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HARBOUR PORPOISE SURVEYS IN ROARINGWATER BAY AND ISLANDS SAC, 2020

Joanne O'Brien & Simon Berrow

An Roinn Cultúir,
Oidhreachta agus Gaeltachta
Department of Culture,
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Front cover, small photographs from top row:

Limestone pavement, Bricklieve Mountains, Co. Sligo, Andy Bleasdale; **Meadow Saffron** *Colchicum autumnale*, Lorcan Scott; **Garden Tiger** *Arctia caja*, Brian Nelson; **Fulmar** *Fulmarus glacialis*, David Tierney; **Common Newt** *Lissotriton vulgaris*, Brian Nelson; **Scots Pine** *Pinus sylvestris*, Jenni Roche; **Raised bog pool**, Derrinea Bog, Co. Roscommon, Fernando Fernandez Valverde; **Coastal heath**, Howth Head, Co. Dublin, Maurice Eakin; **A deep water fly trap anemone** *Phelliactis* sp., Yvonne Leahy; **Violet Crystalwort** *Riccia huebeneriana*, Robert Thompson

Main photograph:

Harbour porpoise, Randal Counihan/IWDG

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Contents

Executive Summary

A visual survey of harbour porpoises (*Phocoena phocoena*) was carried out in Roaringwater Bay and Islands SAC between June and September 2020 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 June and September. 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 Roaringwater Bay and Islands SAC ranged from 51-55 km per survey and was 325 km overall. Surveys were carried out in very favourable weather conditions on all six surveys, with sea-state 0 recorded for 49.7%, sea-state 1 for 47.9% and sea-state 2 for 2.3% of overall survey effort.

The number of porpoise sightings per survey ranged from 5 to 15 and from 8 to 30 individuals with a total of 59 sightings of 104 individual porpoises overall. Other notable species recorded included common and Risso's dolphin, minke and humpback whale, grey seal and basking shark.

Sightings were made throughout the survey area. Density estimates ranged from 0.38 porpoises per km^2 to 2.39 porpoises per km^2 with an overall density estimate of 0.61±.012 porpoises per km^2. The coefficients of variation around the estimates were low with all but one survey ≤0.34 and was 0.20 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) (0.61 porpoises per km^2) and was 0.37 and 0.35 for the other sea-states with a higher CV, hence the best estimate was considered as that using data from all sea-states combined. Mean group size varied between 1.14 and 2.75 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 87±17 with 95% Confidence Intervals of 57-133. The proportion of young porpoises (juveniles and calves combined) recorded on survey days ranged from 6% to 31% and was 16.7% overall.

The density estimate recorded during the current survey was lower than previous estimates from Roaringwater Bay and Islands SAC in 2008, 2013 and 2015 where densities of 1.18, 1.24 and 2.02 porpoises per km^2 were calculated. Surveys during 2020 were carried out in excellent sea conditions and we are confident that the density estimates reported here are robust. The increase in density reported in 2015 has been reversed considerably but whether this reflects a real change in population or more likely a change in the local distribution of porpoises, within and 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 the SAC.

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. These data need to be explored to determine the ability of this method to detect changes given the high variability within year and across surveys. Given the variability in density estimates per survey, consideration should also be given to developing acoustic indices from which to monitor population status. It is likely that acoustic datasets, when put into appropriate models, will be able to identify changes at a higher resolution than visual surveys but these indices will require data replication over a number of years.

Acknowledgements

We would like to thank surveyors Pádraig Whooley, Patrick Lyne and Sean O'Callaghan, LOGGER Rosanne Shelley and skipper Gerry Smith for their commitment to get these harbour porpoise surveys completed in the best possible sea conditions. This survey was funded by the Department of Culture, Heritage and the Gaeltacht 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 coast (Wall *et al.*, 2013). 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. More recently 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.

In 2007 and 2008, the National Parks and Wildlife Service (NPWS) commissioned surveys of harbour porpoise at eight sites including Roaringwater Bay, Galway, Donegal and Dublin Bays and North County Dublin and the Blasket Islands SAC (Berrow *et al.*, 2007; 2008a; 2008b; 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 with estimates for Roaringwater Bay SAC also among the highest recorded for all sites.

To date three dedicated harbour porpoise surveys have been carried out in Roaringwater Bay and Islands SAC since its designation as an SAC. Berrow and O'Brien (2013) estimated harbour porpoise densities during six survey days from July to October 2013. Poor sea conditions during the three latter surveys reduced sightings to 1-3 per survey from 16-23 during the first three surveys. Density estimates during the first three surveys in Roaringwater Bay and Islands SAC were high at 1.86, 1.97 and 2.61 porpoises per km^2 but the overall density estimate was depressed by very low densities on the last three surveys resulting in an overall density of 1.18±0.14 porpoises per km^2. O'Brien and Berrow (2015) repeated this survey along the same track-lines and reported from 5 to 23 sightings per survey ranged with a total of 75 overall. Density estimates ranged from 0.76 porpoises per km^2 to 3.03 porpoises per km^2 and this was equated overall to 2.02 porpoises per km^2 which was a large increase on 2013.

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

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 Roaringwater Bay and Islands SAC were designated as candidate SACs for the species in 2000. More recently in 2012 a third SAC (Rockabill to Dalkey Island SAC) was designated with harbour porpoise as a qualifying interest.

In order to contribute to the Department of Culture, Heritage & Gaeltacht (DCHG) site management and surveillance, visual monitoring of harbour porpoises was carried out in Roaringwater Bay and Islands SAC during the summer of 2020. This was the fourth 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 2020 were to:

i) derive updated summer density and population estimates for harbour porpoises within the Roaringwater Bay and Islands 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 Roaringwater Bay and Islands SAC is approximately 143 km^2. Survey track lines were chosen randomly in order to provide equal coverage probability within the SAC provided by DCHG.

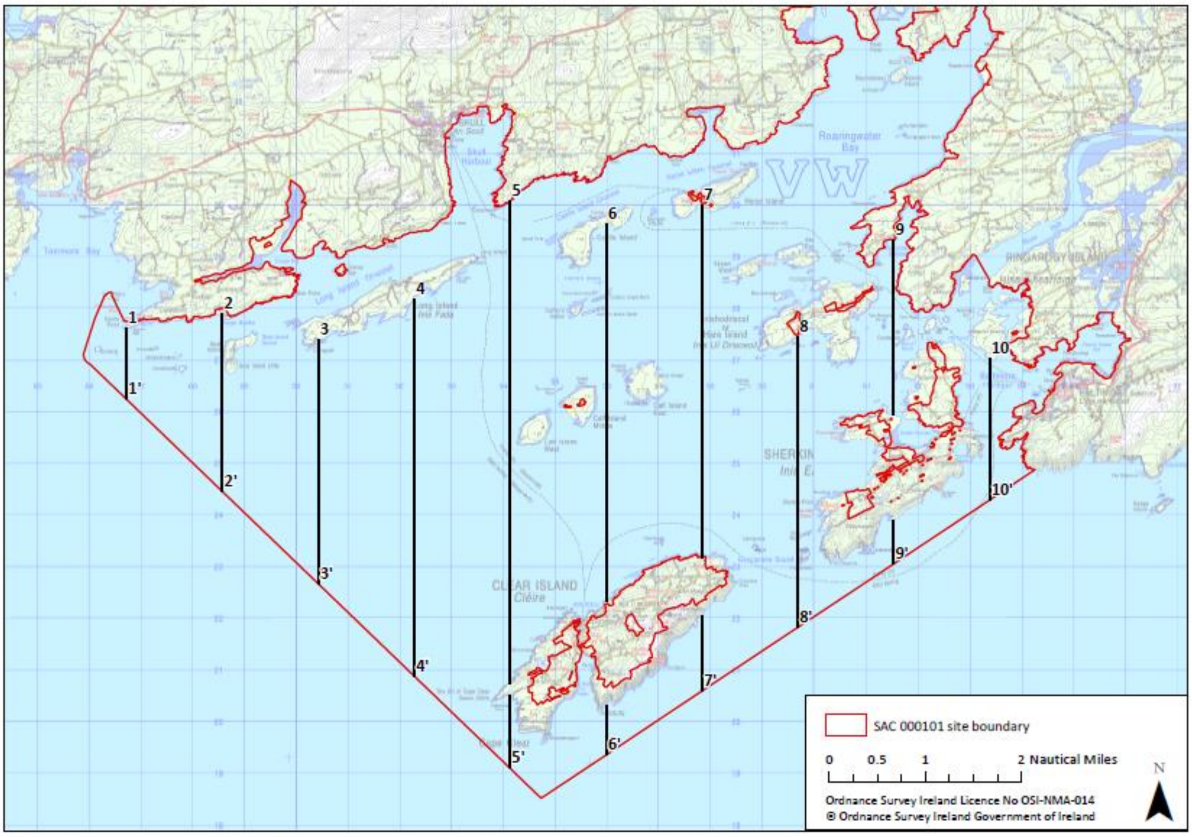


Figure 1 Roaringwater Bay and Islands SAC showing DCHG survey track lines selected for coverage in 2020.

The MV Holly Jo, skippered by Colin Barnes of Cork Whalewatch was used on the first survey (8 June) but MV Wave Chieftain skippered by Gerry Smith of Aquaventures, Baltimore, Co Cork on all subsequent surveys. Both vessels provided a primary observation platform 3.2-3.5m above the waterline (Figure 2).

Figure 2 MV Wave Chieftain and Holly-Jo with flying bridge suitable for line-transect surveying.

COVID-19

HSE guidelines were followed over the duration of this contract. Local observers were used to prevent the need for travel and overnights where possible and due to the size of the vessels, social distancing was easily maintained.

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 DCHG 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 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 500m from the track-line were not used in the distance sampling model to ensure accuracy. 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 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 by each primary observer to assist in distance estimation.

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 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, "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 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.

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 DCHG. 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 Roaringwater Bay and Islands SAC during the present study. Favourable conditions, defined as sea-state ≤2 with good light and visibility to at least 6km, were recorded during all six surveys (Table 1).

Table 1 Overall environmental conditions during surveys of Roaringwater Bay and Islands SAC during 2020.

Date	Swell (m)	Visibility (km)	Wind strength (knots)	Wind direction	Cloud cover	Precipitation
8 Jun	None	11-15km	5	W	5/8	None
25 Jun	None	11-15km	5	W	7/8	None

11 Jul	None	16-20km	3-4	W	1/8	None
20 Jul	None	16-20km	2	W	1/8	None
30 Aug	None	16-20km	3	W	1/8	None
10 Sept	None	11-15km	2-3	W	4/8	None

Sea-state can be influenced by wind and tide and can change throughout the survey. In Roaringwater Bay sea-state 0 predominated for three of the six surveys (8 and 25 June, 11 July) and sea-state was ≤ 1 for all other surveys (20 July, 30 Aug, 10 Sept) (Table 2). Only on the first two surveys (8 and 25 June) was sea-state 2 recorded and only for 1.6 and 11.8% of survey effort (Table 2). No survey effort on any of the six survey days was carried out in sea-state 3.

The total survey effort in Roaringwater Bay and Islands SAC per survey day was very consistent ranging from 51-55km per survey (Table 2). The small differences were due to restrictions in accessing some areas due to tide exposing shallow rocks, which affected the safe distance to which the survey vessel could approach islands.

Table 2 Sea-state and on-effort sighting data for harbour porpoises recorded in Roaringwater Bay and Islands SAC during 2020

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	8 Jun	51.62	27.8	70.7	1.6	15	30
2	25 Jun	54.45	5.8	82.4	11.8	7	8
3	11 Jul	55.09	87.2	12.8	-	12	18
4	20 Jul	54.39	61.4	38.6	-	9	19
5	30 Aug	54.96	69.5	30.4	-	11	17
6	10 Sept	54.31	44.9	55.1	-	5	12
Total		**324.8**	**161.6**	**155.9**	**7.2**	**59**	**104**

The number of sightings per survey ranged from 5 to 15 with a total of 59 overall (Table 2). The highest numbers of sightings were recorded on surveys 1, 3 and 5 (in months June, July and August) suggesting there was no monthly trend in detection rates but days with a good number of detections spread throughout the survey period. The total number of individual porpoises recorded per survey also varied from 8 to 30 with a total of 104 overall (Table 2).

Track-lines surveyed and sightings in Roaringwater Bay and Islands SAC during each survey day are shown in Figures 3a-f. Harbour porpoises were evenly distributed throughout the track-lines with no obvious clusters. Within the overall study area the survey always progressed from east to west as the home port of Baltimore is to the east of the study area, but surveys occurred at different states of the tide. This may have biased results if there was a consistent direction of movement of porpoises through the day; but this does not appear to be the case.

