HARBOUR PORPOISE SURVEYS IN ROCKABILL TO DALKEY ISLAND SAC, 2021

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Keywords: Harbour Porpoise, *Phocoena phocoena*, SAC, density estimates, abundance

Citation: e.g. Berrow, S.D., Cummins, F., Kane, G., Keogh, H. and Wall, D (2021). Harbour porpoise surveys in Rockabill to Dalkey Island SAC, 2020. Report to the National Parks and Wildlife Service, Department Housing, Local Government & Heritage, Ireland.

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Executive Summary

A visual survey of harbour porpoises (*Phocoena phocoena*) was carried out in Rockabill to Dalkey Island SAC in order to derive local density and abundance estimates. Single platform line-transect surveys were carried out according to a standardised design across six days between July and August 2021. Distance sampling was used to produce a detection function based on the observed distribution of harbour porpoise sightings. Abundance estimates were calculated using the survey day as the sample and sightings as the observation for 1) each survey day, 2) stratified by sea state and 3) for all surveys combined

The survey effort in Rockabill to Dalkey Island SAC ranged from 116-124 km per survey and was 728 km overall. Sea-state was ≤2 for the whole of four surveys and 97% of survey 1. Sea-state 0 and sea-state 1 dominated for two surveys each. Only on one survey was sea-state 2 recorded for >50% of survey effort.

The number of porpoise sightings per survey ranged from 12 to 29 and from 12 to 42 individuals per survey with a total of 137 sightings of 181 individual porpoises overall. Clusters of sightings were evident and this survey highlights the importance of the areas between Howth Head and Lambay Island for harbor porpoises.

Sightings were made throughout the survey area. Density estimates ranged from 0.50 porpoises per km^2 to 0.98 porpoises per km^2 with an overall density estimate of 0.83±.014 porpoises per km^2. The coefficients of variation around the estimates were low ≤0.24 and was 0.17 overall. The effect of sea-state on density estimates was investigated by running models on data derived from sea-state 0, sea-state 0+1 and sea-state 0+1+2. The highest density estimate was collected in sea-state 0+1+2 (all survey data) (0.83 porpoises per km^2) and was 0.51 using data collected in sea-state 0 and 0.40 using data collected in sea-state 0 +1. Both these latter estimates had higher CVs, hence the best estimate was considered as that using data from all sea-states combined. Mean group size varied between 1.00 and 1.58 porpoises over the survey duration with no obvious trend over the study period. The overall pooled density estimate from all survey days combined gave an abundance estimate of 227±39 with 95% Confidence Intervals of 163-321. The proportion of young porpoises (juveniles and calves combined) recorded on survey days ranged from 6.3% to 9.5% and was 5.5% overall.

The density estimate recorded during the current survey was lower than previous estimates from Rockabill to Dalkey Island SAC in 2008, 2013 and 2016 where densities of 1.30, 1.47 and 1.62 porpoises per km^2 were calculated. The density estimate in 2021 represent a 46% decline on that reported in 2016 and a 42% decline on that reported in 2013. The number of sightings per survey were similar in 2013 and 2015, but down by 17% on the mean of the previous surveys. Surveys during 2021 were carried out in very favourable sea conditions and we are confident that the density estimates reported here are robust. The decrease in density reported in 2021 is the first significant decline reported since monitoring started, but whether this reflects a real change in population or more likely a change in the local distribution of porpoises, adjacent to the SAC, is not clear. Small changes in local distribution, driven by the distribution of their preferred prey can have profound effects on density estimates within a relatively small SAC compared to individual's home range.

We recommend these surveys are continued using the same methodology but on a more frequent (annual) basis to provide a more robust data time series within the site. Given the variability in density estimates per survey, consideration should also be given to establishing fixed acoustic monitoring stations to derive acoustic indices from which to monitor population status. The most likely driver is the availability of preferred prey which may fluctuate locally over short periods. We recommend a study of the diet of harbour porpoises off the east coast of Ireland be considered including seasonal components.

Acknowledgements

We would like to thank skippers Jeff Brownlee, Peter Beamish and Vincent Duke for their commitment to get these harbour porpoise surveys completed in the best possible sea conditions and to Kevin Heapes for assisting with data delivery. This survey was funded by the Department Housing, Local Government & Heritage (DHLGH) and we thank Loraine Fay for her support throughout.

1 Introduction

The harbour porpoise (*Phocoena phocoena*) is the most widespread and abundant cetacean species in Irish waters (Rogan *et al.*, 2018). It has been recorded off all Irish coasts, including over the continental shelf but is thought to be most abundant off the southwest and east coasts (Wall *et al.*, 2013; Rogan *et al.*, 2018). It is also consistently one of the most frequently recorded species stranded on the Irish coast (O'Connell & Berrow, 2019; 2020).

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) when it covered all waters overlying the continental shelf, 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 in the Irish Sea. Harbour porpoise abundance estimates were generated for three areas; the 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 Ireland survey area included Scotland and an estimate of 10,002 porpoises (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. Rogan *et al.* (2018) recorded a total of 296 harbour porpoise sightings during aerial surveys in 2015 and 2016. Across the total survey area, abundance across both years was higher in the summer than in the winter, with consistently highest summer densities/abundance recorded in the Celtic and Irish Seas. Densities along the south coast in summer 2016 were 0.29 porpoises per km^2 (CV=0.63) and 0.060 porpoises per km^2 (CV=0.73) during winter 2016-17. The predicted distribution of harbour porpoises for both summers highlights the importance of the south west part of the Celtic Sea (over the North Celtic Sea Basin), which had high numbers of sightings and was predicted as an area of high abundance. Recently Nielsen et al. (2021) reported harbour porpoise densities of 0.070 porpoises per km^2 in the Celtic Sea, 0.044 in the North Sea and 0.006 in the English Channel using data from platforms of opportunity.

Single platform line-transect surveys using distance sampling and acoustic monitoring were carried out at a further six regional sites around Ireland 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).

EU Member States are required to designate Special Areas of Conservation (SACs) for species listed under Annex II of the EU Habitats Directive, one of which is the harbour porpoise. The Blasket Islands SAC and Rockabill to Dalkey Island SAC were designated as candidate SACs for the species in 2000. Designation of the Rockabill to Dalkey site as an SAC, with harbour porpoise as a qualifying interest, followed on from a series of harbour porpoise surveys at eight sites throughout Ireland, including Dublin Bay and North County Dublin, during 2008 (Berrow *et al.*, 2008; 2014). Six single platform surveys were carried out at each site between July and October with density estimates calculated for each survey day and for all surveys combined (i.e., pooled estimates). These showed that density estimates were highest for the Blasket Islands SAC, North County Dublin and Dublin Bay.

In 2013, the National Parks and Wildlife Service (NPWS) commissioned a survey of the newly designated Rockabill to Dalkey Island SAC (Berrow & O'Brien, 2013). Density estimates were calculated for five of the six survey days and ranged from 1.13 harbour porpoise per km^2 to 2.61 harbour porpoise per km^2. The overall density was 1.44 which derived an abundance estimate of 391 harbour porpoise within the SAC (Berrow & O'Brien, 2013). A second survey of the Rockabill to Dalkey Island SAC was carried out in 2016 (O'Brien & Berrow, 2016). Density estimates between each survey were very consistent, ranging from 1.37 porpoises per km^2 to a maximum of 1.87 porpoises per km^2, with an overall density of 1.55±0.17 porpoises per km^2 with a very low CV of 0.10. Harbour porpoise abundance ranged from 374 individuals to 511 individuals with an overall estimate of 424±46 with 95% CI of 335-536. Single platform line-transect surveys using distance sampling and acoustic monitoring were also carried out in summer at a further five regional sites (Northwest, West, Southwest, North Irish Sea, South Irish Sea) around Ireland between 2010 and 2012 (Ryan *et al.*, 2010; Berrow *et al.,* 2011; 2012). These sites were generally situated 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).

Density estimates in 2016 were remarkably consistent to surveys carried out in 2013, with 1.44 harbour porpoise per km^2 recorded compared to 1.55 porpoise per km^2 from the 2013 survey. Sea conditions were good on both surveys with 61% of survey effort in 2013 ≤1 and 87% in 2016, although only four surveys were carried out during 2016. During both studies mean group size was similar which suggests that porpoise densities between the two periods were consistent.

In order to contribute to the Department Housing, Local Government & Heritage (DHLGH) site management and surveillance, visual monitoring of harbour porpoises was carried out in Rockabill to Dalkey Island SAC during the summer of 2021. This was the third dedicated line transect survey of harbour porpoises within this SAC which enabled ongoing trends in summer density estimates to be explored. The objectives of the survey in 2021 were to:

i) derive updated summer density and population estimates for harbour porpoises within the Rockabill to Dalkey Island SAC using robust sampling methods for small cetacean density/population estimation;

ii) estimate associated Coefficients of Variation and 95% Confidence Intervals

2 Methods

2.1 Survey site and Platform

The survey site and line-transect survey design is shown in Figure 1. The area of the Rockabill to Dalkey Island SAC is 273 km^2. Survey track lines were provided by the DHLGH to provide equal coverage probability within the SAC but repeatable over time. Standardized visual survey design for the site, measuring c128km in total transect length was provided by DHLGH. To allow for the greatest coverage of the SAC new survey lines (comprising of start, end and turning points) have been provided each survey year, thus there has been no repetition of survey lines across survey years.

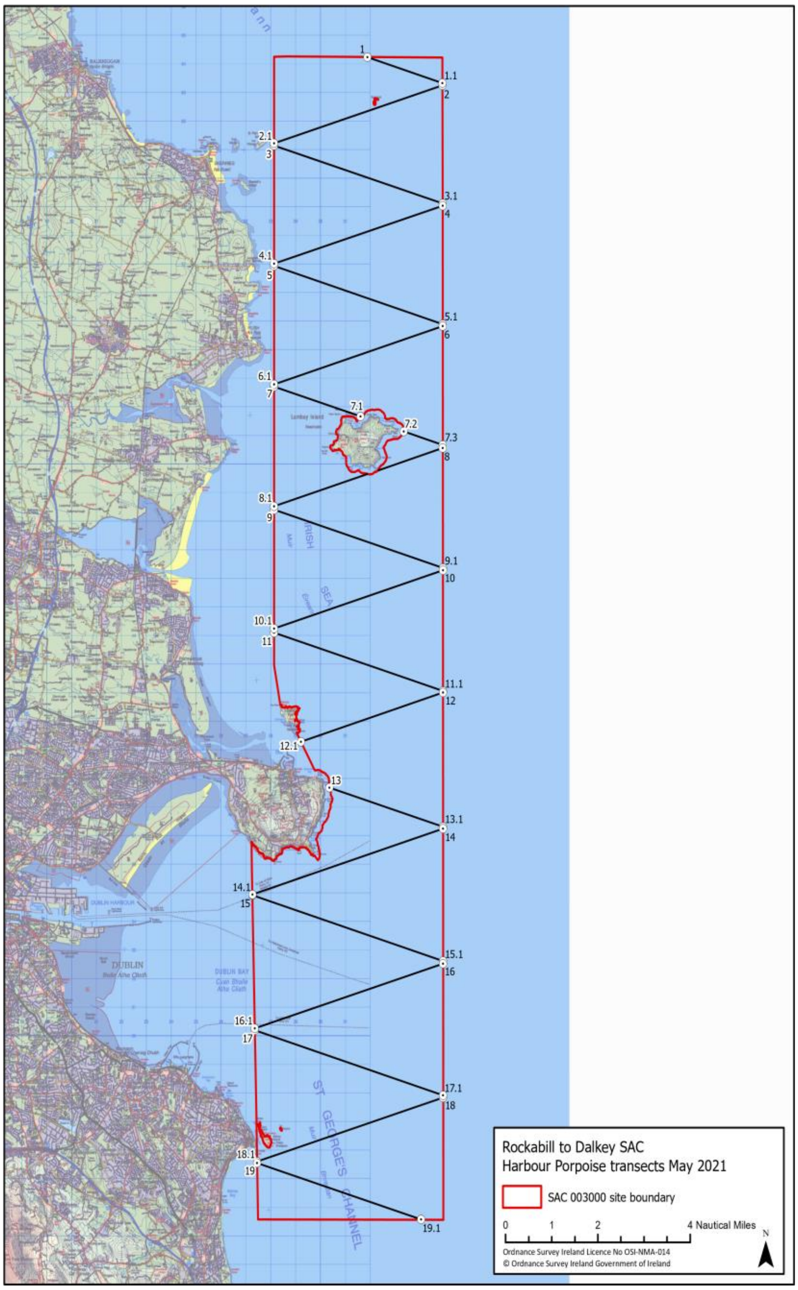


Figure 1 Rockabill to Dalkey Island SAC showing DHLGH track lines selected for coverage in 2021.

