berrow and O'Brien (2013)
North County Dublin	2008	104	1.41	8	2.03	211±47 (137-327)	0.23	4	Berrow *et al.* (2008a)
Dublin Bay	2008	116	1.19	6	1.19	138±33 (86-221)	0.24	4	Berrow *et al.* (2008a)
Blasket Islands SAC	2007	227	2.32	2	1.33	303±76 (186-494)	0.25	5	Berrow *et al.* (2009)
	2008	227	1.76	18	1.65	372±105 (216-647)	0.28	3	Berrow *et al.* (2008)
	2014	227	2.09	6	0.64	146±53 (41-516)	0.36	3	O'Brien and Berrow (2014)
Roaringwater Bay and Islands SAC	2008	128	2.21	7	1.24	159±42 (95-689)	0.27	3	Berrow *et al.* (2008)
	2013	128	1.56	13	1.18	151±18 (119-192)	0.12	3	Berrow and O'Brien (2013)
	2015	128	1.86	14.2	2.02	289±80 (155-541)	0.28	6	O'Brien and Berrow (2015)

Recommendations

Arising from the present study, the following recommendations are made for future harbour porpoise surveys in the Rockabill to Dalkey Island SAC:

1. Harbour porpoise surveys should continue to be carried out in sea-state ≤2 only, as per this survey, aiming to achieve as much of the survey as possible in a sea-state 0 or 1.

2. Density estimates obtained in 2016 were very similar to those obtained in 2013 using similar track-lines. It is recommended to repeat these track-lines using the same methodology during future surveys to improve the time series.

3. Consideration should also be given to developing acoustic monitoring at the site to provide monitoring indices to contribute towards population monitoring within the SAC. It is likely that acoustic datasets, when put into appropriate models, would be able to identify changes in occurrence and distribution at a quicker rate and possibly at a higher resolution than visual surveys, but these indices would also require data replication over a number of years.

4. Density estimates obtained in 2016 were consistent with those obtained in 2013. A power analysis of these datasets should be carried out to inform managers on the number of surveys (and sightings required) to determine changes in density and abundance at different resolutions.

5. These surveys provide very useful data on the habitat use of SACs by harbour porpoises. More value could be obtained from the data, including habitat preferences, feeding areas, etc especially if

combined with other datasets collected from the area. We recommend spatial analysis and habitat modelling of this and all relevant data to explore the drivers of harbour porpoise distribution and abundance within the SAC and in adjacent waters.

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Appendix 1: Sighting distribution maps for additional marine mammal species that were recorded during surveys within Rockabill to Dalkey Island SAC, 2016.