DENSITY ESTIMATES OF HARBOUR PORPOISES *PHOCOENA PHOCOENA* AT EIGHT COASTAL SITES IN IRELAND

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ABSTRACT

Single platform line-transect surveys with distance sampling were carried out at eight sites between July and September 2008 to derive density and abundance estimates of harbour porpoises. Over 37 days at sea, a total of 475 track-lines were surveyed for a total distance of 20,623km. From the 332 sightings, a total of 618 individual harbour porpoise were recorded. Overall density estimates ranged from 0.53 to 2.03 porpoises km^{-2} (without correction for g(0)). Mean group size varied from 1.41 to 2.67. These data provide baseline information to help identify important habitats for harbour porpoise and reference values for monitoring future changes in harbour porpoise distribution and densities in Ireland.

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Cite as follows: Berrow, S., Hickey, R., O'Connor, I. And McGrath, D. 2014 Density estimates of harbour porpoises *Phocoena phocoena* at eight coastal sites in Ireland. *Biology and Environment: Proceedings of the Royal Irish Academy* 2014. DOI: 10.3318/BIOE.2014.03

Received 12 December 2012. Accepted 15 January 2014. Published 28 February 2014

INTRODUCTION

The harbour porpoise (*Phocoena phocoena* L.) is the most widespread and abundant cetacean species in Irish waters (Rogan and Berrow 1996). It has been recorded off all coasts and over the continental shelf but is thought to be most abundant off the southwest coast (Reid *et al.* 2003). Harbour porpoise are also consistently the most frequently recorded species stranded in Ireland (Berrow and Rogan 1997; O'Connell and Berrow 2010).

Despite this, relatively little is known about their abundance or population trends. Leopold *et al.* (1992) carried out five line-transects from Galway to Cork in 1989 on a platform of opportunity and derived an abundance estimate of 19,120 harbour porpoises, equating to an overall density of 0.77 ± 0.26 harbour porpoises per km^2. On a broader scale, a density of 0.18 harbour porpoises per km^2 was calculated for the Celtic Sea as part of an international harbour porpoise survey called SCANS (Small Cetacean Abundance in the North Sea) which was carried out in July 1994 (Hammond *et al.* 2002). This survey was repeated in July 2005 (SCANS-II) but encompassed all Irish waters including the Irish Sea (SCANS II 2008). Harbour porpoise densities were calculated for three areas; Celtic Sea (0.41 porpoise km^{-2}) Irish Sea (0.34) and Atlantic coastal Ireland (0.28). The offshore Ireland survey area included Scotland and a density of 0.07 porpoise km^{-2} was generated for both areas combined. These results suggested the harbour porpoise density in the Celtic Sea had doubled between SCANS I and SCANS II, representing an increase of 11% per annum between 1994 and 2005. The only small-scale survey of harbour porpoise densities carried out in Irish coastal waters was that of Berrow *et al.* (2009), who calculated a density of 1.33 porpoise km^{-2} during a survey in 2007 of the Blasket Islands candidate Special Area of Conservation (cSAC).

As a coastal species, harbour porpoise are vulnerable to many anthropogenic influences such as pollution, fisheries interactions and disturbance, including acoustic disturbance (Jenkins *et al.* 2009; Tougaard *et al.* 2009). In order to assess these impacts it is essential to understand population distribution and abundance and to establish baseline estimates for long-term monitoring (Evans and Hammond 2004). Increasingly, cetacean sightings surveys are being carried out as part of environmental impact assessments of inshore sites. However, there are no data available with which to compare these site surveys in order to assess their relative importance for this species.

The harbour porpoise is also a species of high conservation value throughout Europe. Harbour porpoise is listed on Annex II of the European Union Habitats Directive which requires Member States to designate Special Areas of Conservation (SAC) for their protection. Guidance on what constitutes an important site for harbour porpoises in EU waters is limited, but factors such as good population density (in relation to neighbouring areas) and high ratio of young to adults during certain periods of the year are considered important (EC 2001). Some EU Member States have used a number of methods to try to identify important sites for harbour porpoises. In the UK, Embling *et al.* (2010) used spatial modelling to identify sites with elevated densities off southwest Scotland, while static acoustic monitoring and aerial surveys were

DOI: 10.3318/BIOE.2014.03

used in Germany to identify sites of importance for harbour porpoise (Verfuß *et al.* 2007).