Two vessels, both operating out of Dún Laoghaire, Co Dublin were used during this survey. The MV Beluga, skippered by Jeff Brownlee of Aquamarine Ltd. was used for three of the six surveys and MV Gaviota operated by Dublin Boat Ltd. for the remaining three surveys. MV Beluga had been used as the survey platform on all previous harbour porpoise surveys of the Rockabill to Dalkey Island SAC carried out by the IWDG. Both vessels provided a primary observation platform 3.1m above the waterline (Figure 2).

a. b.

Figure 2 Survey vessels **a.** MV Beluga and b. MV Gaviota. Note: flying bridges suitable for line-transect surveying.

COVID-19

HSE guidelines were followed over the duration of this contract. Local observers were used if possible to minimise the need for travel and overnight accommodation and social distancing was easily maintained throughout all surveys due to the size of the vessels.

2.2 Survey methodology

Conventional single platform line-transect surveys were carried out within the boundaries of the SAC 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 survey conditions prescribed by DHLGH 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.

The survey vessel travelled at a speed of 16-20 km hr^{-1} (9-10 knots), while on survey effort, 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 200-500m (truncation distance depends on each detection function, see Fig 4) from the track-line were not used in the distance sampling model to improve fit. 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 recorded but not included in further data 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 reviewed every 15 minutes following a prompt from the 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 by each primary observer to assist in distance estimation. Environmental conditions were recorded at the start and end of each track-line and if they changed during a track.

2.3 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 6, 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, "survey" 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. Data were also sorted into sea-state and density estimates were also derived with survey effort and sightings carried out in sea-state 0, sea-state 0+1 and sea-state 0+1+2 (all data).

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 (the width of which was modified during each model run to get the best fit) up to 500m from the track-line. 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 if the detection function was a good fit and that whether 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.

2.4 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 DHLGH. Data concerning transects, effort, sightings, abundance and density were stored in a single MS Access database, which was queried and processed via GIS to produce sighting distribution maps.

3 Results

Six survey days were completed in the Rockabill to Dalkey Island SAC during the present study. Favourable conditions, defined as sea-state ≤2 with good light and visibility ≥6km, were recorded during all six surveys (Table 1). No swell or precipitation was recorded. No surveys were carried out in June due to the non-availability of the nominated vessels, which resulted in new survey vessels being identified. Four surveys were completed in July and two in August 2021, with none carried out in September. Advantage was taken of good weather windows and the availability of the new survey vessels, which were in high demand elsewhere. It seems unlikely that this would have had any major impacts on the results as harbour porpoise are highly mobile and large fluctuations in the number of sightings per survey is typical even over very short periods (days) between surveys. The lack of surveys in September may have resulted in an underestimate of calves (neonates see Table 6).

Table 1 Overall environmental conditions during surveys of the Rockabill to Dalkey Island SAC during 2021.

Date	Swell (m)	Visibility (km)	Wind strength (knots)	Wind direction	Cloud cover	Precipitation
7 Jul	None	11-15	6	200	5/8	None
12 Jul	None	6-10	2	270	1/8	None
17 Jul	None	6-10	2	270	1/8	None
21 Jul	None	16-20	5	270	2/8	None
19 Aug	None	6-10	3	110	7/8	None
28 Aug	None	11-15	4	100	2/8	None

Sea-state can be influenced by wind and tide and can change throughout the survey. Sea-state was ≤2 for the whole of four surveys (surveys 3-6) and 97.1% of survey 1. Sea-state 0 (12 and 21 July) and sea-state 1 (17 July and 28 August) dominated for two surveys each (Table 2). Only on one survey (19 August) was sea-state 2 recorded for >50% of survey effort (Table 2).

The total survey effort in the Rockabill to Dalkey Island SAC per survey day was very consistent ranging from 116-124km per survey (Table 2), the differences were due to tidal restrictions around the islands on some days, which affected the safe distance to which the survey vessel could approach islands and requests from Dublin Port VTS to avoid the traffic separation zone entering Dublin Port. A total of 728 km was surveyed during this survey (Table 2).

The number of sightings per survey ranged from 12 to 29 with a total of 137 overall (Table 2). The highest numbers of sightings were recorded on surveys 4 and 6 (21 July and 28 August), and the lowest number on surveys 1 and 2 (7 and 12 July), but the differences were relatively small suggesting there was little monthly trends in detection rates. The total number of individual porpoises recorded per survey also varied from 12 to 42 with a total of 181 overall (Table 2).

Table 2 Sea-state and on-effort sighting data for harbour porpoises recorded in the Rockabill to Dalkey Island SAC during 2021.

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 Jul	116.4	23.5	36.3	37.4	12	12
2	12 Jul	123.0	62.2	23.5	14.3	19	25
3	17 Jul	122.2	27.7	63.1	9.1	22	29
4	21 Jul	124.2	67.0	31.8	1.2	29	32
5	19 Aug	120.1	0.0	42.1	57.9	26	41
6	28 Aug	122.1	14.2	60.5	25.3	29	42
Total		**728**				**137**	**181**

Track-lines surveyed and all harbour porpoise sightings within the Rockabill to Dalkey Island SAC during each survey day are shown in Figures 3a-f. Three surveys (surveys 1, 4 and 6) were surveyed from south to north and three (surveys 2, 3 and 5) were surveyed from north to south. On passage to the northern start of the tracklines the vessels travelled north around Howth Head and along the coast inside Lambay Island to avoid as transiting through the SAC as much as possible. Surveys also occurred at different states of the tide. This randomised the effect of time of day and tidal state throughout the six surveys, which may have influenced porpoise distribution.

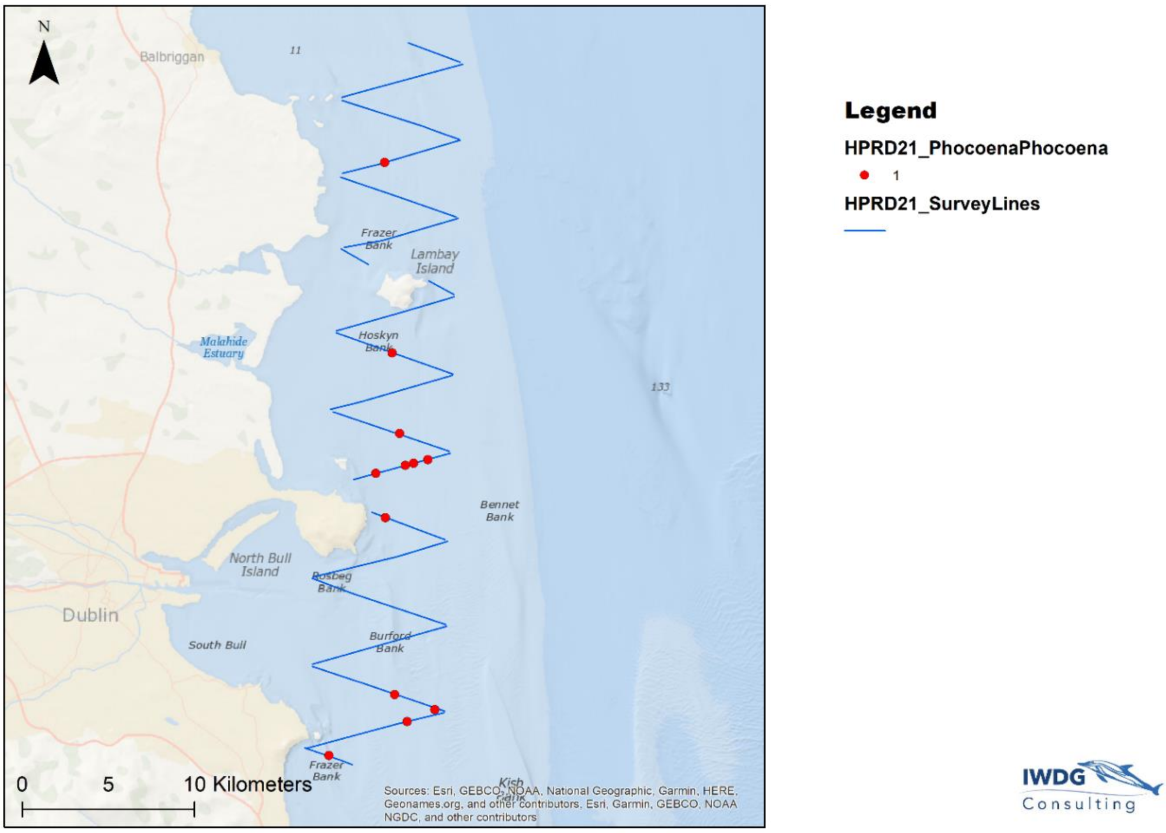


Figure 3a Track-lines and distribution of harbour porpoise sightings on 7 July 2021.