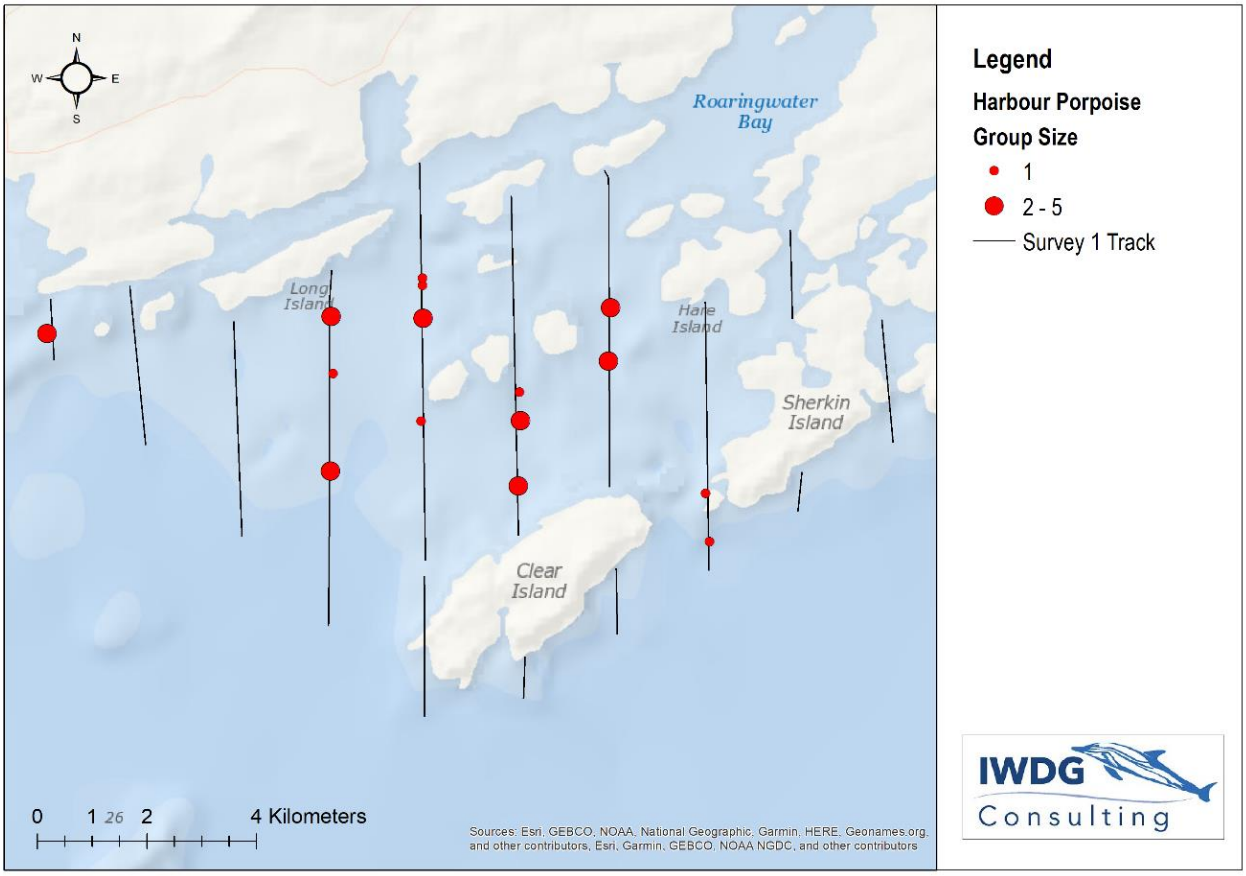


Figure 3a Track-lines and distribution of harbour porpoise sightings on 8 June 2020.

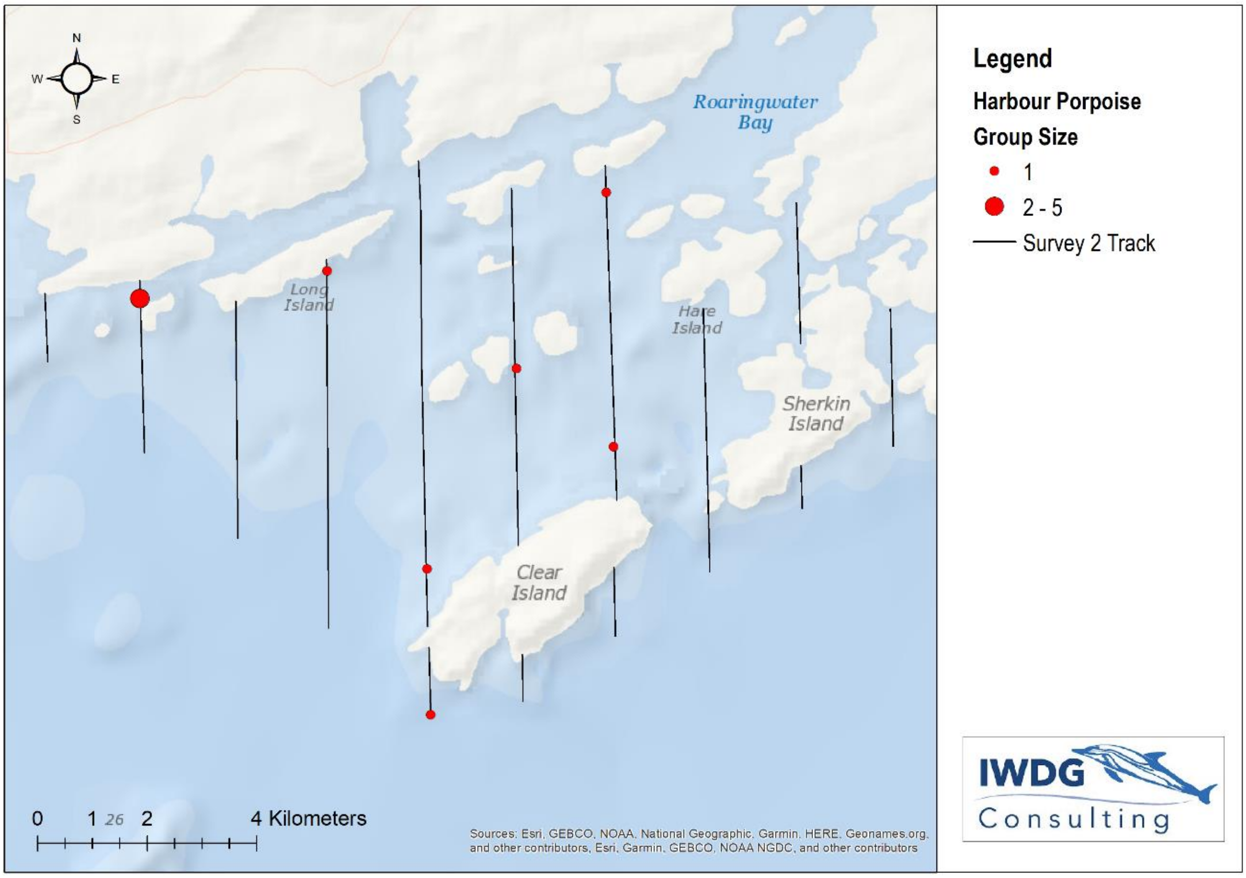


Figure 3b Track-lines and distribution of harbour porpoise sightings on 25 June 2020.

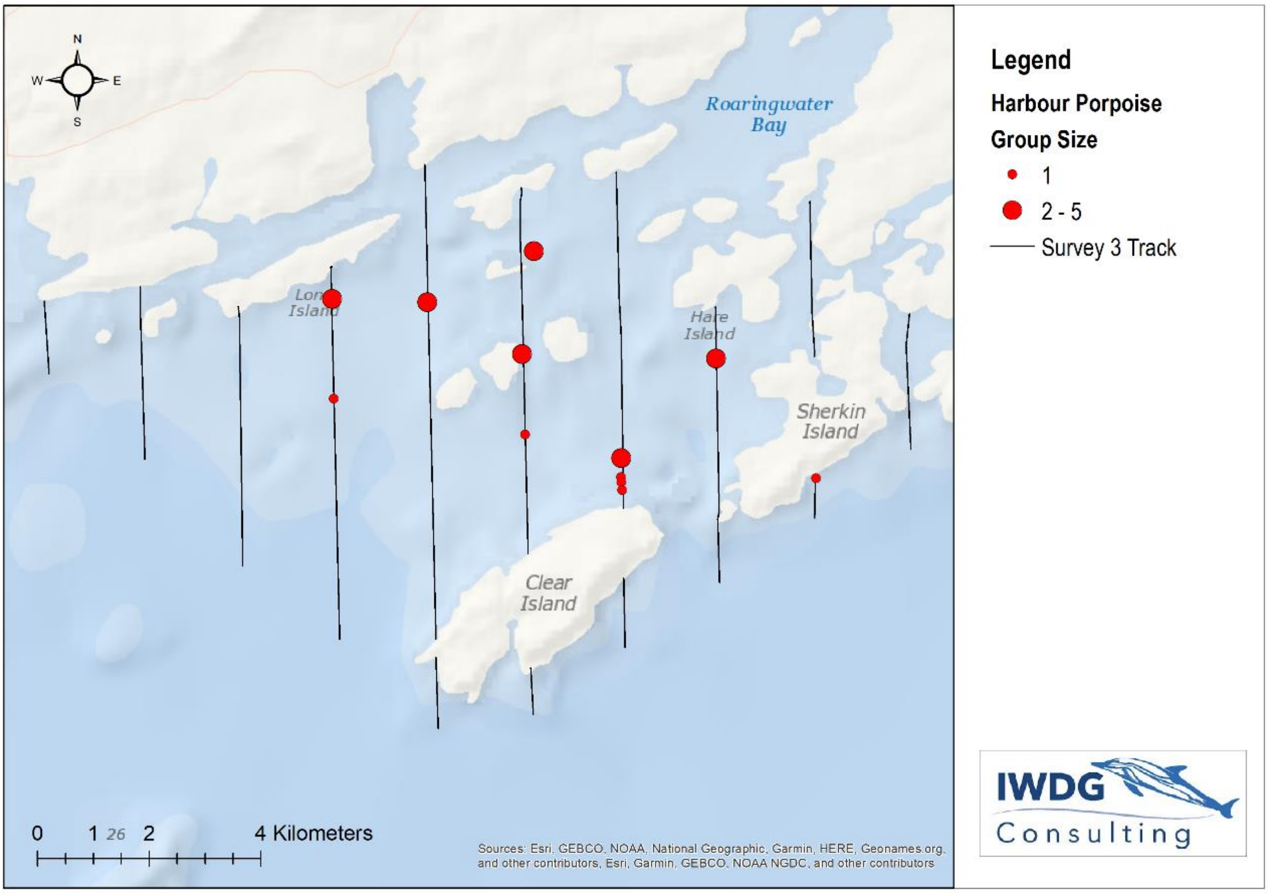


Figure 3c Track-lines and distribution of harbour porpoise sightings on 11 July 2020.