Here we present the results of dedicated line-transect surveys for harbour porpoise using small vessels at eight coastal sites around Ireland, including the Blasket Islands and Roaringwater Bay candidate SACs (cSAC). We present density estimates and discuss variability in the dataset. This is used to explore the limitations and usefulness of using small vessels to record harbour porpoise in relatively small coastal sites. These data could provide reference values to identify sites with elevated densities of harbour porpoise and to compare similar surveys carried out elsewhere.

METHODS

SITE SELECTION

Eight sites were surveyed, two on the east coast, one in the southeast, three in the southwest, one in the west and one in the northwest (Fig. 1). Sites were selected by the National Parks and Wildlife Service (NPWS) because sighting schemes (Berrow *et al.* 2002; 2010) have suggested they have potential for designation as SACs, together with those sites (Blasket Islands and Roaringwater Bay) already designated as cSAC for harbour porpoise. At four sites (North County Dublin, Cork Coast, Roaringwater Bay, Galway Bay) surveys were

Fig. 1—Map of Ireland showing location of sites surveyed for harbour porpoise during 2008.

carried out on six days, two each in July, August and September 2008. At one site (Dublin Bay) five surveys were carried out and at three sites (Carnsore Point, Blasket Islands and Donegal Bay) three surveys were carried out, one in each in July, August and September 2008. Each survey at each site was to be completed in one day as more than one consecutive day of suitable sea conditions to complete a survey is rare in Ireland, especially on the west coast.

SURVEY TRAINING

A team of 19 surveyors were used in this survey, eleven experienced primary observers and eight recording survey effort, all organised into three teams. This made it possible to take advantage of suitable weather conditions at short notice, with occasionally all three teams surveying different sites on the same day. However, the use of multiple primary observers can increase variability within a dataset through differences in observer performance. Trials were organized to train observers in the survey methodology and identify sources of variability (see O'Brien 2009). Two teams of six observers were sent to two sites adjacent to the Shannon Estuary on two occasions. All observers were visually excluded from each other and asked to record the time of any sightings, therefore allowing for the assessment of variability between observers in time taken to record first sighting, estimation of distance to the observed animals and the number of groups.

To assist in estimating distance, two trials were carried out where observers on land were asked to estimate distances to a Rigid Inflatable Boat on the estuary. The distance was then determined using a Leica Rangemaster 1200. This range finder reports an accuracy to within ± 2m over 800m or $\pm 0.5\%$ over 600m. In the first trial observers were given ten distances to estimate between 50 and 1000m with no feedback provided between estimations as to the actual distance. In the second trial, ten more distances were estimated but observers were told the actual distance between each estimate.

SURVEY METHODOLOGY

Twelve different vessels were chartered over the duration of the survey period. Vessels were chosen that could navigate close to the shore, had a shallow draft and a flying bridge and were relatively cheap to charter. They ranged in length from 11m to 18m and platform height above sea-level, from 2.3m to 3.2m. Every vessel had active high-frequency navigation sonar on during each survey due to health and safety requirements: coastal sites navigated have a complex bathymetry and often only poor navigation charts are available. Conventional single platform line-transect surveys were carried out within or in close proximity to the boundaries of survey sites along pre-determined routes as described in detail by Berrow *et al.* (2009). Transect lines were chosen to cross depth gradients and provide as close to equal coverage probability as possible following the recommendations of Dawson *et al.* (2008) who suggested systematic line spacing resulted in better precision than randomised line spacing. At most sites lines were changed for each survey to try to get full coverage of the site over the study period to ensure no potentially important porpoise concentrations were overlooked. In the Blasket Islands cSAC, track-lines were repeated during each survey day to explore the variability on the same track-lines between visits, as Berrow *et al.* (2009) had already carried out a survey of the site in 2007 using randomly placed track-lines.

Each survey vessel travelled at a speed of 12–16km hr^{-1}, which was 2–3 times the typical average speed of the target animal (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 4m and 6m, depending on the height of the platform (Table 1) and each individual

Table 1—Date, sea-state and number of sightings of harbour porpoises at each site during 2008.