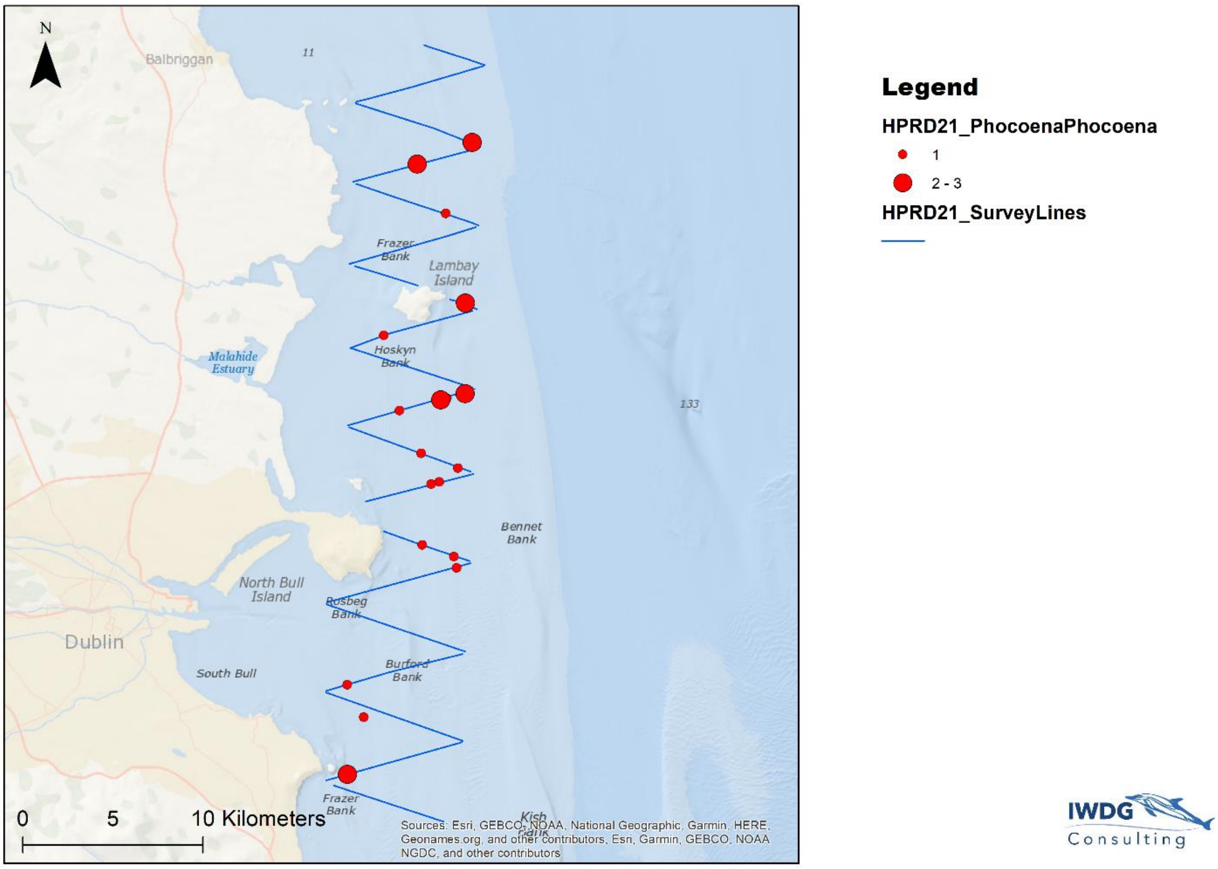


Figure 3b Track-lines and distribution of harbour porpoise sightings on 12 July 2021.

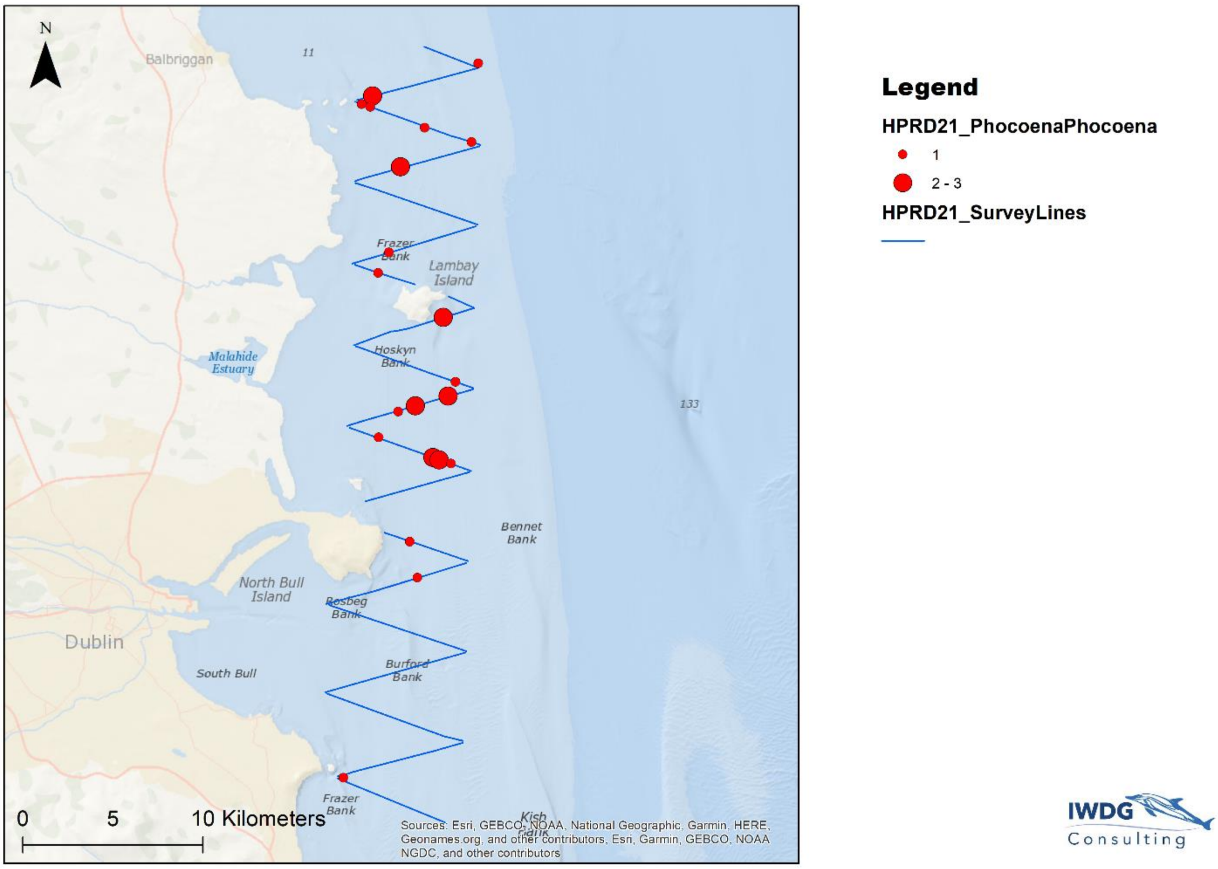


Figure 3c Track-lines and distribution of harbour porpoise sightings on 17 July 2021.

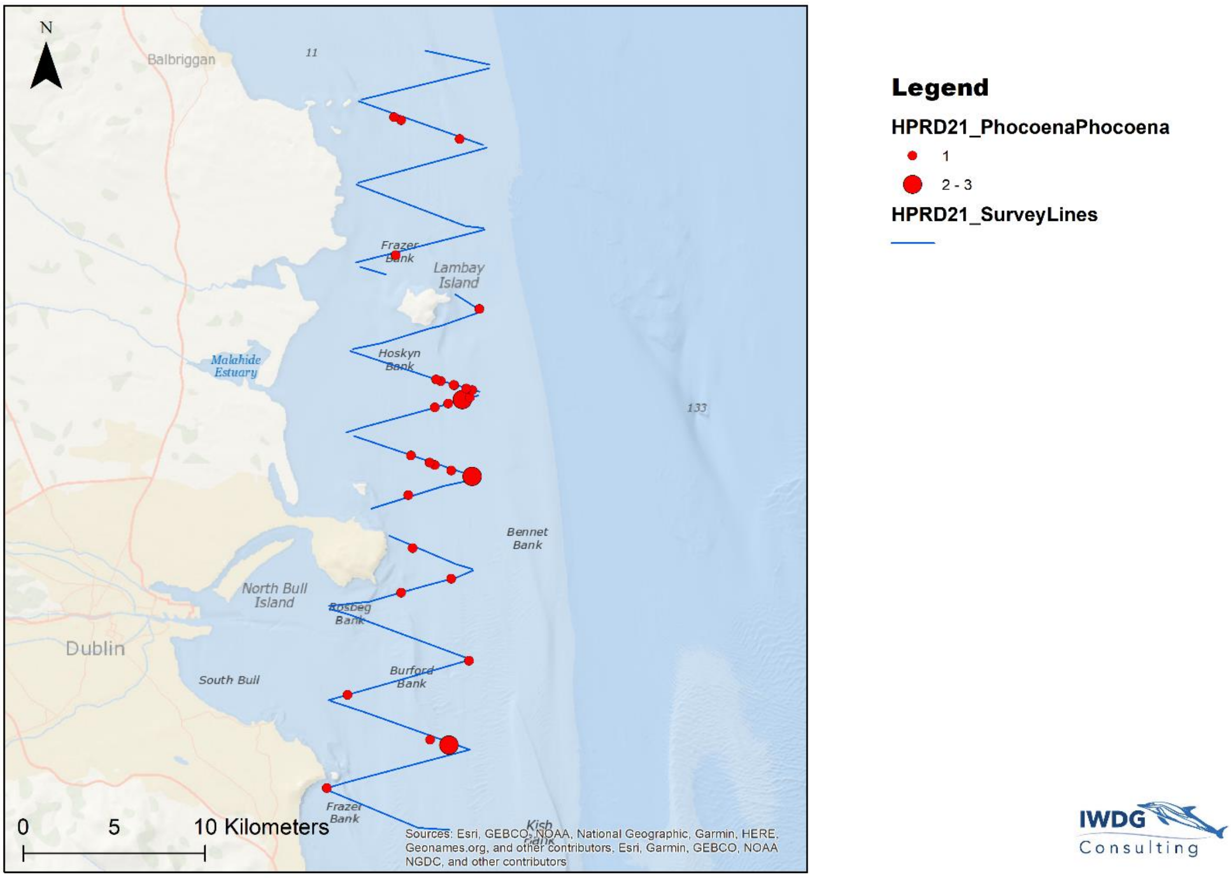


Figure 3d Track-lines and distribution of harbour porpoise sightings on 21 July 2021.