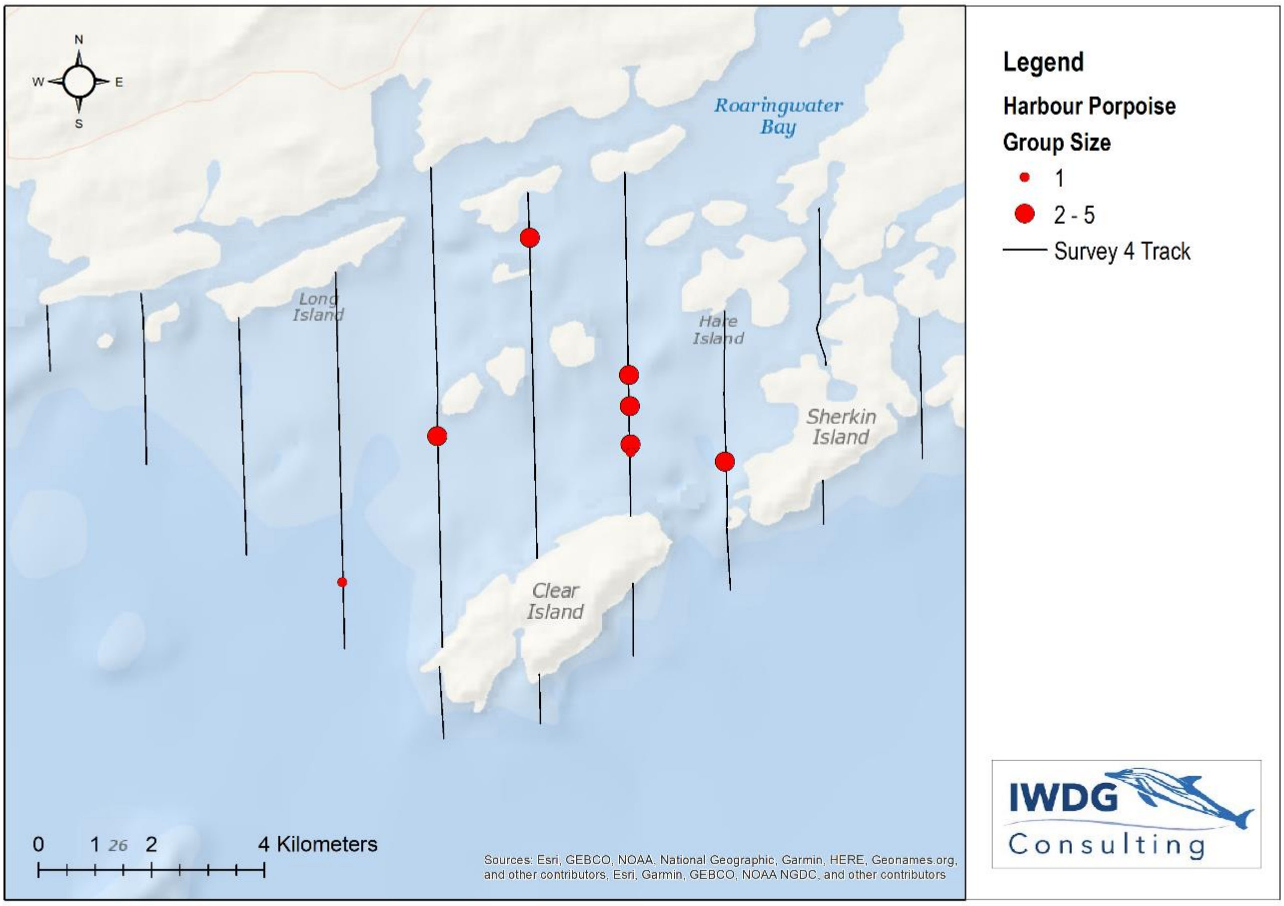


Figure 3d Track-lines and distribution of harbour porpoise sightings on 20 July 2020.

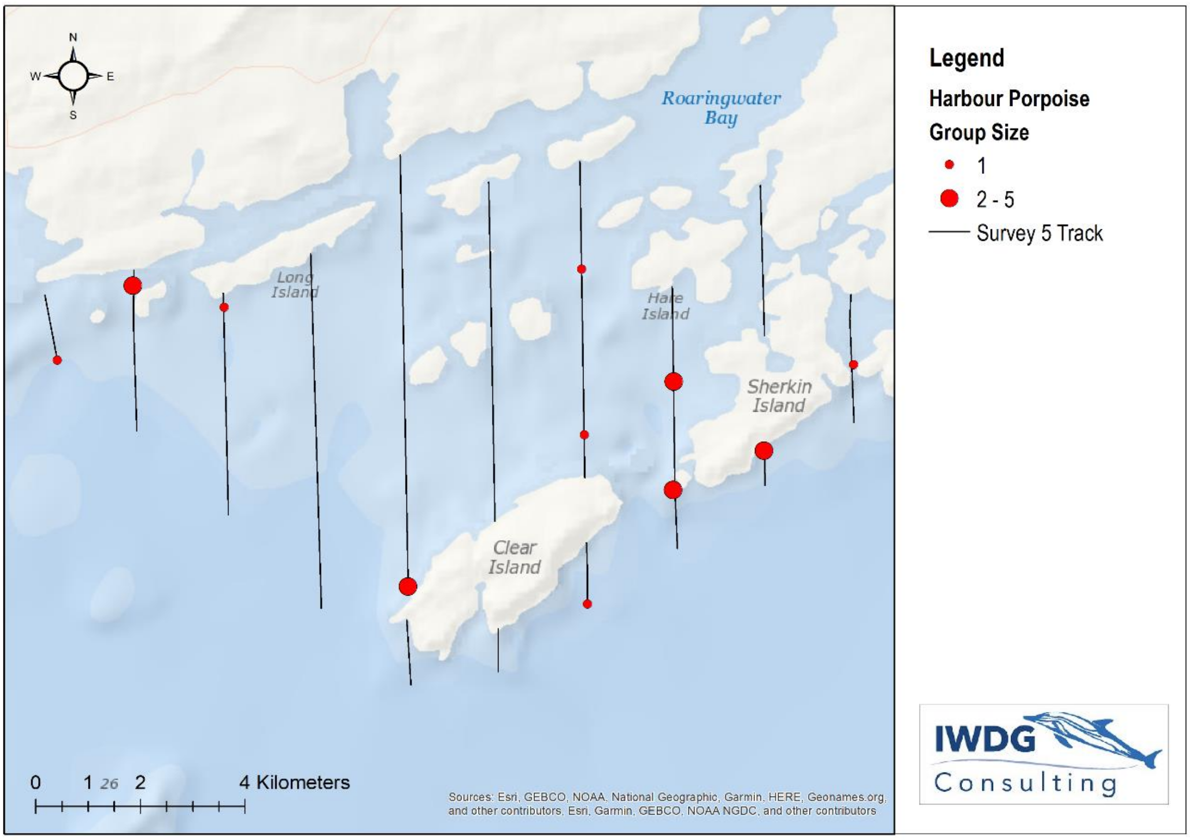


Figure 3e Track-lines and distribution of harbour porpoise sightings on 30 August 2020.

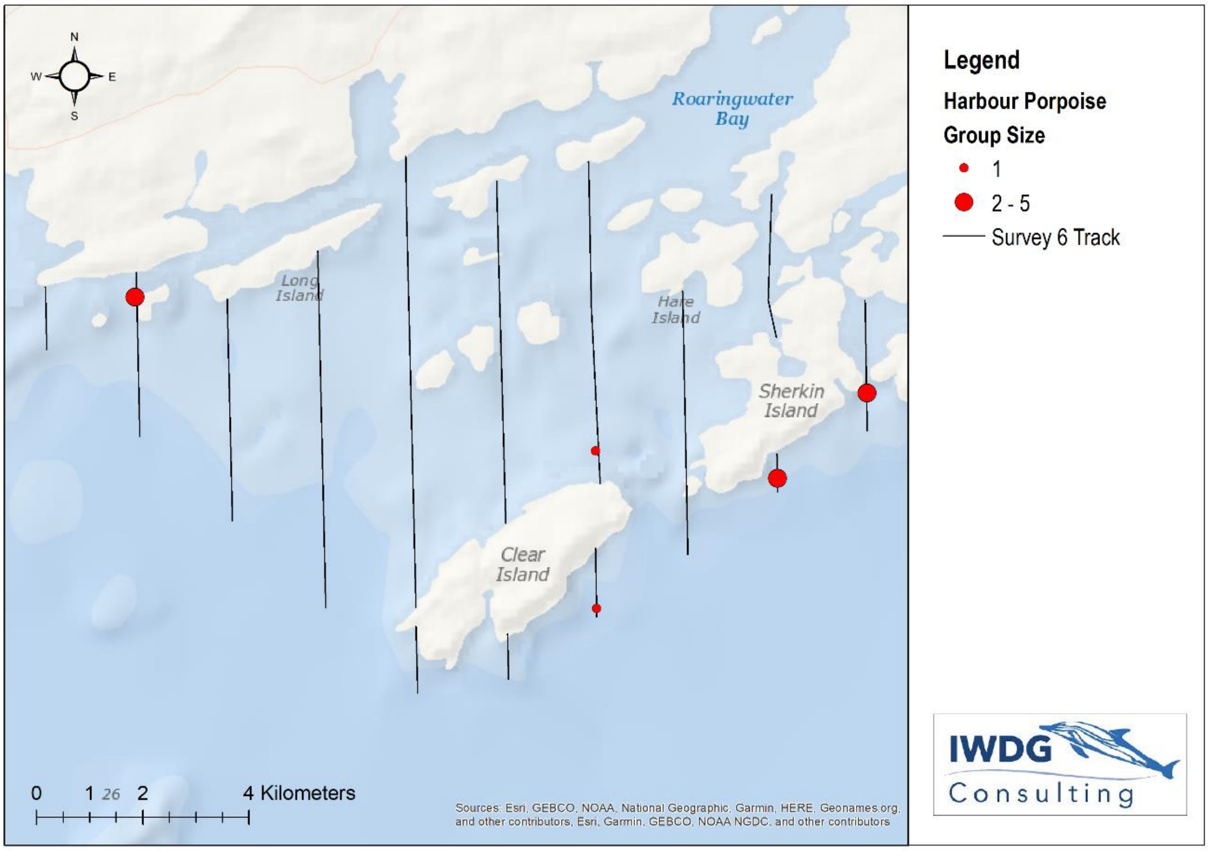


Figure 3f Track-lines and distribution of harbour porpoise sightings on 10 September 2020.

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 for the final survey (Survey 6: 10 September) only 5 sightings were recorded and the results of the analysis should be treated with extreme caution (Table 3).

The detection functions for harbour porpoise during all surveys are shown graphically in Figure 4. Using the Chi-squared test for goodness of fit to the DISTANCE model, data for four of the surveys (Surveys 1, 2, 3 and 5) were good fits but for surveys 4 and 6 the model was a poor fit (Table 3). The goodness of fit for all data combined (Figure 4) was good (Chi ^{2} = 0.18). Surveys were carried out in excellent sea conditions (Table 2) and porpoises frequently observed from >300m from the track-line. Data were truncated at 500m, which has led to sightings being pooled into wide distance categories (Figure 4).

Evasive reactions of porpoises from the survey vessel were most evident on surveys 1, 3 and 6 and for all surveys combined with a peak in sightings some 200-300m from the track-line (Figure 4). Although this could lead to some underestimate of animal density, this is 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). The DISTANCE model could be adjusted to account for this movement but this was not carried out in the current analysis.

Table 3 Model data used in the harbour porpoise abundance and density estimation process for each survey of Roaringwater Bay and Islands SAC in 2020 (Note: A half-normal model with cosine series adjustments and sightings data truncated at 300-500m was used).

Sample Day	Chi^2 P value	Effective Strip Width (m)	Mean Cluster size ± SE	Variability (D)		
				Detection	Encounter	Cluster
1	0.24	288	2.00±0.3	62.9	-	37.1
2	0.21	162	1.14±0.1	94.7	-	5.3
3	0.17	278	1.50±0.02	78.3	-	21.7
4	0.64	238	2.37±0.46	66.7	-	33.3
5	0.38	201	1.54±0.21	71.4	-	28.6
6*	0.73	124	2.75±0.86	33.8	-	66.2
Overall	**0.18**	**263**	**1.81±0.14**	**29.5**	**57.2**	**13.4**

* treat with caution, high CV and poor goodness of fit

Mean group (cluster) size was greatest on surveys 1, 4 and 6 (2.0, 2.37 and 2.75; Table 4), with a slight increase in group size with month.

The proportion of variability in the data accounted for by the detection probability was highest for all surveys apart from survey 6 which should be treated with extreme caution due to the lower number of sightings (5). Overall the variability was highest for encounter rate and lowest for cluster size which is to be expected as there was great variability in the number of sightings per survey (range 5-15; Table 4).

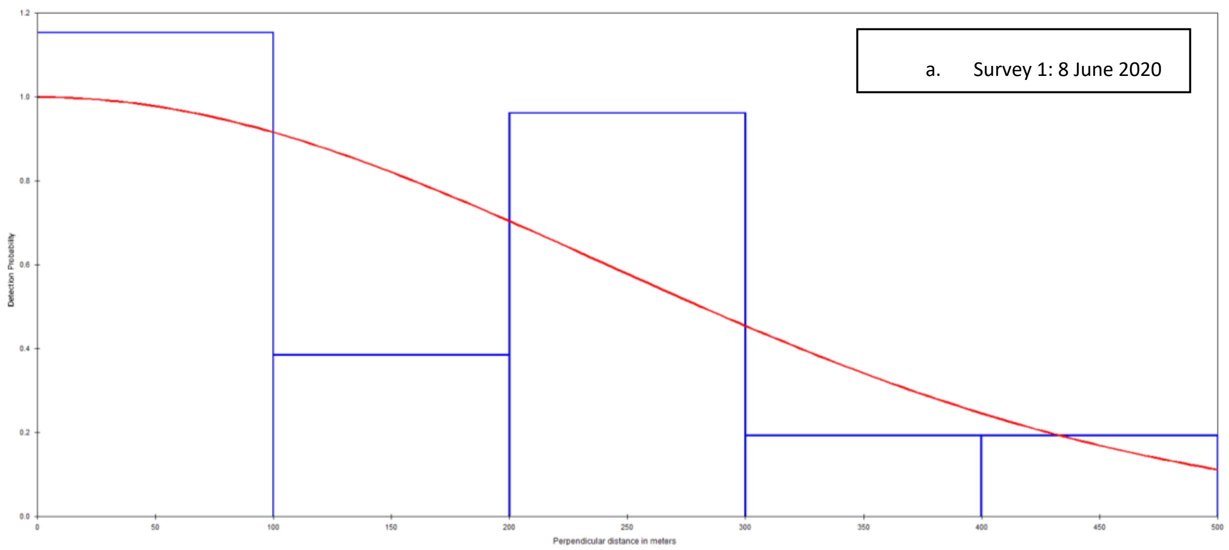
Table 4 Estimated density, abundance (N) and group sizes of harbour porpoise recorded during surveys of Roaringwater Bay and Islands SAC, 2020.