Site	*No. of survey days*	*No. of track lines*	*Total distance in sea-state ≤ 2 (km)*	*Sea-state (% of total survey time)*				*Number of sightings*	*Total Animals*
				0	1	2	3		
North County Dublin	6	69	293.75	15.4	47.6	19.5	14.7	82	111
Dublin Bay	5	75	289.38	15.8	34.0	34.0	14.1	56	69
Carnsore Point	3	33	183.59	2.7	34.5	43.0	19.8	13	23
Cork Coast	5	58	435.97	3.2	34.3	48.3	14.2	28	72
Roaringwater Bay	6	70	330.63	10.9	53.7	19.7	15.8	47	110
Blasket Islands	3	54	208.26	19.3	25.2	47.8	7.8	31	57
Galway Bay	6	82	627.10	23.2	33.6	25.8	17.5	62	134
Donegal Bay	3	34	230.95	51.1	26.9	18.9	2.8	19	42

observer. Primary observers watched with naked eye from dead ahead to 90° to port or starboard depending on which side of the vessel they were stationed. All sightings were recorded but sightings over 200m (300m if sea-state 0 predominated) perpendicular distance from the track-line were not used in the distance model, following the recommendations of Buckland *et al.* (2001.) These extreme values do not contribute much to the density estimate and they make it difficult to fit the detection function. Calves were defined as animals less than half the length of the accompanying animal (adult) and juveniles half to two-thirds of the adult length.

During each transect, the position of the survey vessel was tracked continuously through a GPS receiver connected directly to a laptop, while survey effort, including environmental conditions (sea-state, wind strength and direction, glare etc.) were recorded directly onto LOGGER software (©IFAW) every 15 minutes. 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 perpendicular distance of the sighting from the vessel recorded. These data were communicated to the recorder in the wheelhouse via VHF radio. The angle was recorded to the nearest degree via an angle board attached to the vessel immediately in front of each observer. Accurate distance estimation is essential for distance sampling. At some sites during each survey an orange buoy 225mm in diameter was towed 200m astern of the observers' position on the survey vessel. This provided a reference point against which to estimate distance.

ABUNDANCE ESTIMATE

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 is used to calculate the density of animals on the track-line of the vessel. In this survey we assumed that all animals on the track-line were observed, i.e. that $g(0) = 1$. This was clearly not the case but without a double-platform survey technique the true value of $g(0)$ cannot be determined. This survey was intended to be conducted from small vessels operating inshore, and the inability to conduct a double-platform methodology was one of the inherent constraints. The DISTANCE software allows the user to select a number of models in order to identify the most appropriate for the data. It also permits the truncation of outliers when estimating variance in group size and testing for evasive movement prior to detection.

The track-line was used as the sample with sightings as observations following Berrow *et al.* (2009). Estimates of abundance were calculated for each survey day, providing there were sufficient sightings to generate an estimate. The overall abundance estimate was derived from all track-lines in sea-state 2 or less from all days combined. This was necessary to obtain sufficient sightings (minimum required is 40–60, Buckland *et al.* 2001) for a robust estimate. For the model, we have assumed that there were no major changes in distribution within each site between sample days or any immigration or emigration into or out of the site over the survey period.

We fitted the data to a number of models. We found that a half-normal model with hermite polynomial series adjustments best fitted the data according to Akaike's information criterion. The recorded data were grouped into equal distance intervals of 0–20m, 20–40m and up to 180–200m for surveys where sea-state >1 and 0–30, 30–60 and up to 300m for surveys when sea-state <1. The detection functions were calculated from all survey data combined, as the number of sightings recorded each day were too few to generate robust density estimates. This would be compounded further if data were stratified by sea-state, vessel, etc., thus the detection function was determined from a pooled dataset in each site. Cluster size was analysed using size-bias regression method with $\log(n)$ of cluster size against estimated $g(x)$. The variance was estimated empirically.

A Chi-squared test is associated with each detection function. If significant then this indicated that the detection function was a good fit and the estimate is robust. Some fits were not significant and thus the results from these detection functions should be treated with extreme caution. We present them to show the effect of small samples sizes (number of survey days, sightings) on the model and thus the limitations of the methodology. The proportion of the variability accounted for by the encounter rate, detection probability and group size is presented with each detection function. Variability associated with the encounter rate reflects the number of sightings on each track-line, which will vary from zero to up to seven or eight. The detection probability reflects how far the sightings were from the track-line and group size the range of group sizes recorded at each site.