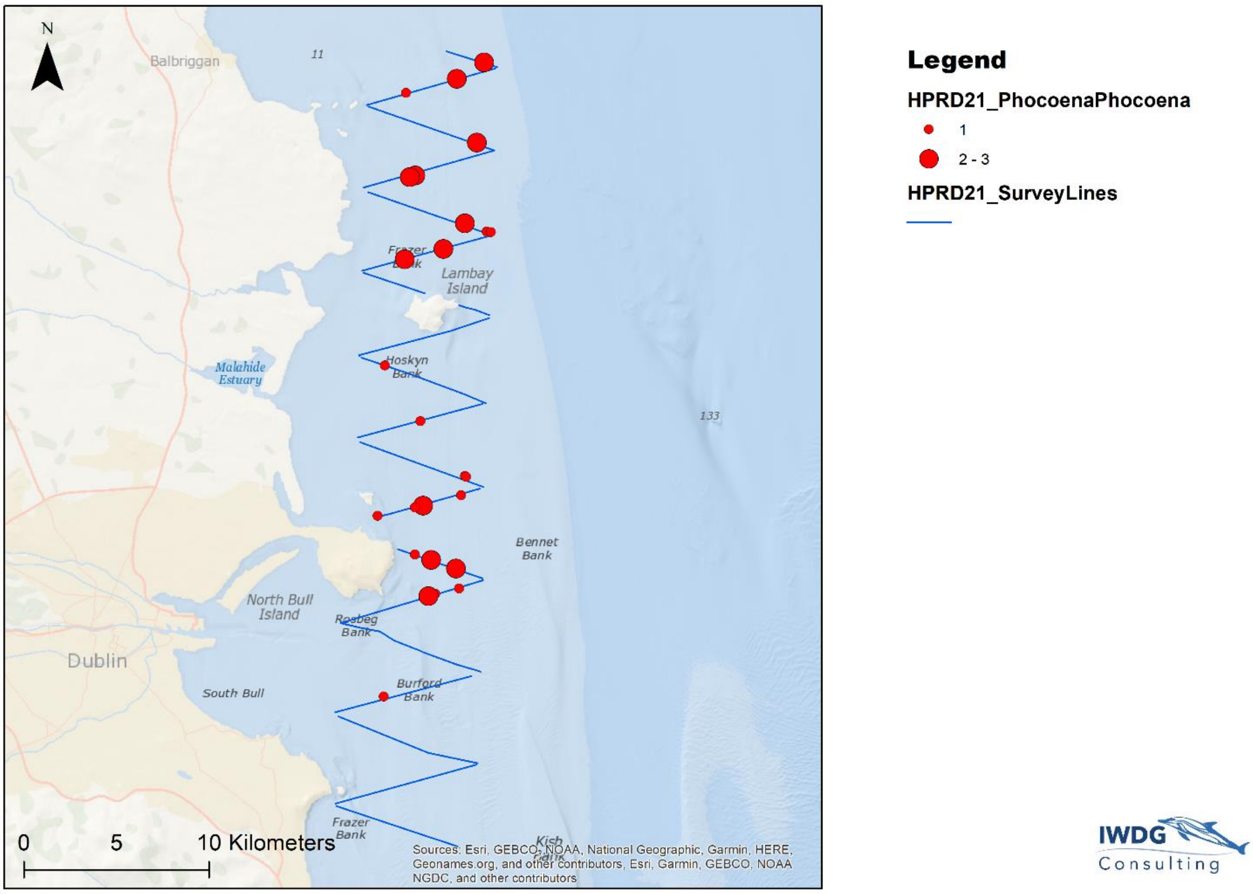


Figure 3e Track-lines and distribution of harbour porpoise sightings on 19 August 2021.

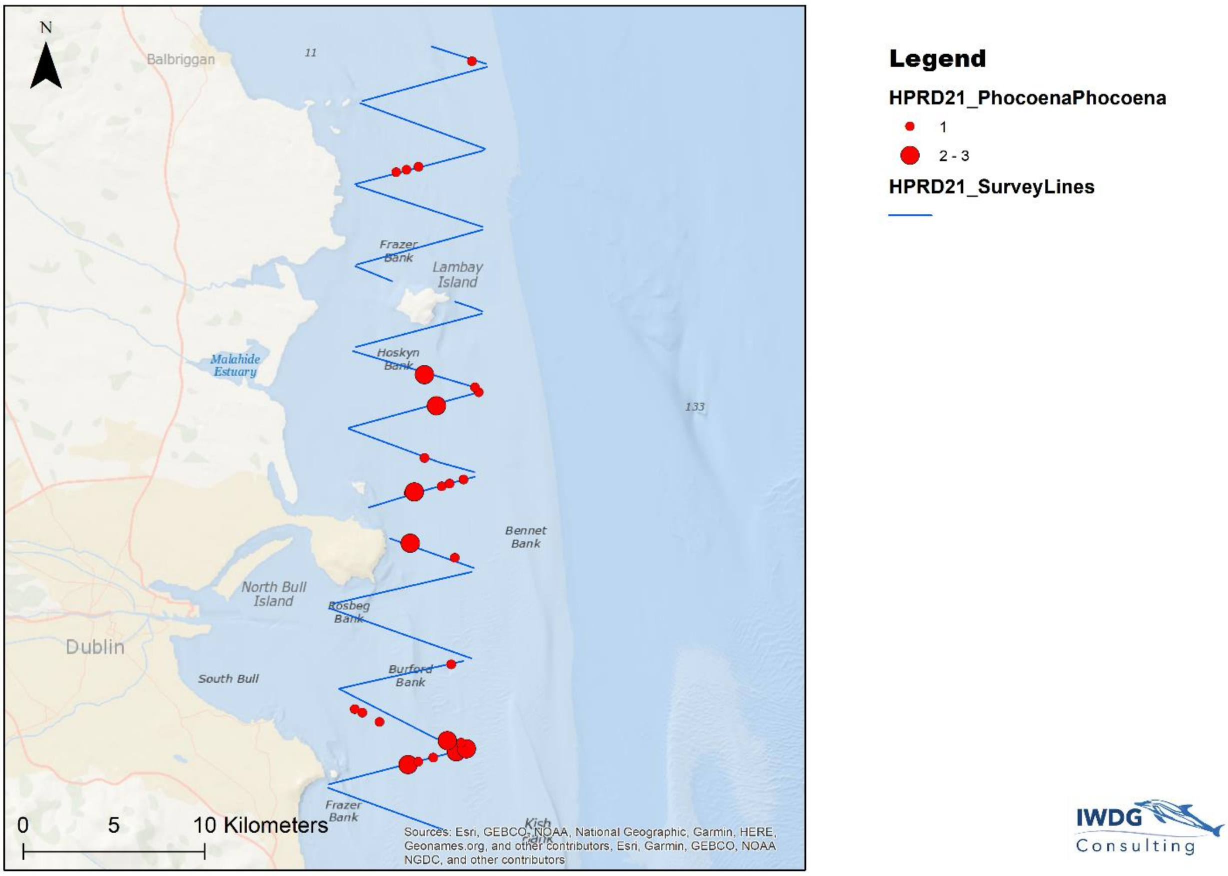


Figure 3f Track-lines and distribution of harbour porpoise sightings on 28 August 2021.

Harbour porpoises were evenly distributed throughout the track-lines. Clusters of sightings were frequently recorded south of Lambay Island with the highest concentrations in this area of surveys 2, 3, 4 and 6. Clusters were reported south of Rockabill to the north of the survey area on surveys 3 and 5 and to the south off east of Dalkey Island on survey 6.

3.1 Density and abundance estimation

Density estimates for harbour porpoises within the SAC were calculated for each survey day and all days combined (Table 3). It should be noted that only 12 sightings were recorded on Survey 1 and the results of the analysis should be treated with caution (Table 3).

The detection functions for harbour porpoise during all surveys are shown graphically in Figure 4af. Using the Chi-squared test for goodness of fit to the DISTANCE model, data for five of the surveys (Surveys 1, 2, 4, 5 and 6) were good fits (P>0.54) but for survey 3 the model was a poor fit (P=0.14; Table 3). Its not clear why a better fit couldn't be established as the number of sightings (n=22) was good. The goodness of fit for all data combined (Figure 4g) was good ($Chi^2 = 0.52$). Surveys were carried out in good sea conditions (Table 2) and porpoises frequently observed from >300m from the track-line. Data were truncated at 250-300m, which has led to sightings being pooled into wide distance categories (Figure 4a-g).

Evasive reactions of porpoises from the survey vessel, which is typical of harbour porpoise which can react to vessels from considerable distance, were only evident on survey 5 (Fig 4e). Evasive reactions could lead to an underestimate of animal density, as animals are already moving away from the track-line when first detected, but the effect of this in the current survey was likely to be very small as the influence of sightings on the overall density estimate decreases with increasing distance from the track-line (Buckland *et al.* 2001).

Table 3 Model data used in the harbour porpoise abundance and density estimation process for each survey of the Rockabill to Dalkey Island SAC in 2021 (Note: A half-normal model with cosine series adjustments with data truncated at 250-300m was used).

Sample Day	Chi^2 P value	Effective Strip Width (m)	Mean Cluster size ± SE	Variability (D)		
				Detection	Encounter	Cluster
1[1]	0.62	104	1.00±0.00	100	-	0
2	0.79	154	1.28±0.11	85	-	15
3[2]	0.14	175	1.33±0.11	85	-	15
4	0.66	126	1.11±0.06	96	-	4
5	0.54	190	1.58±1.15	78	-	22
6	0.54	208	1.42±0.15	80	-	20
Overall	**0.52**	**134**	1.31±0.04	**63**	**33**	**4**

Mean group (cluster) size was greatest on surveys 5 and 6 (1.58 and 1.42; Table 4), which was towards the end of the survey period. The proportion of variability in the data accounted for by the detection

[1] treat with caution, low number of sightings (n=12)

[2] treat with caution, as poor fit to model

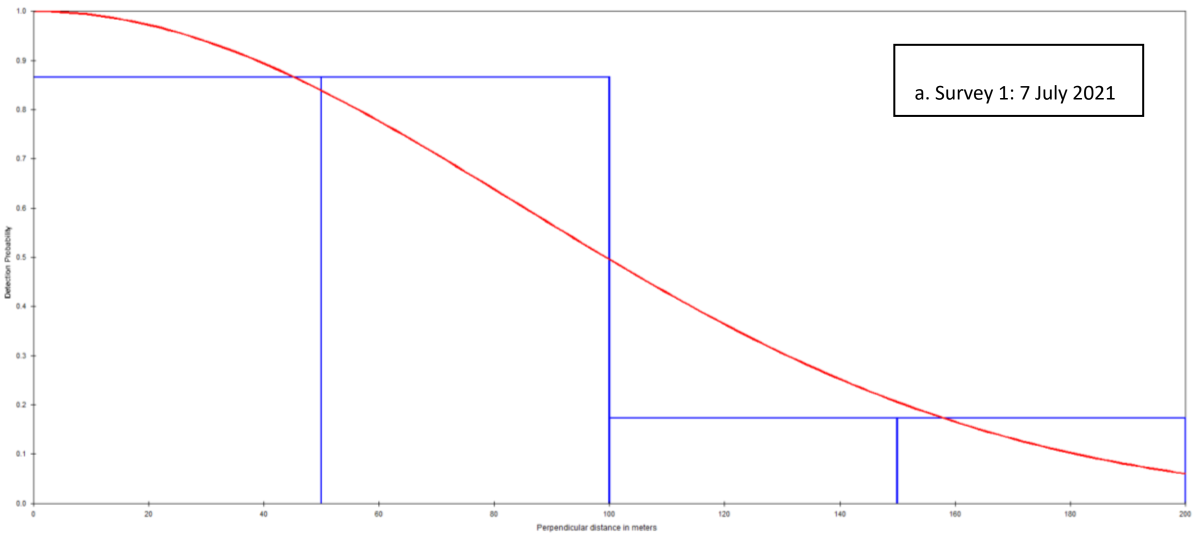
probability was as expected highest for all surveys. Variability associated with cluster size (Table 3) was greatest for surveys 5 and 6 which coincided with the greatest mean group size. This reflects the number of groups with 3 individuals recorded during surveys 5 (3 groups) and survey 6 (5 groups) while no groups this big were recorded during the first four surveys. Overall, the sources of variability were highest for detection rate and lowest for cluster size which is to be expected as there was relatively low variability in the number of sightings per survey (range 12-29; Table 2).