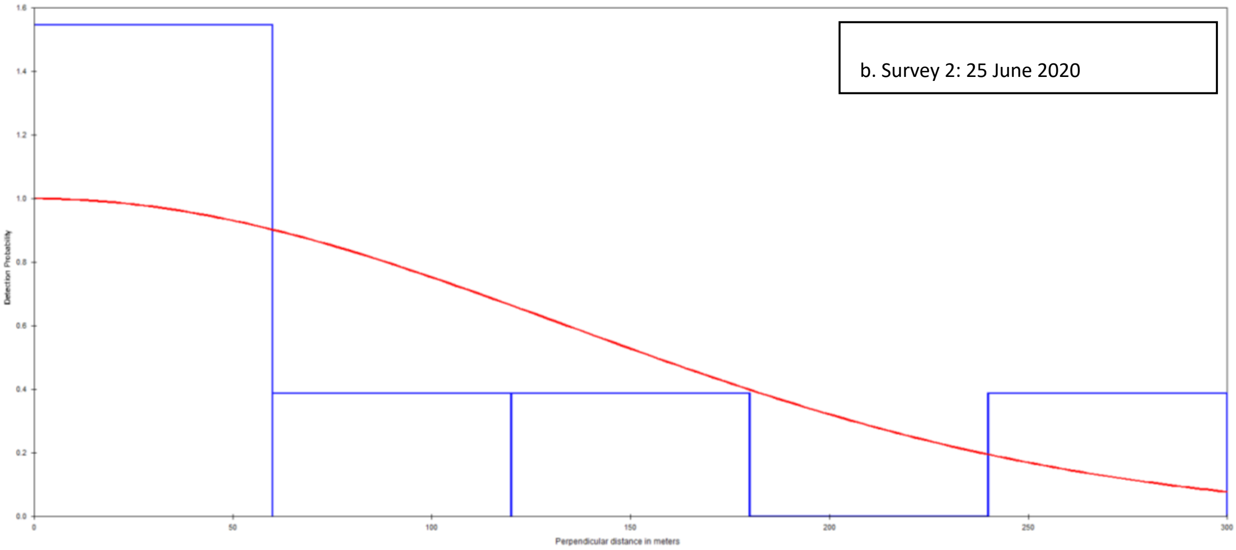
Sample Day	N (95% CI)	SE	CV	Density (per km^2)	Mean group size (95% CI)
1	179 (102-306)	50	0.28	1.25±0.35	2.0 (1.41-2.73)
2	54 (25-116)	18	0.33	0.38±0.12	1.1 (1.00-1.55)
3	82 (46-146)	23	0.28	0.57±0.16	1.5 (1.20-1.87)
4	75 (36-155)	26	0.34	0.52±0.18	2.4 (1.51-3.74)
5	122 (70-214)	33	0.27	0.85±0.23	1.5 (1.15-2.08)
6*	342 (64-1834)	224	0.66	2.39±1.56	2.8 (1.04-7.22)
Overall[1]	**87 (57-133)**	**17**	**0.20**	**0.61±0.12**	**2.8 (1.56-2.10)**

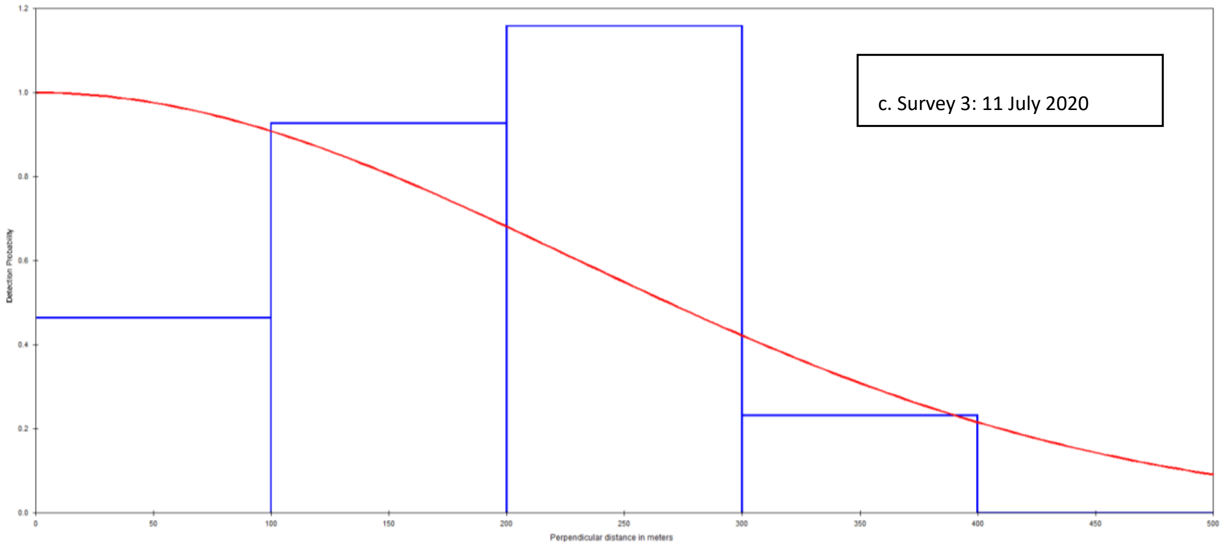
* treat with caution, high CV and poor goodness of fit

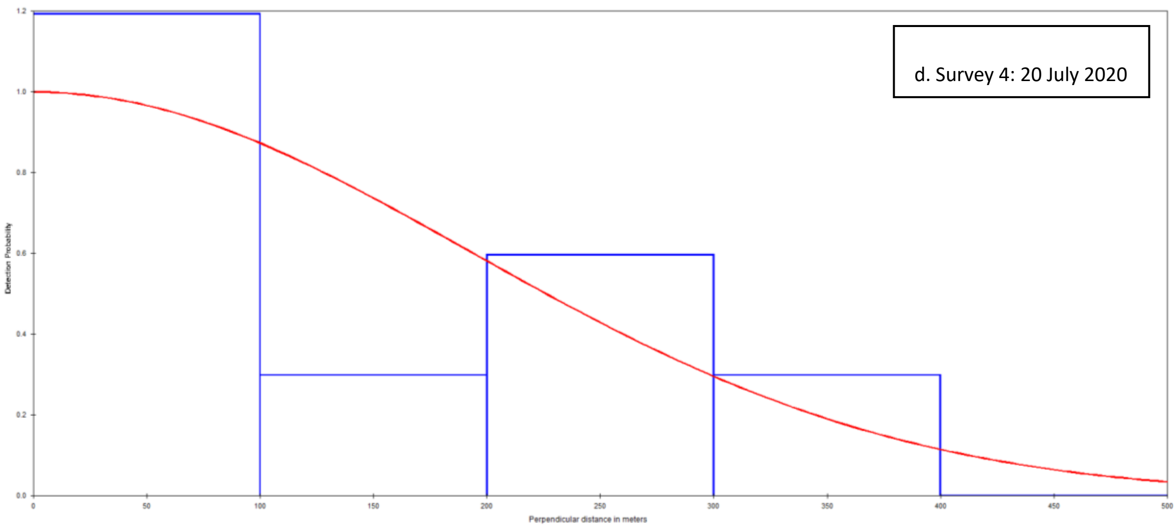
Density and abundance estimates for harbour porpoise in Roaringwater Bay and Islands SAC are shown in Table 4. The density estimates varied quite considerably between surveys with highest densities on surveys 1 and 6. High densities on survey 1 correlated with the greatest number of sightings, while survey 6, which should be treated with extreme caution due to the low number of sightings, had the highest mean group size (2.75±0.86), which would have inflated the density estimate. The lowest density estimate was on survey 2 with only 0.38 harbour porpoises per km^2 and coincided with low sighting numbers (7) and the lowest mean group size (1.14±0.1) (Table 4).

The overall density estimate was 0.61±0.12 with a 95% CI of 0.40 to 0.93 (Table 4). This estimate had a low CV of 0.20. This produced an abundance estimate of 87±17 porpoises with 95% Confidence Intervals = 57- 133 porpoises. (Table 4; Figure 4a-g).




b. Survey 2: 25 June 2020
Detection Probability
Perpendicular distance in meters


c. Survey 3: 11 July 2020
Detection Probability
Perpendicular distance in meters


d. Survey 4: 20 July 2020
Detection Probability
Perpendicular distance in meters

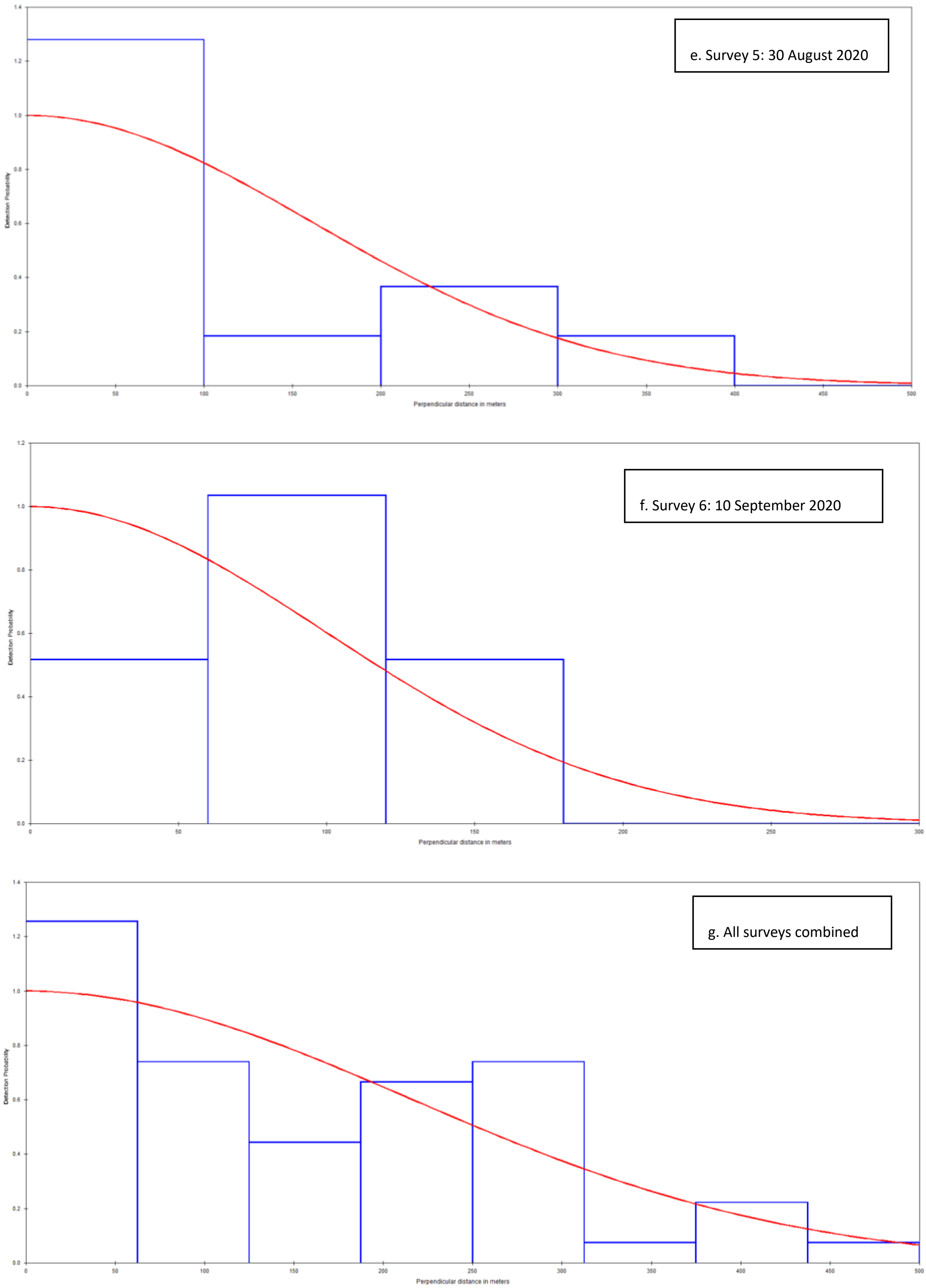


Figure 4 a-g Detection function plots for each survey of harbour porpoises in Roaringwater Bay and Islands SAC, 2020.