Maps were created using Irish Grid (TM65 Irish Grid) with ArcView 3.2 while maps of the survey areas were obtained from the National Parks and Wildlife Service

RESULTS

SURVEY TRAINING

The results from the distance trials show very accurate distance estimation up to 200m with a

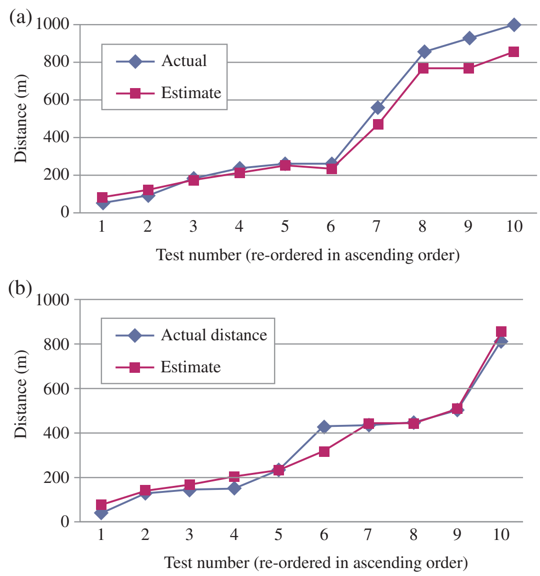

Fig. 2—Mean distance estimates during blind trials a) with no feedback and b) with feedback.

very small under-estimate at short distances (Fig. 2a). At greater distances accuracy was less, with a tendency to under-estimate the distance. In the second trial, observers were told the actual distance between each estimate, which enabled them to improve slightly on estimation of large distances following this feedback (Fig. 2b).

SITE SURVEYS

During 37 survey days, a total of 475 track-lines were surveyed for a total distance of 20,623km in sea-state ≤ 2. From the 332 sightings, a total of 618 individual harbour porpoise was recorded (Table 1). The proportion of the variability accounted for by the encounter rate ranged from 80% to 49% with between 15% and 34% attributed to detection probability and 29% to 22% due to group size. This shows that generally it is the number of sightings on each track-line that shows the greatest variability, which is to be expected as many track-lines will have no sightings, while others will have many. However significant variability at some sites was attributed to detection probability (e.g. Galway Bay) and group size (e.g. Carnsore Point). The detection functions from each site indicated some minor evasive movement with a peak in sightings generally between 20m and 60m from the track-line. A summary of results from each site is presented.

North County Dublin

The track-lines and sightings for the six surveys carried out in North County Dublin are shown in Fig. 3. The distribution of effort in sea-state 0 and 1 (black lines) is good, with effort in all areas of the study site. There was considerable variability in the number of sightings per survey day, ranging from