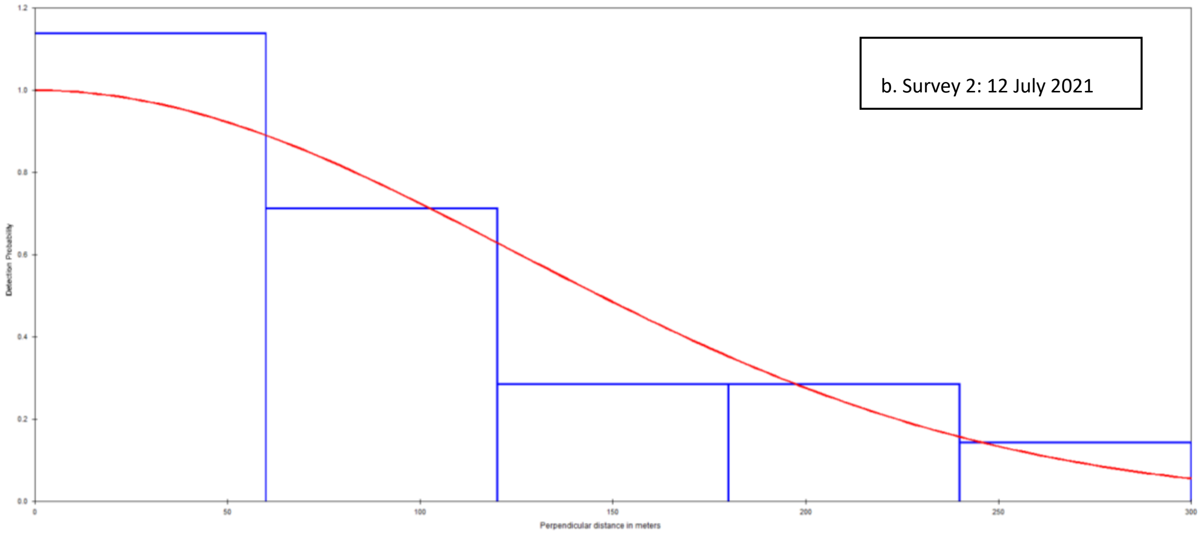
Table 4 Estimated density, abundance (N) and group sizes of harbour porpoise recorded during surveys of the Rockabill to Dalkey Island SAC, 2021.

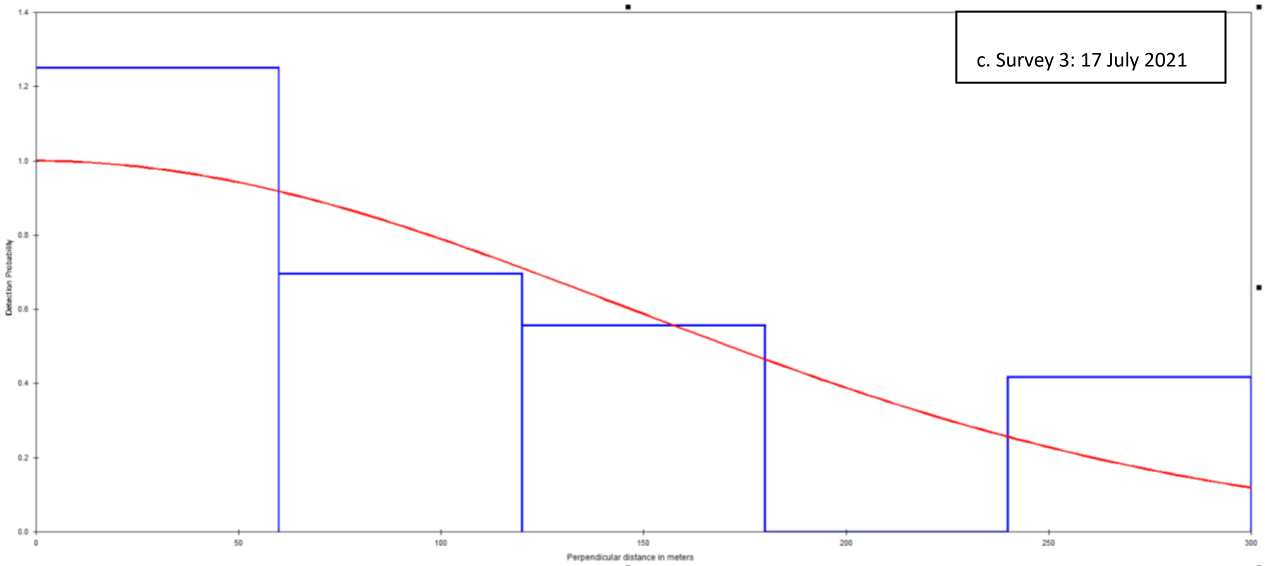
Sample Day	Density (95% CI) per km^2	SE	CV	Abundance (95% CI)	Mean group size (95% CI)
1[1]	0.50 (0.29-0.84)	0.12	0.24	136 (80-229)	1.00 (0.00-0.00)
2	0.66 (0.43-1.01)	0.14	0.21	180 (117-276)	1.28 (1.06-1.53)
3[2]	0.63 (0.42-0.96)	0.13	0.20	172 (114-262)	1.33 (1.13-1.57)
4	0.98 (0.61-1.55)	0.22	0.23	266 (167-425)	1.11 (1.00-1.25)
5	0.80 (0.52-1.21)	0.17	0.21	218 (144-332)	1.58 (1.30-1.92)
6	0.72 (0.48-1.10)	0.15	0.21	198 (130-300)	1.42 (1.15-1.76)
Overall	**0.83 (0.59-1.17)**	**0.14**	**0.17**	**227 (161-321)**	**1.31 (1.22-1.42)**

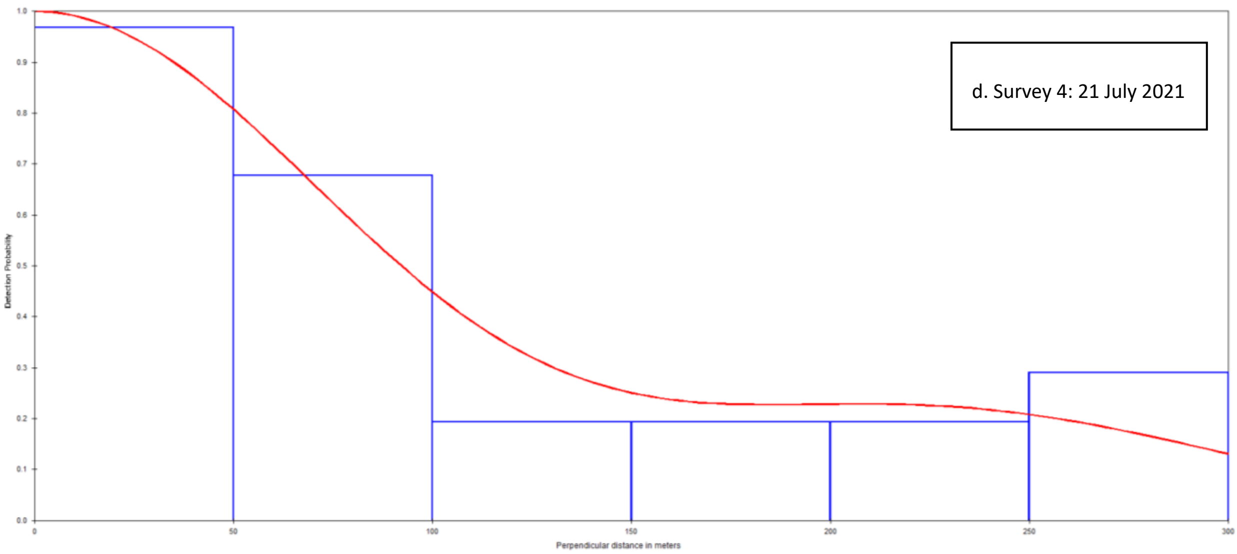
Density and abundance estimates for harbour porpoise in the Rockabill to Dalkey Island SAC during 2021 are presented in Table 4. Despite differences in the number of sightings per survey and mean group size the density estimates did not vary that much ranging from 0.50 to 0.98 harbour porpoises per km^2, with one-half between 0.66 and 0.80 (Table 4). The highest density (0.98) was recorded on survey 4 (21 July). The lowest density estimate was on survey 1 (0.50) with only 12 harbour porpoise sighting and the lowest mean group size (1.00±0.0) (Table 4).

The overall density estimate was 0.83±0.14 with a 95% Confidence Intervals of 0.59 to 1.17 (Table 4). This estimate had a low CV of 0.17 and produced an abundance estimate of 227±39 porpoises with 95% Confidence Intervals of 161 -321 porpoises (Table 4).