3.2 Density and abundance estimation in different sea-states

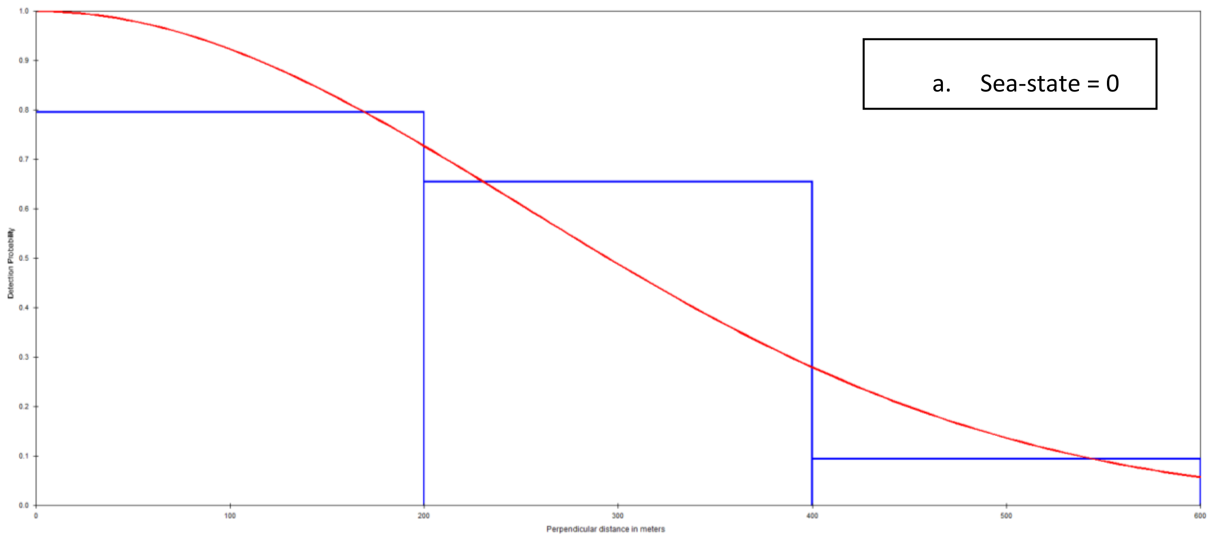
In order to explore the potential effect of sea-state on density estimates, the data for all surveys were pooled and stratified by sea-state. Detection functions were then calculated for increasing sea-state (Table 5, Figure 5). A detection function was determined for all sightings in sea-state 0 over the six surveys combined, followed by a similar analysis for sea-state 0+1 and sea-state 0+1 (Figure 5 a&b). Total sighting effort (in km) was calculated for each sea-state and used in the analysis.

Density estimates classified by sea-state provided the highest figure for all data combined (sea-state 0+1+2) at 0.61±0.12 porpoises per km^2. Density estimates for all data collected in sea-state 0 and sea-state 0+1were only 0.37 and 0.35 porpoises per km^2 (Table 5).

The CV for the estimate in sea-state 0+1+2 (0.20) was the lowest for all categories suggesting this is the best estimate. These data also suggest it is appropriate to pool the survey data from all survey days and in all sea-states.

Table 5 Density, abundance (N) and group size estimates of harbour porpoise in Roaringwater Bay and Islands SAC across increasing sea-states.

Sea-state Class	Effort (km)	Chi ^{2} P value	Mean group size ± SE	Density (per km^2)	SE	CV	N (95% CI)
0	161.6	0.17	1.76±0.16	0.37	0.10	0.28	53±15 (29-97)
0+1	317.5	0.15	1.84±0.14	0.35	0.08	0.24	49±12 (30-80)
0+1+2	324.7	0.18	1.81±0.14	0.61	0.12	0.20	87±17 (57-133)



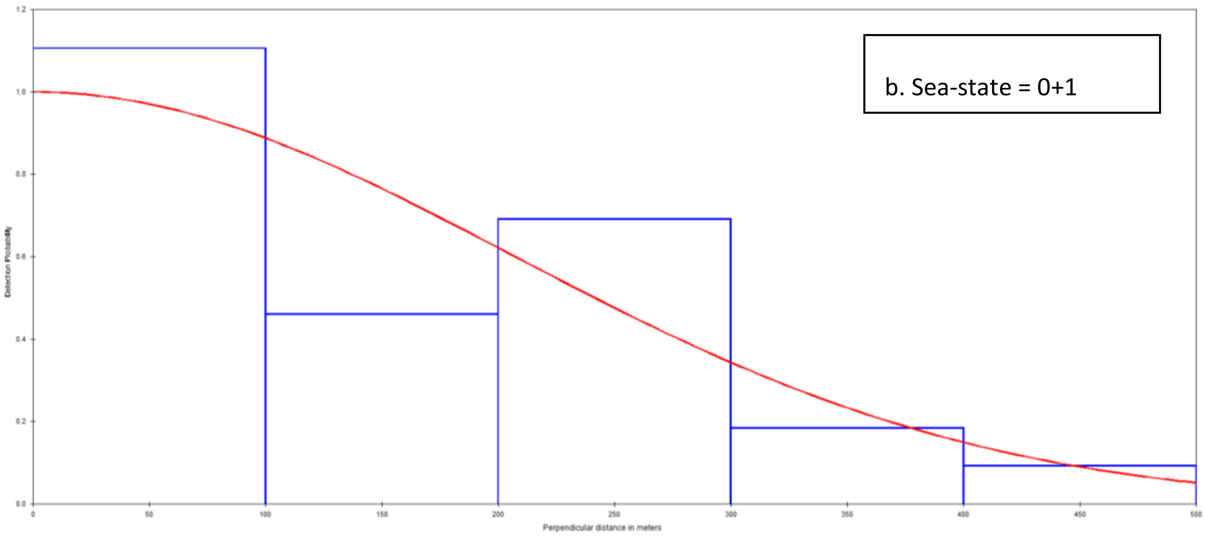


Figure 5 a&b Detection function plots for harbour porpoise surveys of Roaringwater Bay and Islands SAC, 2020 according to different sea-state classes.

3.3 Proportion of juveniles and calves

The proportion of young porpoises and calves to all porpoises (including adults) was calculated for each survey (Table 6). This includes two "off effort" sightings from survey 4, which are not included in Table 1. The proportion of juveniles ranged from 0% to 18.9% and calves from 0-12.5% on each survey. The observed proportion of juveniles to adults was highest on surveys 4 and 5 (11 July and September) and adults to calves on survey 5 (30 August). Calves were nearly all recorded on the last three surveys in July, August and September. The proportion of young porpoises (juveniles and calves combined) recorded on survey days ranged from 6% to 31% and was 16.7% overall (Table 6).

Table 6 The numbers and proportions of adult harbour porpoises, juveniles and calves recorded during surveys in Roaringwater Bay and Islands SAC, 2020.

Survey	Number of sightings	Number of Individuals	Adults	Juveniles	Calves	% young	% calves
1	15	30	28	1	1	3.3	3.3
2	7	8	7	1	0	12.5	0.0
3	12	18	17	3	0	16.7	0.0
4	11	22	16	4	2	18.2	9.1
5	11	16	11	3	2	18.8	12.5
6	5	12	11	0	1	0.0	8.3
Overall	**59**	**108**	**92**	**12**	**6**	**11.1**	**5.6**

3.4 Additional marine mammal and megafauna sightings

Short-beaked common dolphins (*Delphinus delphis*) were the most abundant other marine mammal species recorded with totals each day ranging from 30 to 151 individuals and these were recorded on each of the six surveys (Table 7). Grey seals (*Halichoerus grypus*) were the second most frequently recorded species recorded during the study with sightings logged during every survey day bar the first (when observers did not know they were to record seals). Minke whales (*Balaenoptera acutorostrata*) were recorded on five occasions over three surveys and a single humpback whale (*Megaptera novaengliae*) was observed on survey 4 (20 July). Four basking shark (*Cetorhinus maximus*) sightings were also made in June and July. See Appendix I for maps of distribution and abundance.

Table 7 Other marine mammal species and basking sharks recorded during surveys in Roaringwater Bay and Islands SAC, 2020.

Survey	Common dolphin	Risso's dolphin	Minke whale	Humpback whale	Unid Dolphin	Grey seal	Basking shark
1	1 (30)	2 (12)	-	-	-	-	-
2	4 (81)	-	-	-	1 (1)	1 (11)*	3 (4)
3	10 (51)	-	2 (2)	-	1 (1)	16 (24)	1 (1)
4	8 (151)	-	1 (2)	1 (1)	-	17 (25)	-
5	15 (61)	-	2 (2)	-	2 (2)	8 (15)	-
6	15 (81)	-	-	-	3 (7)	2 (8)	-
Overall	**53**	**2**	**5**	**1**	**7**	**44**	**4**

* Hauled out on rocks

4 Discussion

This was the fourth dedicated survey of harbour porpoises in Roaringwater Bay and Islands SAC since it was designated for harbour porpoise and the third consecutive survey using the same fixed track-lines. Similar single platform line transect surveys carried out in 2008, 2013, 2015 and 2020 now provide some measure of inter-annual comparisons in density and the status of this qualifying interest. The survey carried out in 2020 was very successful in that sea conditions were very favourable throughout all six surveys and porpoises were recorded on all surveys, albeit with a large range in the number of sightings per survey.

Distance sampling was 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 DCHG 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 evasive movement relative to the survey boat on two of the six surveys, which caused 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.,* 2008a; Berrow and O'Brien, 2013, O'Brien and Berrow, 2015).

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 there was little difference in the density estimates which supports the decision to survey sites in conditions up to and including sea-state 2. Although overall detection function and density estimates when data were analysed per survey day or per sea-states were the same, the CV and other statistics around the estimates were slightly different. These differences are attributed to the number of sightings entered into each models. The number of sightings on each survey day were quite low, with a maximum of 15 sightings on survey 1. Only on three surveys were they more than 10 sightings in total. These are too low to provide robust density estimates and we suggest the model using the combined data from all survey days is the most robust estimate.

4.1 Harbour porpoise density estimates in Roaringwater Bay and Islands SAC

Roaringwater Bay and Islands Special Area of Conservation was designated as a candidate SAC in 2000 with harbour porpoise as one of its qualifying features. An abundance estimate was carried out in 2008 via six zig-zag line-transect surveys spanning roughly the same area (Berrow *et al.,* 2008a). In 2013 the track-lines were changed and fixed and comprised ten randomly set parallel track-lines (Berrow and O'Brien, 2013). These same track-lines were surveyed again in 2015 (O'Brien and Berrow 2015) and were repeated again in the current survey.

Table 8 Density, abundance and group size estimates for harbour porpoise within Roaringwater Bay and Islands SAC from 2008 to 2020.

Year	Survey effort (km)	No. of sightings (animals)	Mean group size	Density (per km²)	Abundance ± SE	CV	Reference
2020	324	59 (104)	1.81	0.61	87±17	0.20	This survey
2015	324	75 (141)	1.86	2.02	289±80	0.28	O'Brien and Berrow (2015)
2013	250	67 (107)	1.56	1.18	151±18	0.12	Berrow and O'Brien (2013)
2008	331	47 (110)	2.21	1.24	159±42	0.27	Berrow *et al.* (2008a)

A breakdown of the density and abundance estimates and associated statistics derived from all four surveys to date is given in Table 8.

Line-transect designs were notably different in 2008 to recent years, but the survey effort carried out across all three surveys are similar, with a total of 324 km of track-line surveyed in 2015 and 2020, compared to 250 km in 2013 and 331 in 2008 (Table 8). The number of sightings per survey were similar in 2013 and 2015, 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 2015 but very similar to the total number of individuals recorded in 2013 however the total survey effort was also lower in 2013 around 30%. Mean group size (1.81) was very similar to that recorded in 2015 (1.86, Table 8).