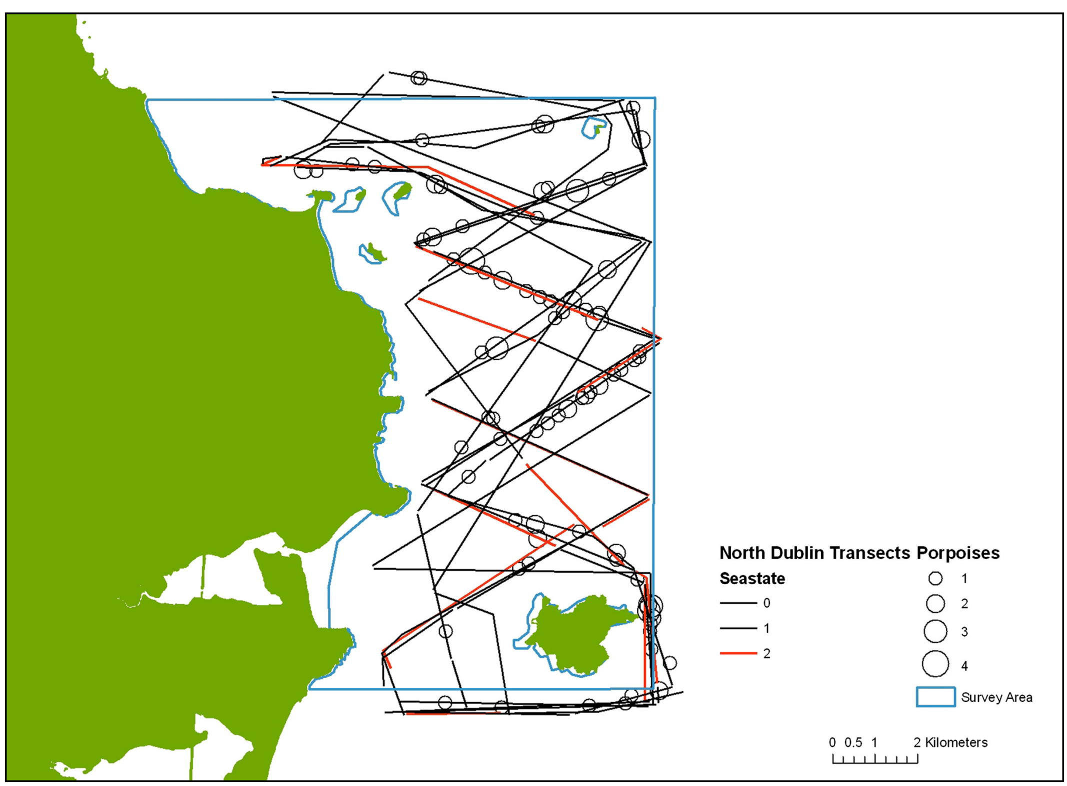

Fig. 3—Map showing location of all track lines surveyed and harbour porpoise observed in North County Dublin.

none to 48; even in excellent sea-state variability was large. On 12 July, despite sea-state 0 and 1 occurring for 94% of the survey only 8 sightings of a total of 9 individuals were recorded, however on 29 August a total of 48 sightings of a total of 67 individuals were recorded in sea-state 0 and 1 for 88% of survey effort. However, only two weeks later in sea-state 0 or 1 for 96% of survey effort only 15 sightings of 21 individuals were recorded. Density estimates for North County Dublin ranged from 0.54km^{-2} on 12 July to 6.93km^{-2} on 29 August. Mean group size was consistent at between 1.14 and 1.41 per sighting. The overall density estimate was 2.03km^{-2}, which gave an abundance estimate of 211 ± 47 (CI and CV values for all site estimates are given in Table 3).

Dublin Bay

Track-lines and the position of each sighting during five survey days in Dublin Bay are shown in Figure 4. Effort in the inner bay was restricted by water depth (< 5m). Effort in sea-state 0 and 1 was distributed throughout the site though there was more effort in sea-state 2 (red lines). There were concentrations of harbour porpoises to the north of the site but porpoises were distributed throughout. For the DISTANCE analysis, data from the first two days (13 and 28 July) were omitted as the sea-state was high and the number of sightings low (two and three on each day). Thus a total of 54 track-lines and 50 sightings were used in the analysis. Density estimates ranged from 0.48 to 2.05 km^{-2}. The mean group size was quite consistent ranging from 1.08 to 1.50. The overall density estimate was 1.19 km^{-2}, which gave an abundance of 138 ± 33.

Carnsore Point

Three surveys were carried out off Carnsore Point (Table 2). On 21 July, sea-state 2 or less was recorded during 77% of the survey, and we recorded seven sightings. On 22 August although sea-state 2 or less was recorded on 95% of the survey, nearly one-half was in sea-state 2 and only two sightings were recorded. On the last day (13 September) sea-state was mainly 2 but sea-state 3 accounted for 32% of the survey time; only four sightings were made. An important constraint at this site was the strong tides. With a mean survey duration of 5-6 hours there was always a period of strong tides during the survey causing high sea-states especially on the shallow sand banks to the northwest of the study site. Track-lines and sightings are shown in Figure 5. The distribution of effort in sea-state 0 and 1 (black lines) is concentrated to the southern half of the study site. Harbour porpoises were distributed throughout the study area with concentrations to the south-east. The detection function at this site was a poor fit