b. Survey 2: 12 July 2021
Detection Probability
Perpendicular distance in meters


c. Survey 3: 17 July 2021
Detection Probability
Perpendicular distance in meters


d. Survey 4: 21 July 2021
Detection Probability
Perpendicular distance in meters

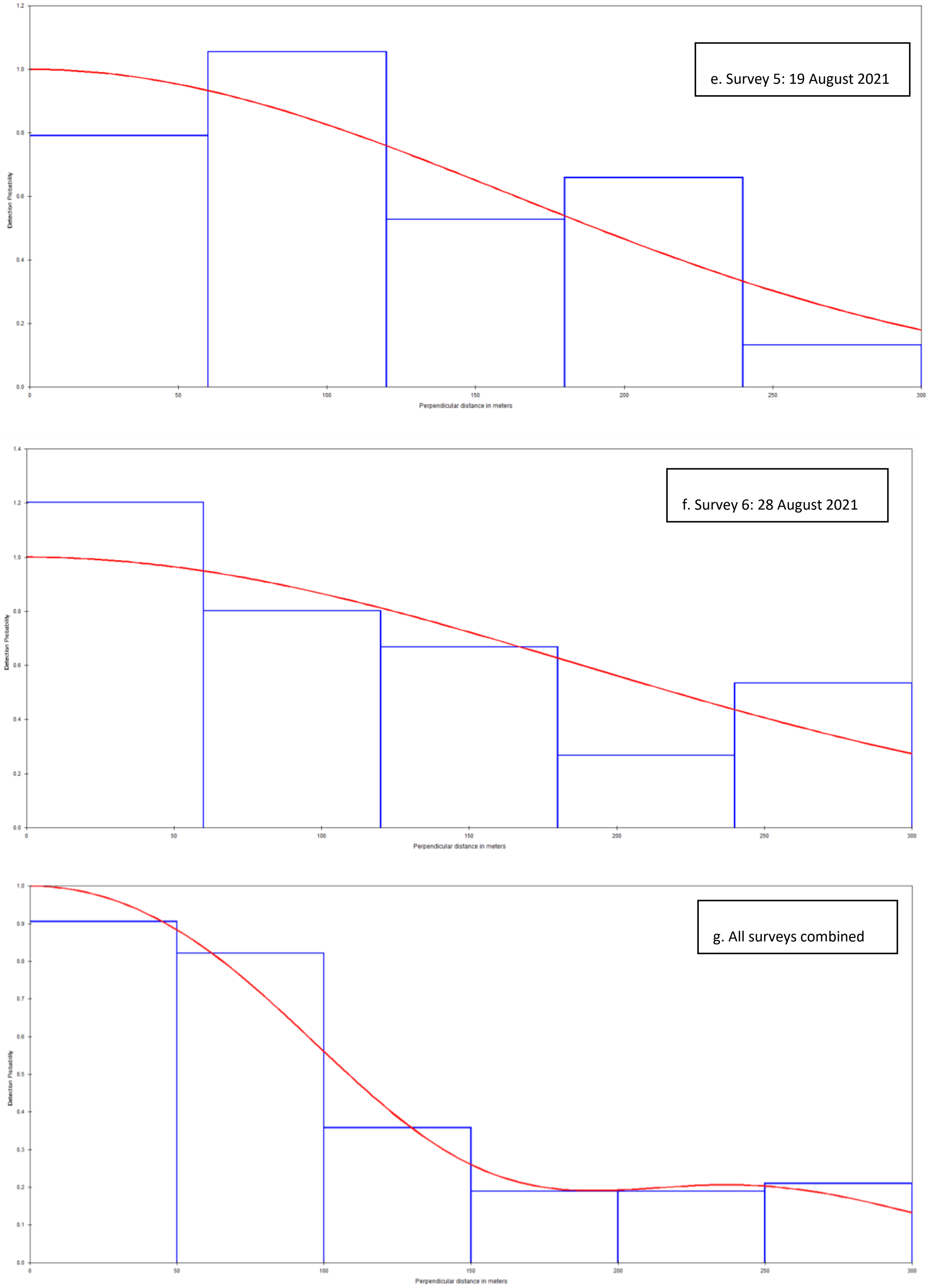


Figure 4 a-g Detection function plots for each survey of harbour porpoises in the Rockabill to Dalkey Island SAC, 2021. (Note: detection probability is on the y-axis and perpendicular distance from the track-line on the x-axis).

3.2 Density and abundance estimation in different sea-states

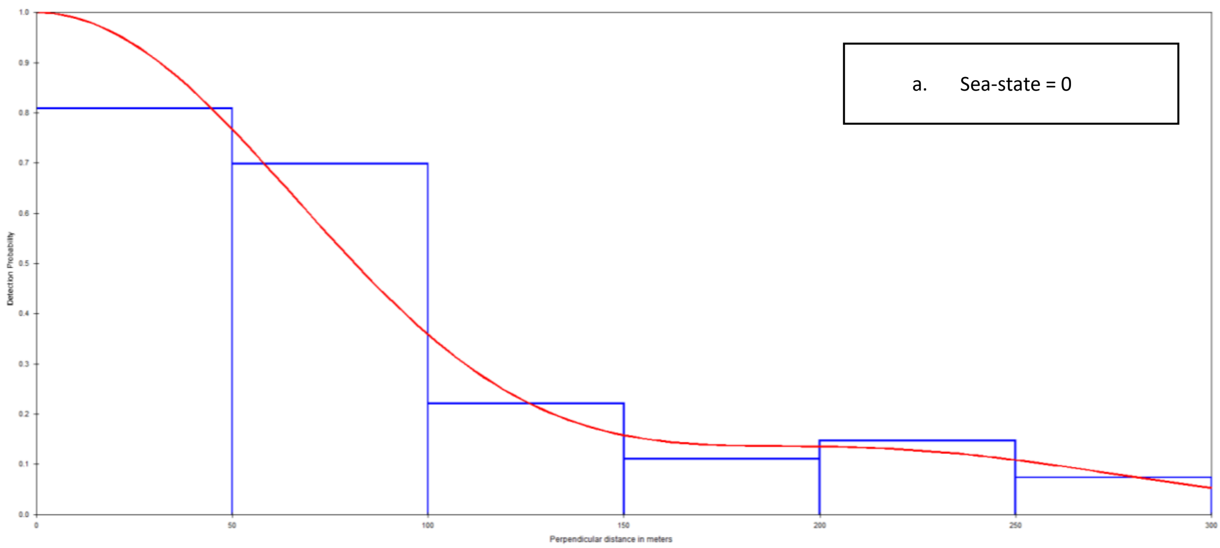
In order to explore the potential effect of sea-state on density estimates, the data for all surveys were pooled and stratified by sea-state. Detection functions were then calculated for increasing sea-state (Table 5, Figure 5a-b.). A detection function was determined for all sightings in sea-state 0 over the six surveys combined, followed by a similar analysis for sea-state 0+1 and sea-state 0+1+2 (Figure 5 a-b). There was a total of 59 sightings in sea-state 0, 58 in sea-state 1 and 20 in sea-state 2 (Table 5). There were no sightings in the small amount of effort (1.34 km) carried out in sea-state 3. Total sighting effort (in km) was calculated for each sea-state and used in the analysis. Note all sightings and effort in sea-state 0+1+2 is the same as All Surveys presented in Table 4.

Density estimates classified by sea-state 0 and sea-state 0+1 were lower than for all data combined (sea-state 0+1+2) (0.83 harbour porpoise per km^2). Density estimates for all data collected in sea-state 0 and sea-state 0+1were only 0.51 and 0.40 porpoises per km^2 (Table 5). These data also suggest it is appropriate to pool the survey data from all survey days and in all sea-states.

Although the CV for the estimate in sea-state 0 (0.23) was the highest for all categories, the total survey effort (239.1km) was low compared to the total survey data available (728.0km) and we suggest that data for all sea-states combined (sea-state 0+1+2) is the best estimate of the density of harbor porpoises in the Rockabill to Dalkey Island SAC during July and August 2021.

Table 5 Density, abundance (N) and group size estimates of harbour porpoise in the Rockabill to Dalkey Island SAC, during 2021 across increasing sea-states.

Sea-state Class	Effort (km)	Sightings	Chi ^{2} P value	Mean group size ± SE	Density (per km^2)	SE	CV	N (95% CI)
0	239.1	59	0.65	1.13	0.51	0.11	0.23	138 (84-229)
0+1	552.6	117	0.24	1.21	0.40	0.08	0.19	109 (74-161)
0+1+2	728.0	137	0.52	1.31	0.83	0.14	0.17	227 (161-321)



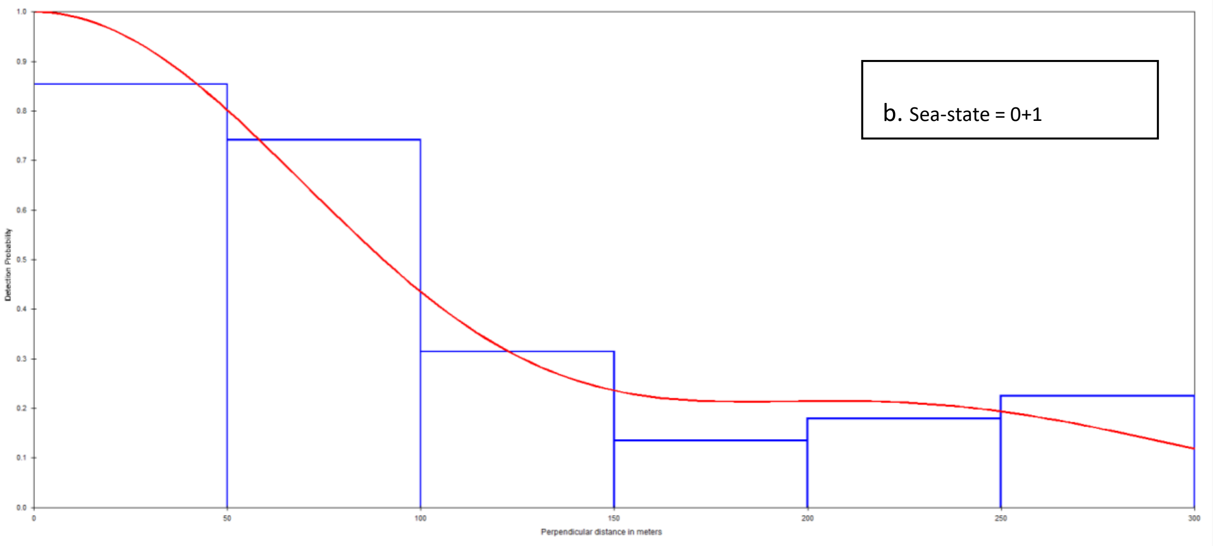


Figure 5 a&b Detection function plots for harbour porpoise surveys in the Rockabill to Dalkey Island SAC, 2021 according to different sea-state classes. (Note: detection probability is on the y-axis and perpendicular distance from the track-line on the x-axis).

3.3 Proportion of juveniles and calves

The proportion of juvenile porpoises and calves to all porpoises (including adults) was calculated for each survey (Table 6). The proportion of juveniles per survey ranged from 0% to 7.1% and calves from 0 to 4.9% on each survey. The observed proportion of juveniles to adults was highest on surveys 4 and 6 (21 July and 28 August) and adults to calves on survey 5 (19 August). Calves were all recorded on second and on the last two surveys in August. The proportion of young porpoises (juveniles and calves combined) recorded on survey days ranged from 6.3% to 9.5% and was 5.5% overall (Table 6).

Table 6 The numbers and proportions of adult harbour porpoises, juveniles and calves recorded during surveys of the Rockabill to Dalkey Island SAC, 2021.

Survey	Number of sightings	Number of Individuals	Adults	Juveniles	Calves	% juveniles	% calves
1	12	12	12	0	0	0	0
2	19	25	21	0	2	0	8.0
3	23	29	29	0	0	0	0
4	29	32	30	2	0	6.3	0
5	26	41	39	0	2	0	4.9
6	29	42	41	3	1	7.1	2.4
Overall	**137**	**181**	**172**	**5**	**5**	**2.8**	**2.8**

Table 7 The numbers and/or proportions of adult harbour porpoises, juveniles and calves recorded during surveys of the Rockabill to Dalkey Island SAC, 2021.

Survey	Number of sightings	Number of Individuals	Adults	Juveniles	Calves	% juveniles	% calves
2021	137	181	172	5	5	2.8	2.8
2016	152	246	221	10	14	9.8	5.7
2013	201	292	272	14	6	6.8	2.0
2008[3]	82	111	102	1	8	8	7.2
2008[3]	56	69	65	1	3	6	4.6

The proportion of juveniles was lower than reported on previous surveys while the proportion of calves within the range reported from previous surveys (Table 7). Juveniles are animals born in previous years and not within the survey year so this is not a consequence of the timing of the surveys. Harbour porpoise become sexually mature at around 3 years of age (Lockyer & Kinze 2003).

3.4 Additional marine mammal and megafauna sightings

Outside of Harbour porpoises, sightings of other marine mammals were quite scarce. Grey seal (*Halichoerus grypus*) were the most frequently recorded other marine mammal species and was recorded on four of the six surveys (Table 8) and throughout the survey area (Figure 6). Short-beaked common dolphin (*Delphinus delphis*) was the only other marine mammal species recorded, occurring on two surveys in July and August both at the northern boundary (Figure 6). A group of 30 individuals were recorded at the end of the fifth survey, north of Rockabill Island.

Table 8 Other marine mammal species recorded during surveys in Rockabill to Dalkey Island SAC, 2021.