Thus there does seem to have been a real decrease in the density of harbour porpoises recorded in Roaringwater Bay and Islands SAC during 2020, after a real increase was reported in 2015 compared to the two previous surveys in 2008 and 2013.

4.2 Proportion of juveniles and calves

The proportion of young recorded in 2020 was very consistent with 2013 and 2015 but greater than reported in 2008 (Table 9). The proportion of calves was also higher than previous estimates. Sonntag *et al.* (1999) estimated that up to 18% calves were present at the Isle of Sylt in Germany, which is considered an important calving area in the North Sea. However, the proportion is consistent with other studies at around 3-5% (Hammond *et al.*, 2002; Evans and Hammond, 2004).

Table 9. The numbers and/or proportions of adult harbour porpoises, juveniles and calves recorded during surveys in Roaringwater Bay and Islands SAC from 2008 to 2020.

Survey	Number of sightings	Number of Individuals	Adults	Juveniles	Calves	% young	% calves
2020	59	108	92	12	6	11.1	5.6
2015	76	141	111	15	5	14.2	3.5
2013	67	107	93	10	4	13.1	3.7
2008	47	110	102	8	0	7.3	0.0

4.3 Trends in harbour porpoise density estimates in Roaringwater Bay and Islands SAC

The results from the present survey demonstrate an apparent large decrease in overall density in 2020 compared to 2015 and also a decrease, although not as large, compared to estimates from 2008 and 2013 (Figure 6). However it must be noted that 2015 and 2020 are the only years when all 6 surveys were completed. These fluctuations in density estimates may be due to a number of factors and not necessarily due to any changes in population size. Small changes in distribution, with porpoises occurring inside and outside the SAC and therefore the survey area during the survey period will have profound effects on density estimates. Continued monitoring would enable further exploration but a power analysis is required to determine the power of this monitoring technique to detect changes given these large fluctuations between surveys is required.

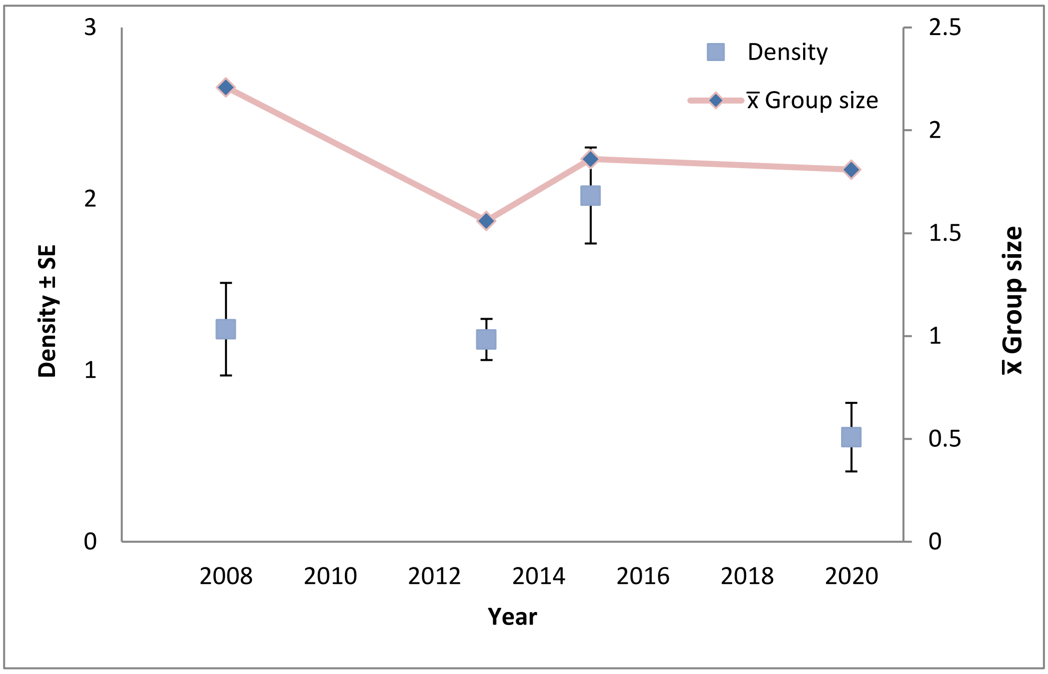


Figure 6 Changes in the recorded density of harbour porpoises in Roaringwater Bay and Islands SAC over time.

We can only suggest that there was a significant change in the distribution of harbour porpoises during summer 2020 compared to previous surveys (Table 8). This change is most likely associated with changes in prey distribution leading to lower densities of porpoises within the site. A better understanding of the ecology of harbour porpoise in this region, including 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 dramatic decrease repeated again in 2021 to determine if there is an outlier or part of a trend. We recommend annual surveys to explore short-term (annual) changes in densities.

2. A power analysis on the current datasets should be carried out to explore the power of this monitoring technique to measure changes in population, given the high between-survey variability recorded in studies of the site so far.

3. Given the variability in density estimates from distance sampling, consideration should be given to developing 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.

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Appendix 1

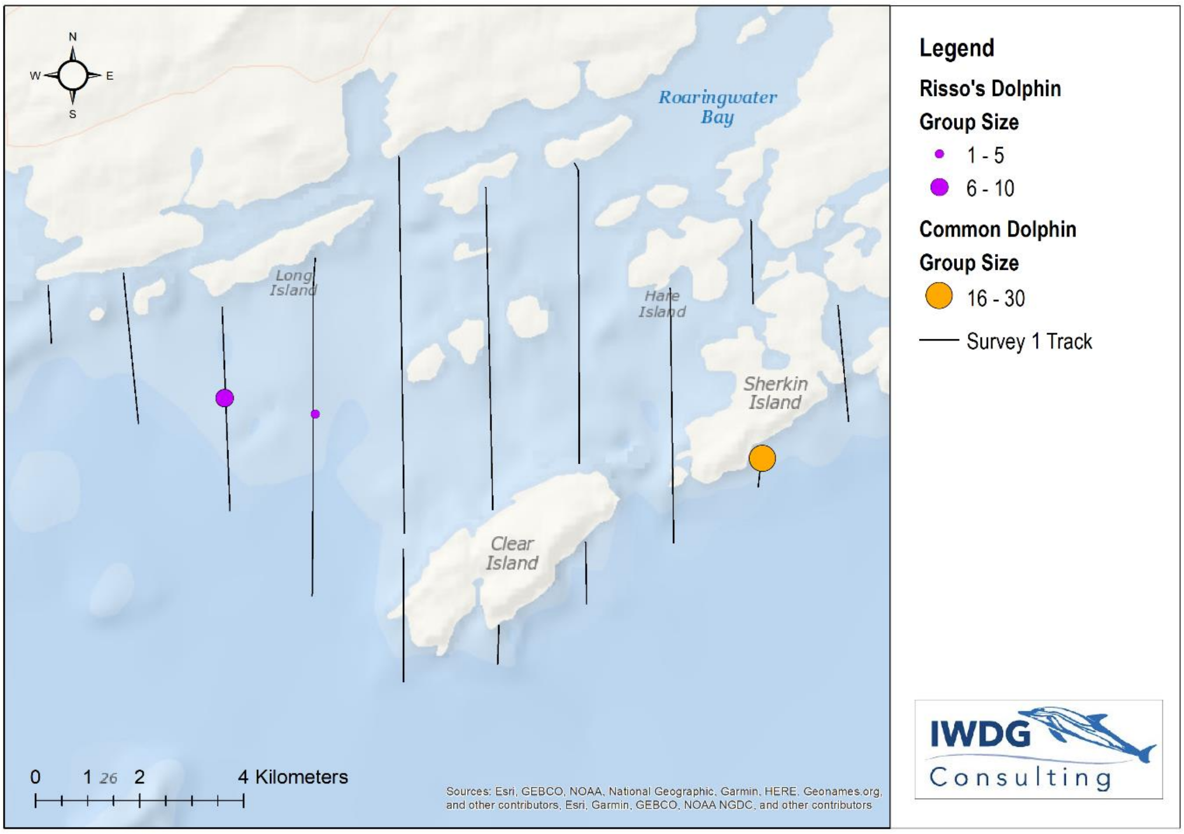

Figure 7. Vessel track-lines, estimated group sizes and distribution of other species sighted on survey 1.

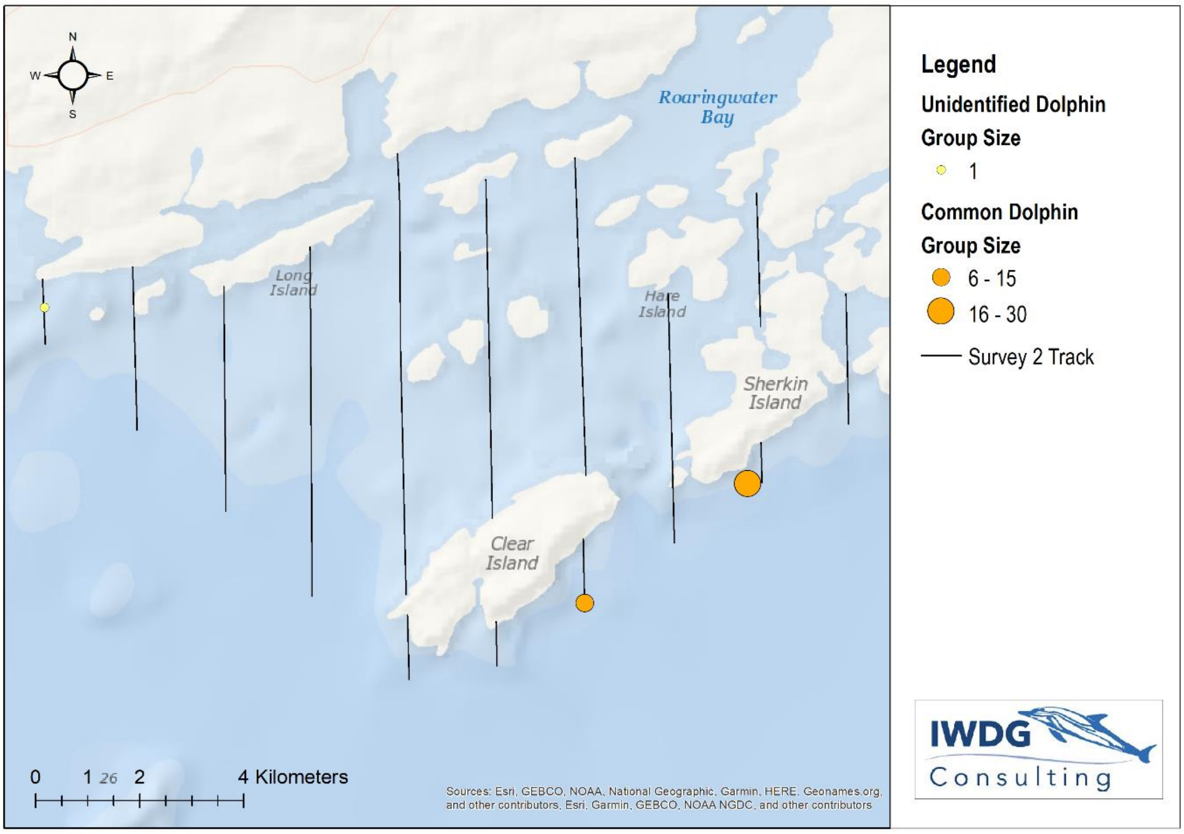

Figure 8. Vessel track-lines, estimated group sizes and distribution of other species sighted on survey 2.