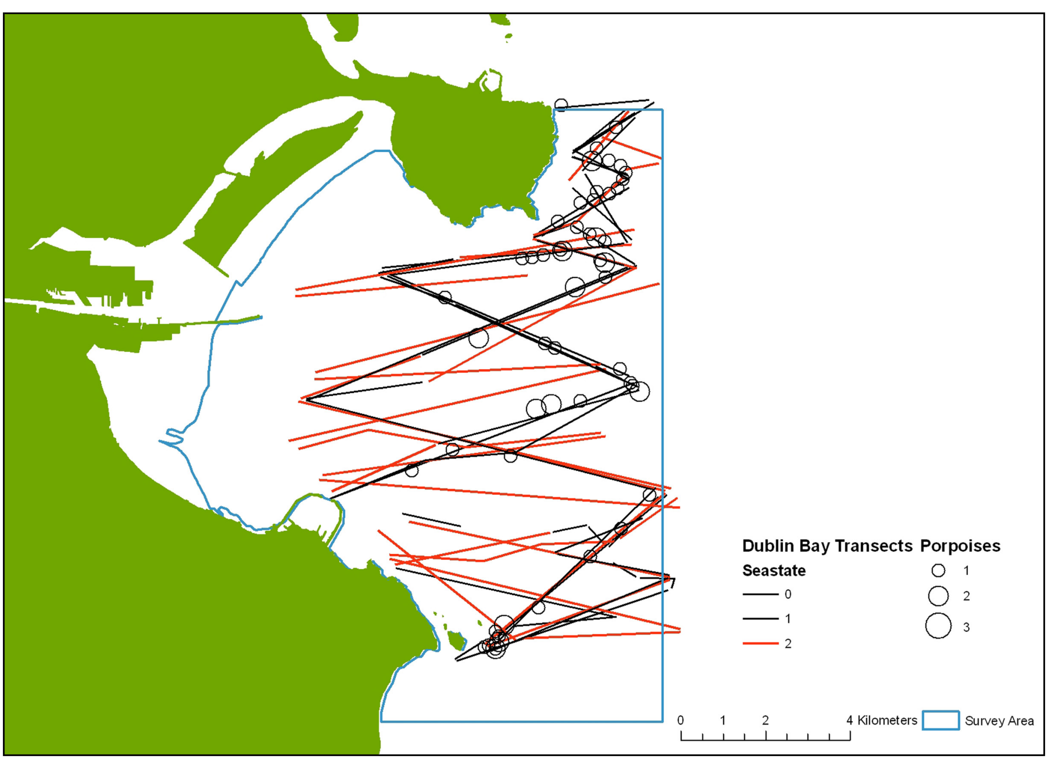

Fig. 4—Map showing location of all track lines surveyed and harbour porpoise observed in Dublin Bay.

Table 2—The goodness of fit of the detection function using DISTANCE analysis and the proportion of variability attributed to each main variable at each site surveyed.

Site	*Detection Function (X2)*	*Proportion of variability (%)*		
		Encounter Rate	*Detection Probability*	*Group Size*
North County Dublin	13.7, p = 0.09	80.3	15.3	4.4
Dublin Bay	22.4, p = 0.01	78.0	19.0	2.9
Carnsore Point	6.10, p = 0.64	49.3	28.3	22.4
Cork Coast	6.86, p = 0.55	55.0	26.8	18.2
Roaringwater Bay	6.43, p = 0.60	61.2	25.1	13.7
Blasket Islands	7.33, p = 0.50	68.0	23.7	8.4
Galway Bay	3.88, p = 0.09	50.2	34.3	15.3
Donegal Bay	5.92, p = 0.66	59.6	23.8	16.7

Table 3—Mean overall density and abundance of harbour porpoise at eight sites

Site	*N (95% CI)*	*SE*	*CV*	*Density (km^{-2})*	*Group size mean (95% CI)*
North County Dublin	211 (137–327)	47.1	0.22	2.03	1.41 (1.26–1.56)
Dublin Bay	138 (86–221)	33.2	0.24	1.19	1.22 (1.11–1.34)
Carnsore Point	87 (39–196)	36.3	0.42	0.58	1.91 (1.25–2.92)
Cork Coast	173 (92–326)	56.6	0.33	0.53	2.67 (1.96–3.64)
Roaringwater Bay	159 (95–689)	42.4	0.27	1.24	2.21 (1.85–2.64)
Blasket Islands	372 (216–647)	105.3	0.28	1.65	1.76 (1.50–2.07)
Galway Bay	402 (267–605)	84.1	0.21	0.73	2.15 (1.84–2.51)
Donegal Bay	249 (106–586)	111.5	0.45	0.88	2.40 (1.63–3.53)