Survey	Date	Number of sightings (total number of individuals)	
		Common dolphin	Grey seal
1	7 Jul	-	2 (2)
2	12 Jul	-	4 (4)
3	17 Jul	-	-
4	21 Jul	1 (1)	3 (3)
5	19 Aug	1 (30)	-
6	28 Aug	-	6 (6)
Overall		**2 (31)**	**15 (15)**

[3] from Berrow *et al.* (2008)

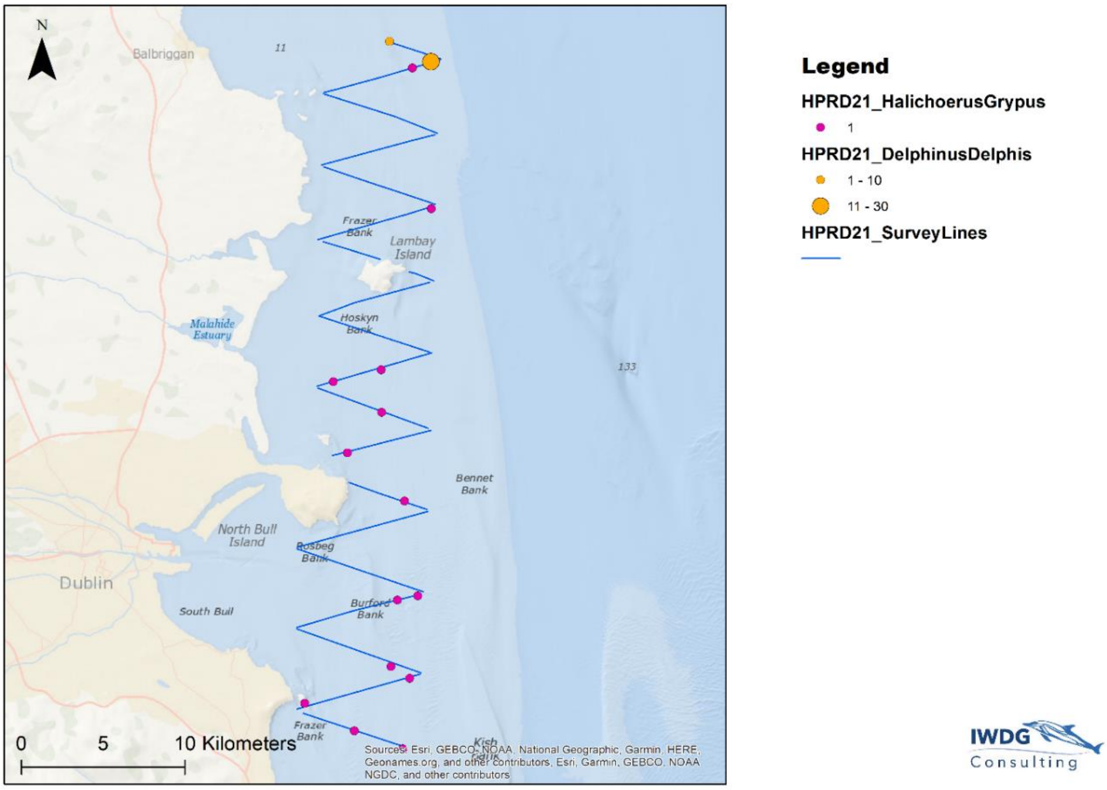


Figure 6 Distribution of marine mammals other than harbour porpoises recorded during surveys of Rockabill to Dalkey Island SAC during 2021.

The limited species diversity of marine mammals is consistent with previous surveys although the species recorded was different. During the survey in 2013 a single minke whale was reported and during 2016 only seals, with a total of 12 grey and common seal sightings and no cetaceans.

4 Discussion

This was the third dedicated survey of harbour porpoises in the Rockabill to Dalkey Island Special Area of Conservation (SAC) since it was designated in 2013. Similar single platform line transect surveys were also carried out in 2008 and combined with 2013 and 2016 now provide some measure of inter-annual trends in density and the status of this qualifying interest. The survey carried out in 2021 was very successful in that sea conditions were very favourable throughout all six surveys and porpoises were recorded on all surveys in quite consistent numbers.

Distance sampling has been used to derive density and abundance estimates for harbour porpoise within the site. 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 line in any given direction. During the current survey randomised pre-determined track-lines were provided by DHLGH which provided equal coverage probability within the SAC. 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 observer. 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 object, as performed in this study. 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). Thus, less than half of the animals on the track-line may only be detected. If this was the case during the present survey then we could perhaps double the density estimate to obtain a truer density estimate. Without a double-platform line-transect methodology it is not possible to accurately determine the number of porpoise detections on the track-line that were missed. The detection functions derived for individual surveys in the current analysis also suggested that there was some evidence of evasive movement relative to the survey boat on one of the six surveys, which resulted in a poor fit to the DISTANCE model. Such factors will tend to lower the density estimates and increase the CVs delivered via the modelling process. However, these sources of variability were consistent throughout the present survey and are also consistent with previous surveys carried out at the site (Berrow *et al.*, 2008; Berrow & O'Brien, 2013, O'Brien & Berrow, 2016).

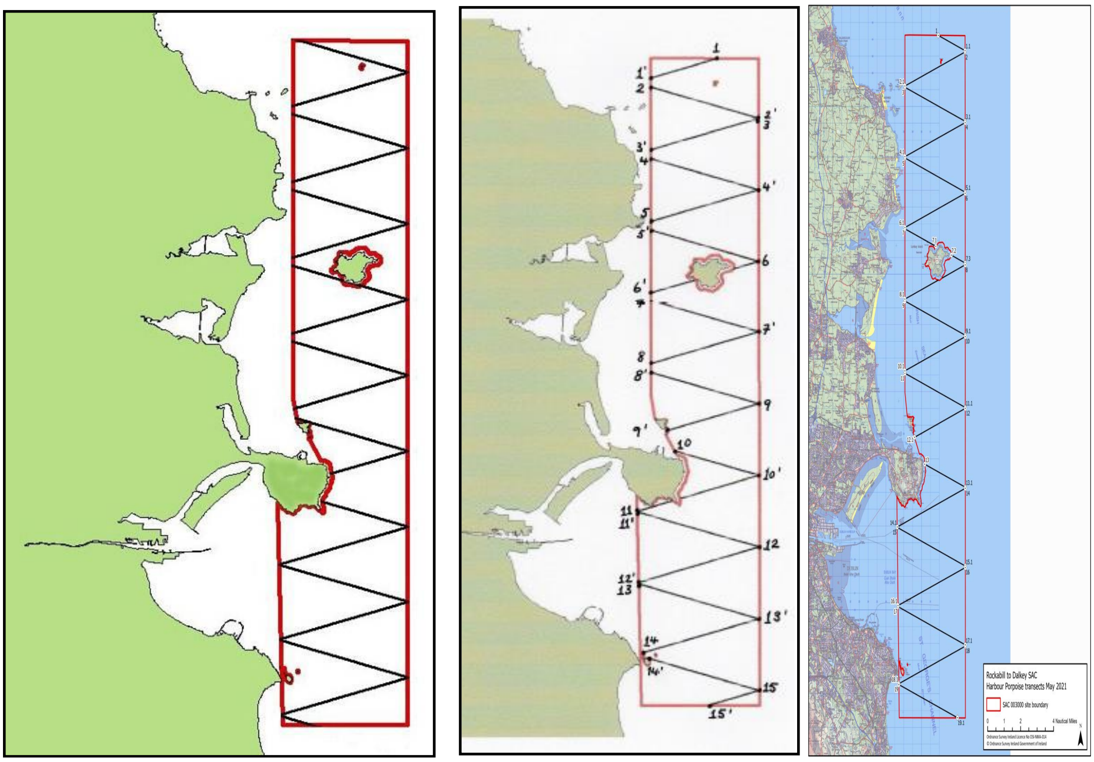
The ability to visually detect harbour porpoises at sea, and thus the accuracy of density and abundance estimates, is extremely dependent on sea-state. During the present study all transect lines were carried out in sea-state 2 or less (as per contractual obligations), since the ability to detect harbour porpoises decreases significantly in sea-states ≥3 (Teilmann, 2003). In the present study, when the data were stratified by sea-state the best estimate was using data from sea-states up to 2, which supports the decision to survey sites in conditions up to and including sea-state 2 and use the pooled data.

4.1 Harbour porpoise density estimates in Rockabill to Dalkey Island SAC

Abundance estimates were carried out in Dublin Bay and North County Dublin during the summer of 2008 as part of a wide ranging survey to identify sites with elevated harbour porpoise densities (Berrow *et al.* 2014). After designation in 2013, a survey was carried out along pre-determined track-lines in a zig-zag survey design (Berrow & O'Brien, 2013) (see Fig 7a). This was repeated in 2016 (O'Brien & Berrow, 2016) using similar track-lines but reversed, with different start and end points but with the same total transect length (Fig 7b). During the current survey a similar zig-zag survey design was used but the orientation of the track-lines were reversed within the same survey block but again with the same total transect length (see Fig 7c). The results of these surveys are presented in Table 9.

Table 9 Density, abundance and group size estimates for harbour porpoise within Rockabill to Dalkey Island SAC from 2008 to 2021.

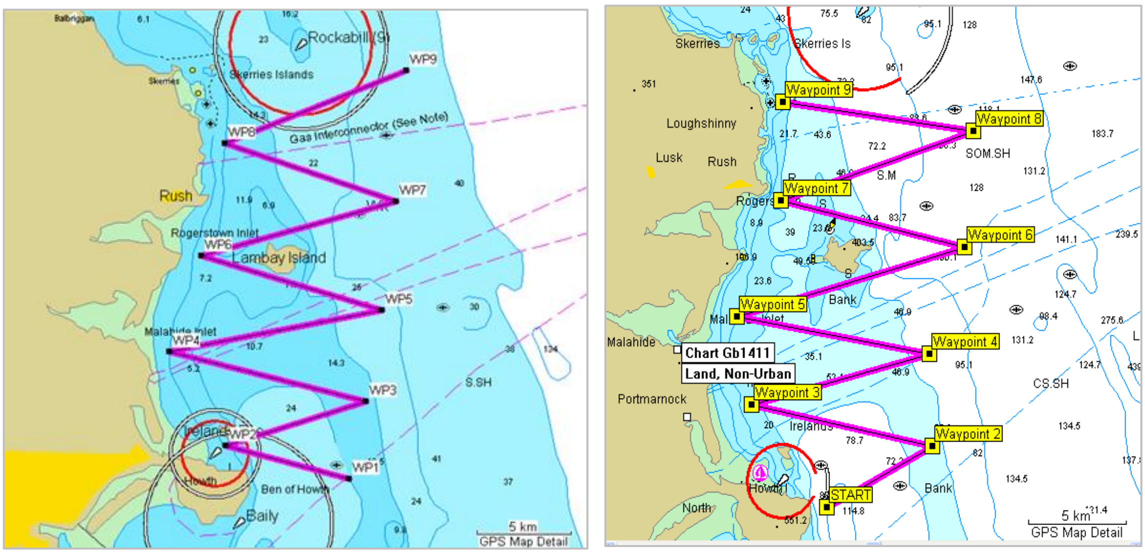
	Year	Density ± SE (per km^2)	Mean group size	Abundance ± SE	CV	Reference
Rockabill to Dalkey Isl SAC	2021	0.83±0.14	1.31	227±39 (161-321)	0.17	This study
Rockabill to Dalkey Isl SAC	2016	1.55±0.17	1.62	424±45 (335-536)	0.10	O'Brien & Berrow (2016)
Rockabill to Dalkey Isl SAC	2013	1.44±0.09	1.47	391±25 (344-445)	0.09	Berrow & O'Brien (2013)
North County Dublin	2008	2.03	1.41	211±47 (137-327)	0.23	Berrow *et al.* (2008)
Dublin Bay	2008	1.19	1.19	138±33 (86-221)	0.24	Berrow *et al.* (2008)