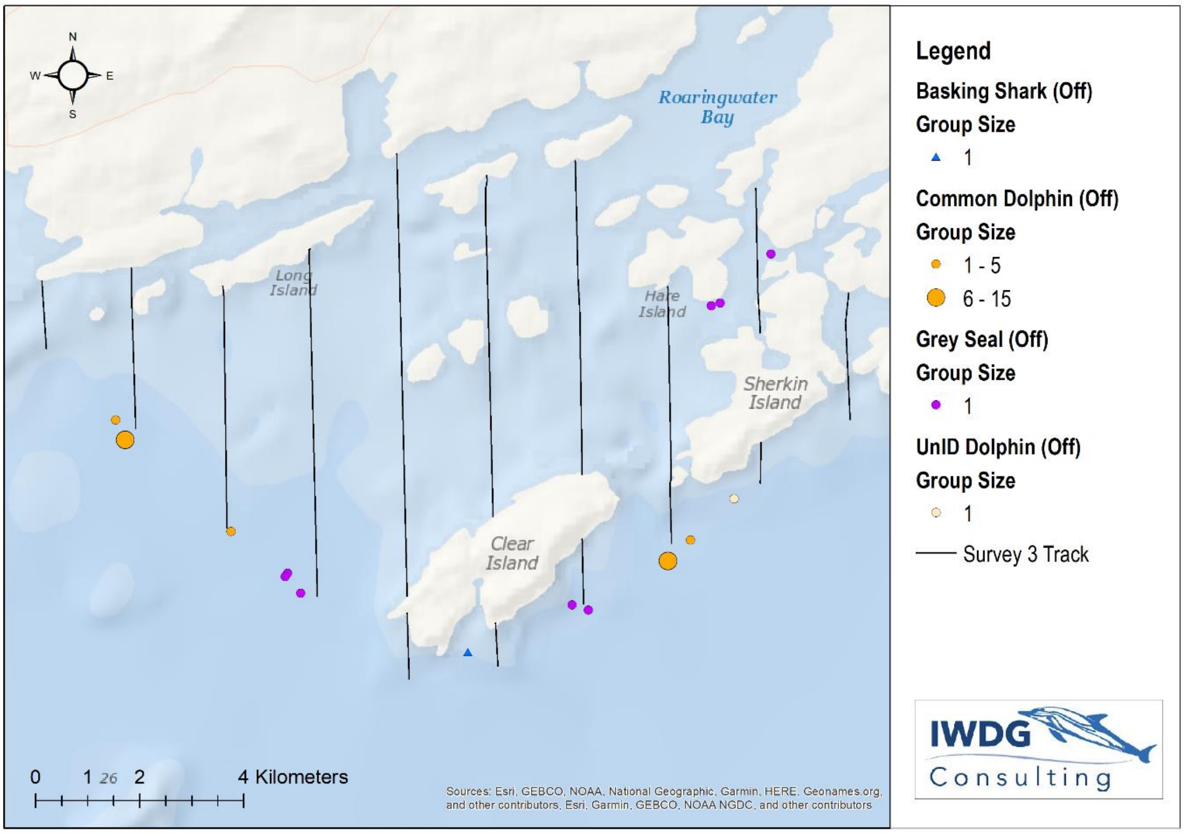

Figure 9. Vessel track-lines, estimated group sizes and distribution of other species sighted on and off-effort survey 3.

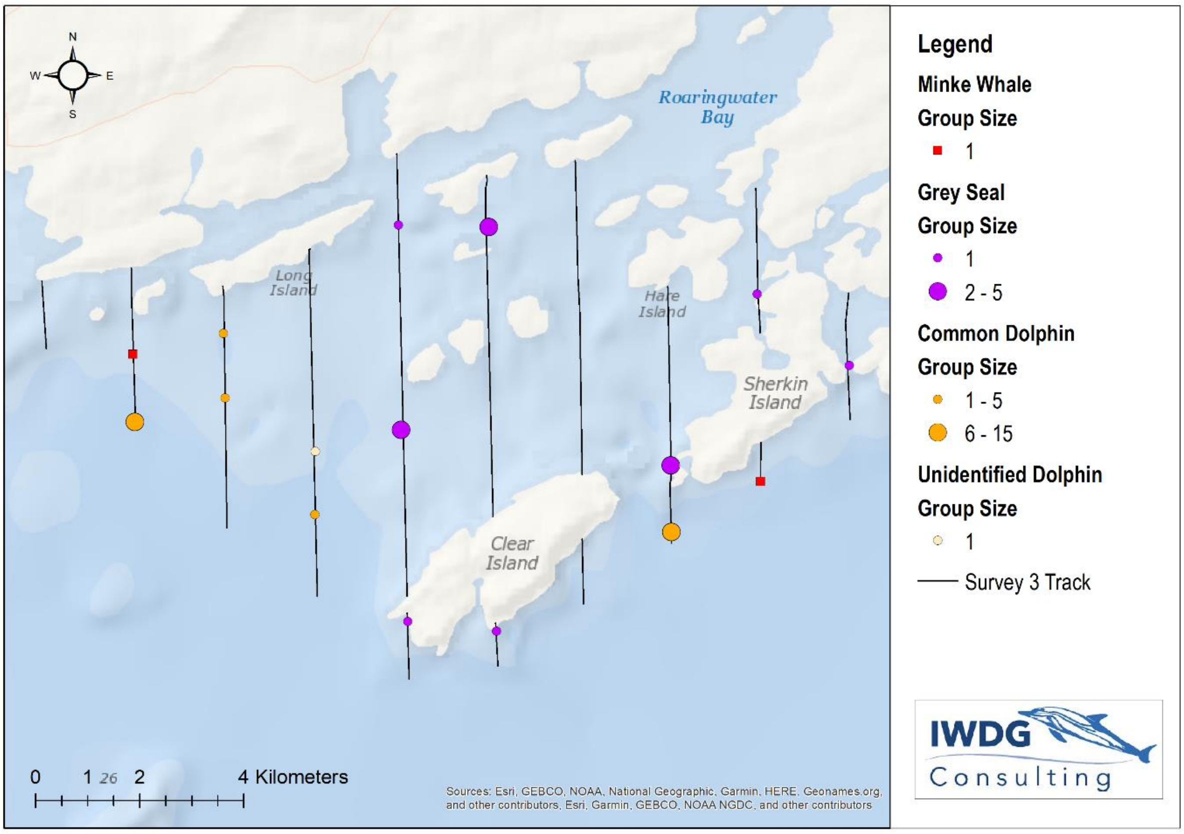

Figure 10. Vessel track-lines, estimated group sizes and distribution of other species sighted on survey 3.

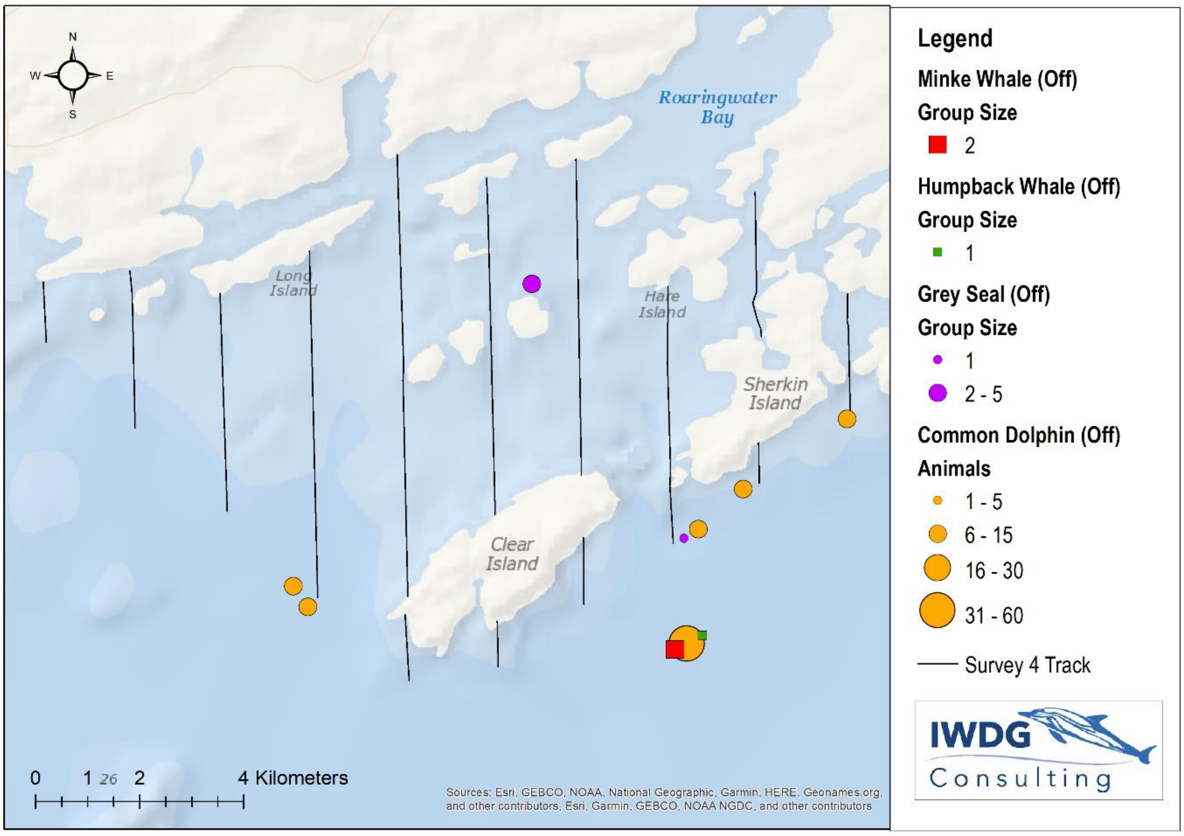

Figure 11. Vessel track-lines, estimated group sizes and distribution of other species sighted off-effort on survey 4.

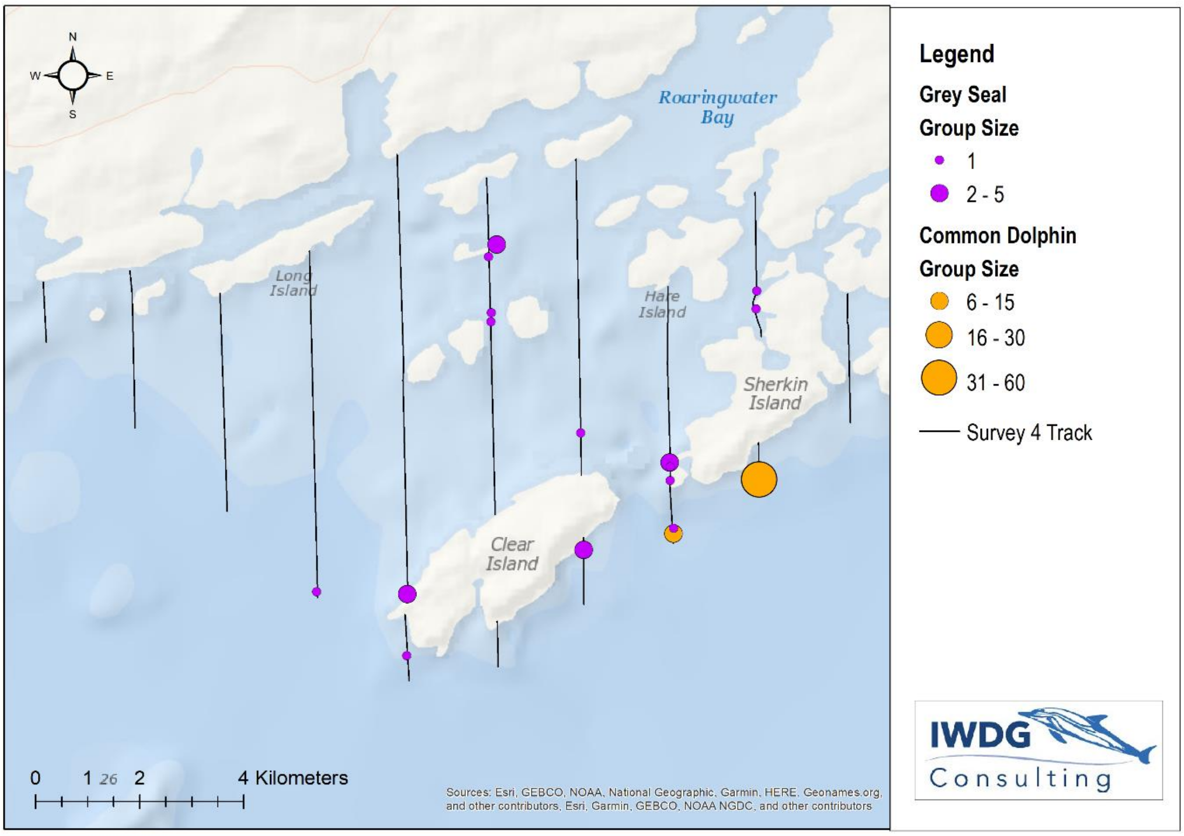

Figure 12. Vessel track-lines, estimated group sizes and distribution of other species sighted on survey 4.