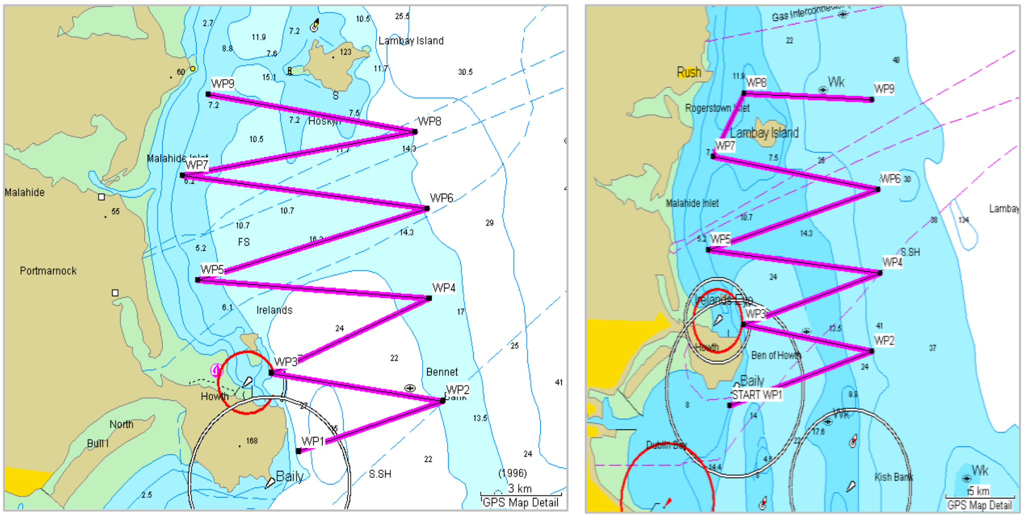
a. b. c.

Figure 7 Zig-zag survey design used during harbour porpoise surveys of Rockabill to Dalkey Island SAC in a. 2013 b. 2016 and c. 2021

As part of an environmental assessment of a proposed sewage outfall pipe, 11 dedicated surveys using distance sampling were carried out between April 2015 and January 2017 (Meade *et al*., 2017). Four of these were carried out between Howth Head and Rockabill Island and seven between Howth Head and Lambay Island an area considered to be most favourable for harbour porpoise (Fig 8).



a. April 2015 b. August and November 2015



c February 2016 and January 2017 d. August and October 2016

Figure 8a-d Track-lines used during harbour porpoise surveys for the Greater Dublin drainage Project between April 2015 and January 2017 (from Meade *et al*., 2017).

Table 10 Estimated density, abundance (N) and group sizes of harbour porpoise recorded for the Greater Dublin Drainage project (from Meade *et al*., 2017).

Date	Density (per km2)	SE	CV	Mean group size (95% CI)
Apr 2015	0.78	54	0.33	1.44 (1.00-2.12)
Aug 2015	1.91	114	0.32	1.85 (1.48-2.30)
Nov 2015	1.76	50	0.36	1.17 (1.12-1.31)
Feb 2016	0.61	12	0.23	1.00
Aug 2016	2.29	70	0.15	1.53 (1.25-1.85)
Oct 2016	0.97	54	0.28	1.37 (1.00-1.89)
Jan 2017	0.89	38	0.21	1.35 (1.07-1.69)

Density estimates are shown in Table 10 and ranged from 0.78-1.91 harbour porpoise per km^2 in the wider survey area and 0.61-2.29 harbour porpoise per km^2 between Howth Head and Lambay Island.

These data provide baselines for marine mammal surveys currently underway off the east coast of Ireland. Site surveys for offshore windfarms and other coastal developments to estimate density and abundance of marine mammals, especially harbour porpoises to assess environmental impacts use a variety of methodologies and platforms. These uncorrected density estimates (where g(0) is assumed to be 1) should be used as reference values as the data were collected in ideal sea conditions, on suitable platforms and with experienced observers.

Proportion of juveniles and calves

The proportion of young recorded in 2021 was lower than that reported at the same site in 2016. The proportion of calves was similar to that reported in 2013 but the proportion of juveniles was less than that reported in 2013. No surveys were carried out in September 2021 but were during September 2013 and 2016, which have had a small influence of this metric as adults with calves are more frequently reported later in the season. This may have resulted in a lower estimate of the proportion of calves present.

Although the proportion of young to adults was considerably less than that reported by Sonntag *et al.* (1999) from the Isle of Sylt in Germany, with up to 18% calves, the proportion is consistent with other studies at around 3-5% (Hammond *et al.*, 2002; Evans and Hammond, 2004). Calving success and survival may fluctuate greatly between years and although the proportion of young reported here is low only more regular surveying will be able to determine if this is within the ranges of normal annual variability or part of a long term decline.

4.3 Trends in harbour porpoise density estimates in Rockabill to Dalkey Island SAC

Although line-transect survey designs were notably different in 2008, the model outputs are worth comparing with more recent surveys (Table 9). Density estimates in 2013 and 2016 were similar to that reported in 2008 especially for North County Dublin, suggesting there had been little change in porpoise densities over this eight year period. The density estimate in 2021 (0.83 harbour porpoise per km^2) is around 44% of that reported in 2013 and 2016. The number of sightings per survey were similar in 2013 and 2016 but down by around 17% on the mean of the previous surveys. The total number of individuals recorded was also down by 26% on those recorded in 2016 but very similar to the total number of individuals recorded in 2013 however the total survey effort was also lower in 2013 by around 30%. Mean group size (1.31) was 20% less than that recorded in 2016 (1.62, Table 9).

The data here were collected during favourable sea conditions, on excellent platforms and with experienced surveyors and we are satisfied the density estimate is accurate. Thus there does seem to have been a real decrease in the density of harbour porpoises recorded in the Rockabill to Dalkey Island SAC during 2021, compared to the two previous surveys in 2013 and 2016. This is of concern and the drivers of the local distribution and abundance of harbour porpoises in this SAC needs to be explored.

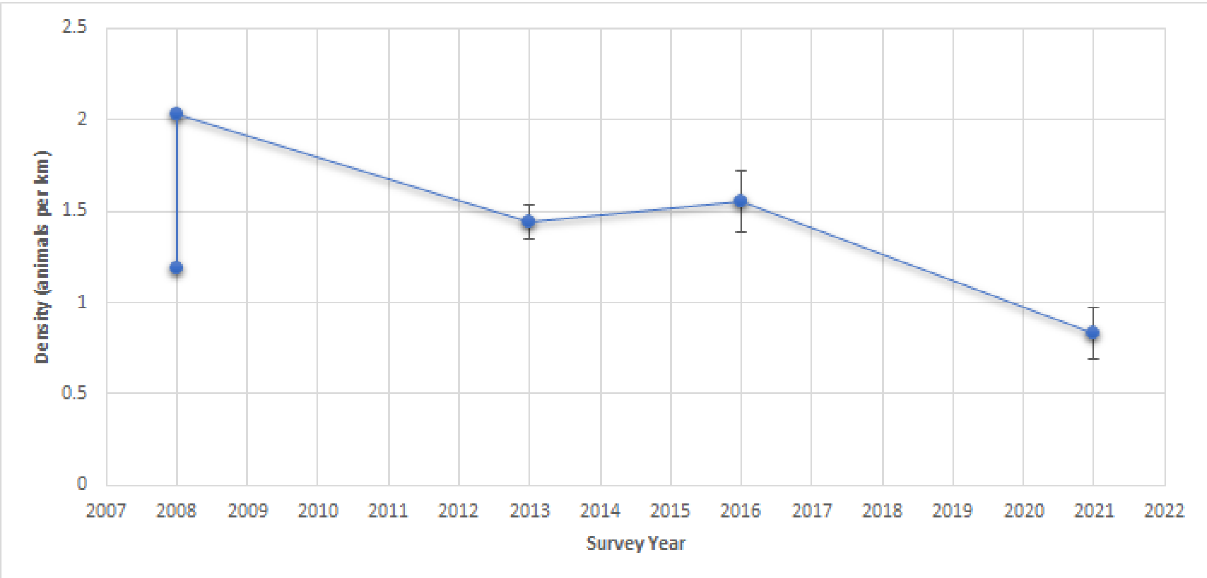


Figure 9 Changes in the recorded density of harbour porpoises in the Rockabill to Dalkey Island SAC over time.

This decrease in densities in the only Special Area of Conservation for harbour porpoises off Irelands' east coast should be put into a wider context. The most recent harbour porpoise surveys, using the same methodology, in the other two SACs with harbour porpoise as qualifying interests, namely Roaringwater Bay and Islands SAC in Co Cork and Blasket Islands SAC in Co Kerry also reported significant declines in harbour porpoise densities. O'Brien & Berrow (2020) reported a 70% decline in porpoise densities in the Roaringwater Bay and Islands SAC between 2016 and 2020 and a 53% decline between 2020 and 2013. O'Brien & Berrow (2018) reported a 56% decline in harbour porpoise densities between 2014 and 2018 in the Blasket Islands SAC. This suggests that the drivers of the decline in harbour porpoise densities is widespread in Irish coastal waters.

This does not necessarily imply a decline in overall population size but perhaps changes in distribution and habitat use at a local scale. The distribution and abundance of top predators such as harbour porpoises is strongly influenced by the availability of preferred prey. The diet of porpoise in Ireland is not well known, but it is thought to be a mixture of pelagic and benthic fish including sandeels and gobies as well as crustaceans (Rogan, 2008). One possible reason for a decline in density within the Rockabill to Dalkey Island SAC was a change in the distribution of their preferred prey outside of the SAC boundaries, resulting in lower densities of porpoises within the site. A better understanding of the ecology of harbour porpoise in this region, including their diet and foraging ecology, is required in order to interpret this apparent decline in abundance between survey years.

4.4 Recommendations

1. These surveys should be continued and given the decrease reported here repeated again in 2022 to determine if this is an outlier, or part of a trend. We recommend annual surveys to explore short-term (annual) changes in densities.

2. Given the variability in density estimates from distance sampling, consideration should be given to establishing fixed acoustic monitoring stations to derive acoustic indices from which to monitor population status. It is possible that acoustic datasets when put into appropriate models could identify changes at a higher resolution than boat-based visual surveys and offer year round coverage.

3. It is unclear what the drivers of short and long-term changes in the distribution and abundance of harbour porpoises within the Rockabill to Dalkey Island SAC. The most likely driver is the availability of preferred prey which may fluctuate locally over short periods. We recommend a study of the diet of harbour porpoises off the east coast of Ireland should be considered including seasonal components.

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