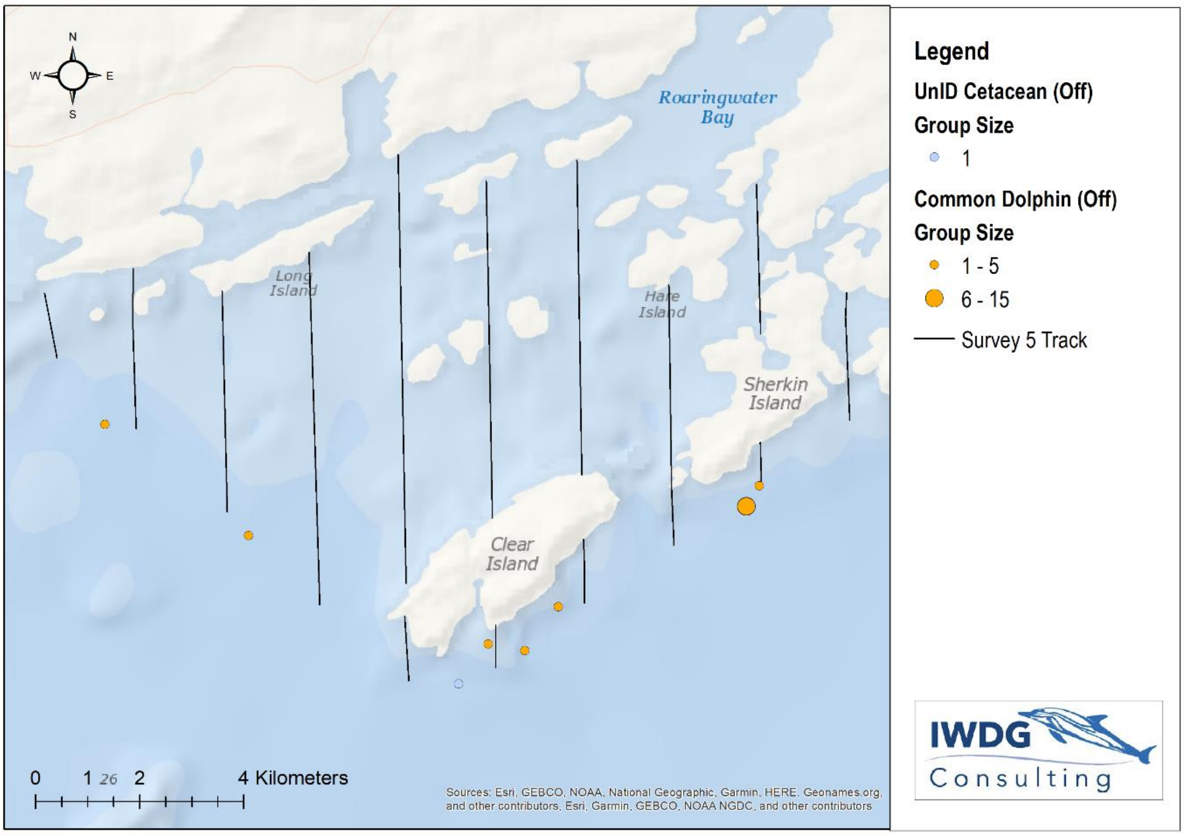

Figure 13. Vessel track-lines, estimated group sizes and distribution of other species sighted off effort on survey 5.

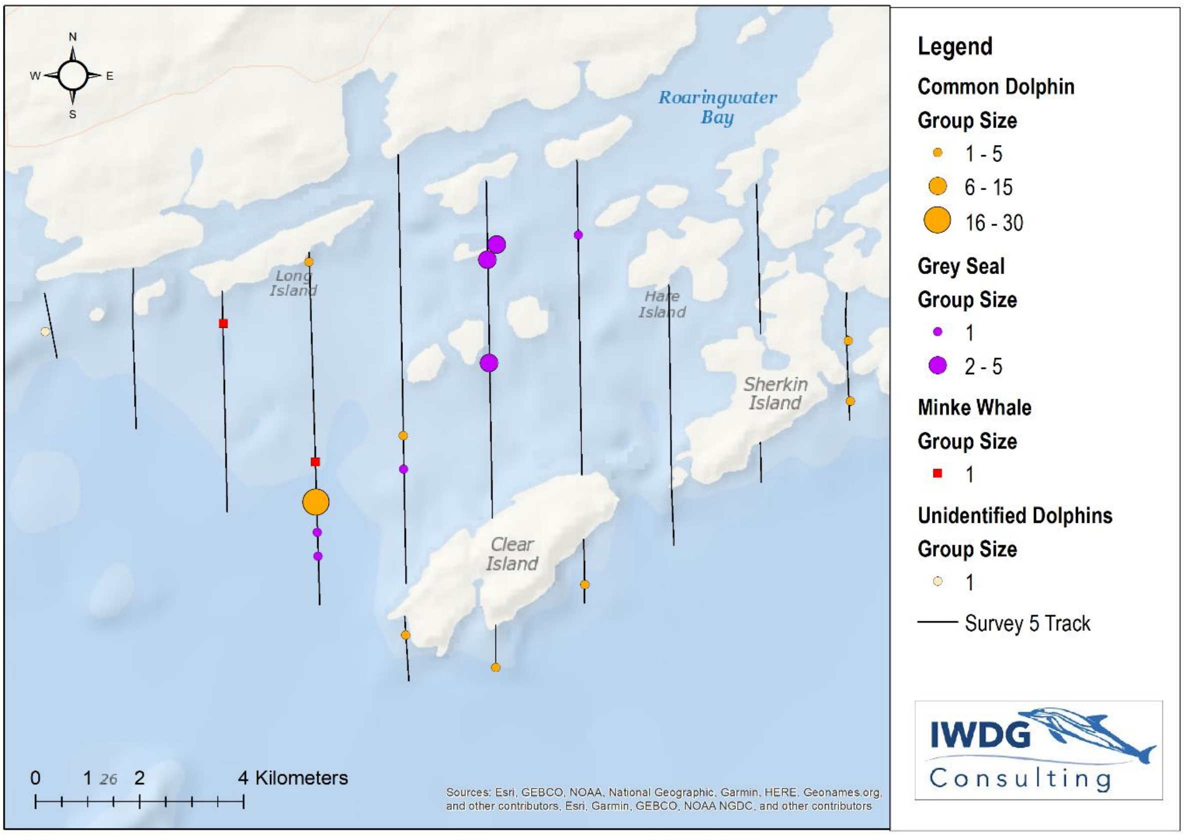

Figure 14. Vessel track-lines, estimated group sizes and distribution of other species sighted on survey 5.

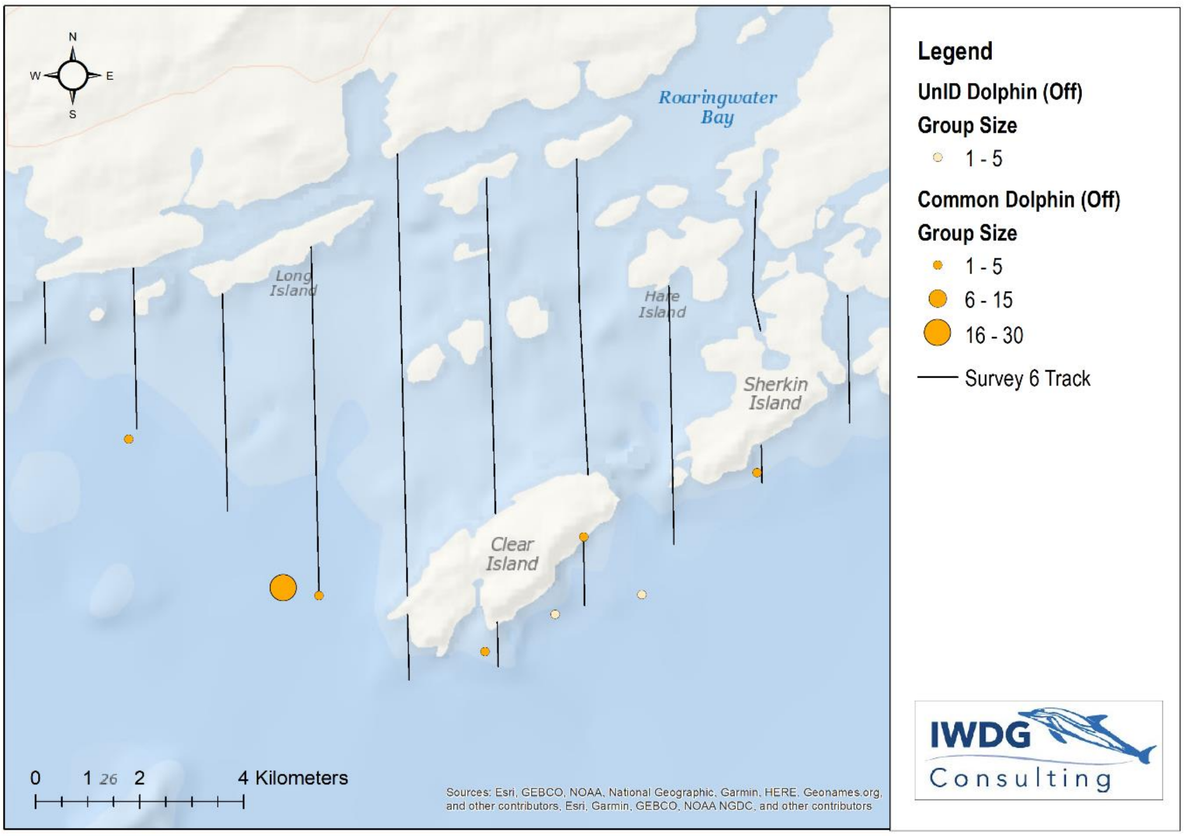

Figure 15. Vessel track-lines, estimated group sizes and distribution of other species sighted off effort on survey 6.

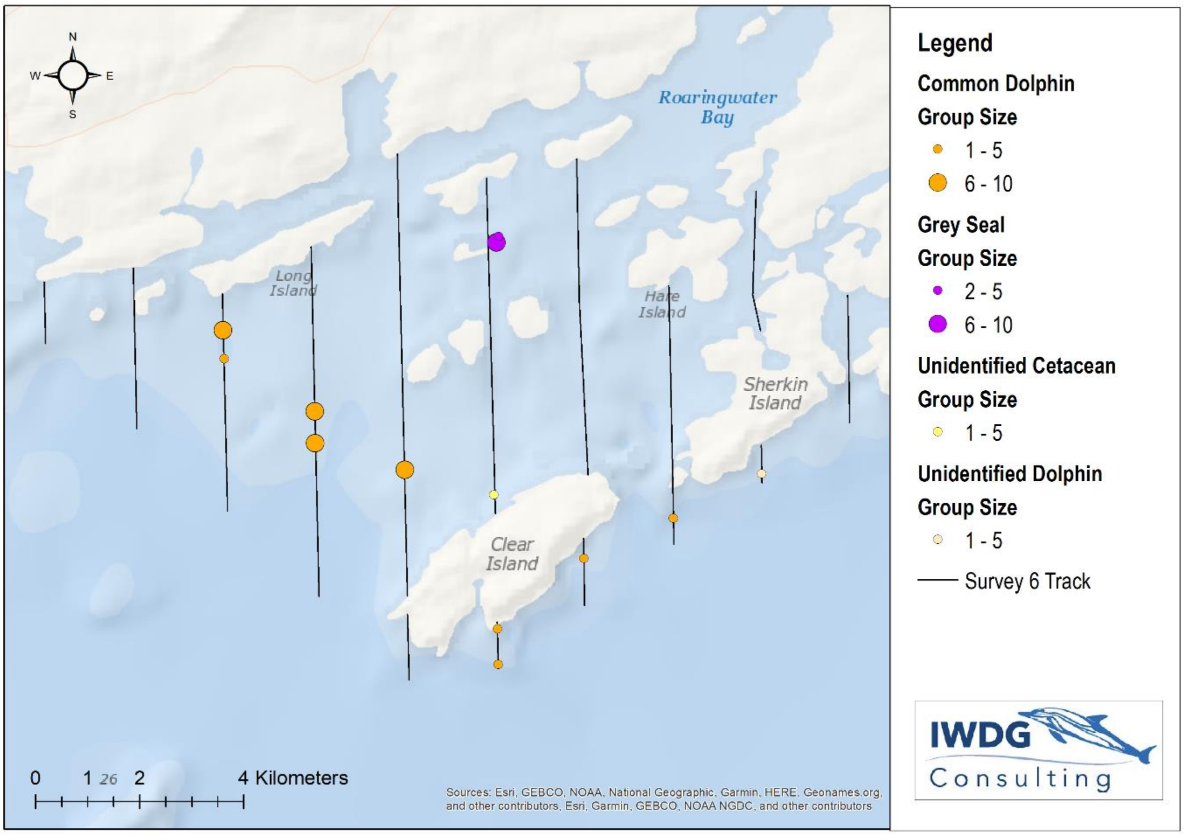

Figure 16. Vessel track-lines, estimated group sizes and distribution of other species sighted on survey 6.