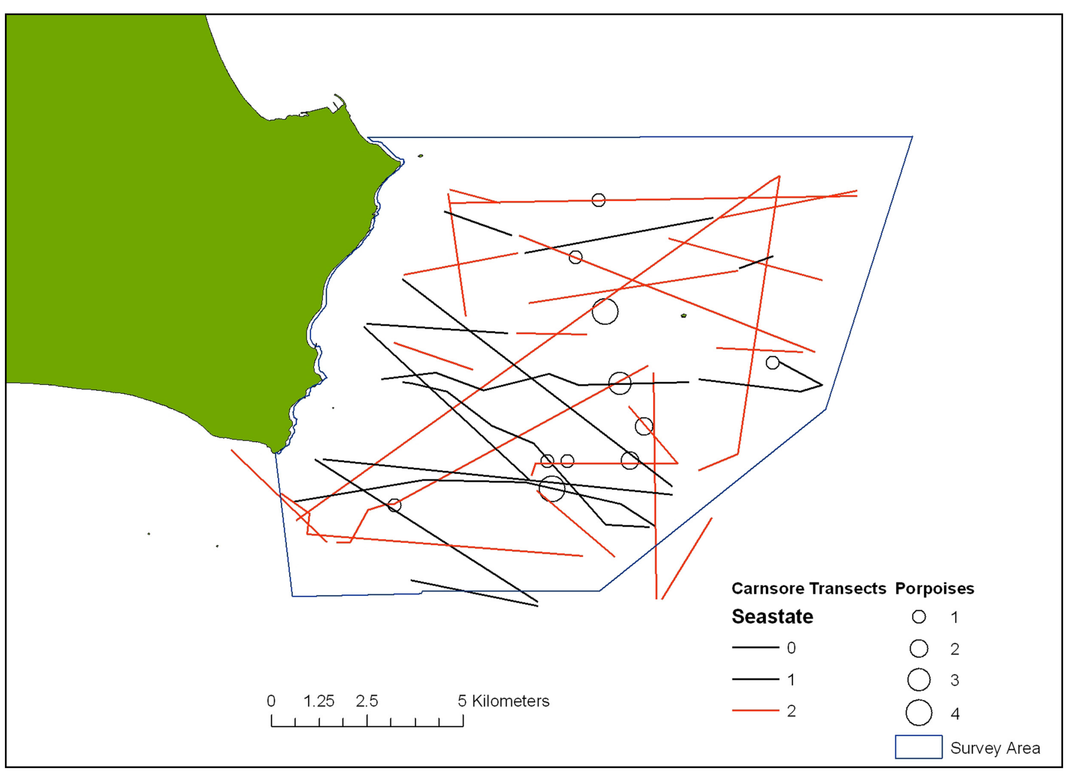

Fig. 5—Map showing location of all track lines surveyed and harbour porpoise observed off Carnsore Point.

(P = 0.64) reflecting the very low number of sightings. The proportion of the variability accounted for by the encounter rate was 49.3%, with 28.3% attributed to detection probability and 22.4% due to group size. These figures again reflect the small number of sightings and this density estimate should be treated with extreme caution. The overall density estimate for Carnsore Point was 0.58 harbour porpoises km^{-2}. Mean group size was ca. two animals. This resulted in an abundance estimate of 87 ± 36.3.

Cork Coast

Six survey days were carried out in the Cork coast site (Table 8). Track-lines and sightings for the Cork coast are shown in Figure 6. Sea-state ≤1 and sea-state 2 were distributed throughout the site but most sightings were off the Old Head of Kinsale and to a lesser extent Seven Heads and Galley Head (Figure 6). The detection function was considered a poor fit (P = 0.55) and thus the results should be treated with caution. The proportion of the variability accounted for by the encounter rate was 55.0%, with 26.8% attributed to detection probability and 18.2% due to group size. This is somewhat different to other sites where the variation due to encounter rate was higher with lower variation due to group size. However the dataset for this site is small and the low number of sightings (albeit of relatively large group sizes (up to eight individuals)) will have had a large negative influence on the significance of the detection function. The overall density estimate from the Cork coast was 0.53 harbour porpoise km^{-2}. This estimate is higher than might have been expected from the low sighting rate which is due to the high group size estimates, including two observations of eight harbour porpoises and one of six.

Roaringwater Bay cSAC

Six survey days were carried out in Roaringwater Bay cSAC with good sea conditions recorded on two days, which returned 13 and 23 sightings. Overall there were 47 sightings of a total of 110 individuals. Track-lines and sightings for Roaringwater Bay are shown in Figure 7. Track-lines surveyed in sea-state ≤2 were distributed throughout the site. Most sightings were around Gascanane Sound between Sherkin and Clear Islands and off the western tip of Cape Clear (Figure 7). The detection function was not considered a good fit (P = 0.60). There was some evidence of evasive behaviour by the porpoises, with a peak on the track-line but also at 20–40m and 60–100m from the track-line. The proportion of the variability accounted for by the encounter rate was 61.2%, with 25.1% attributed to detection probability and 13.7% due to group size. This was similar to the Cork coast and may be due to the high variability in the number of sightings per survey day. Mean

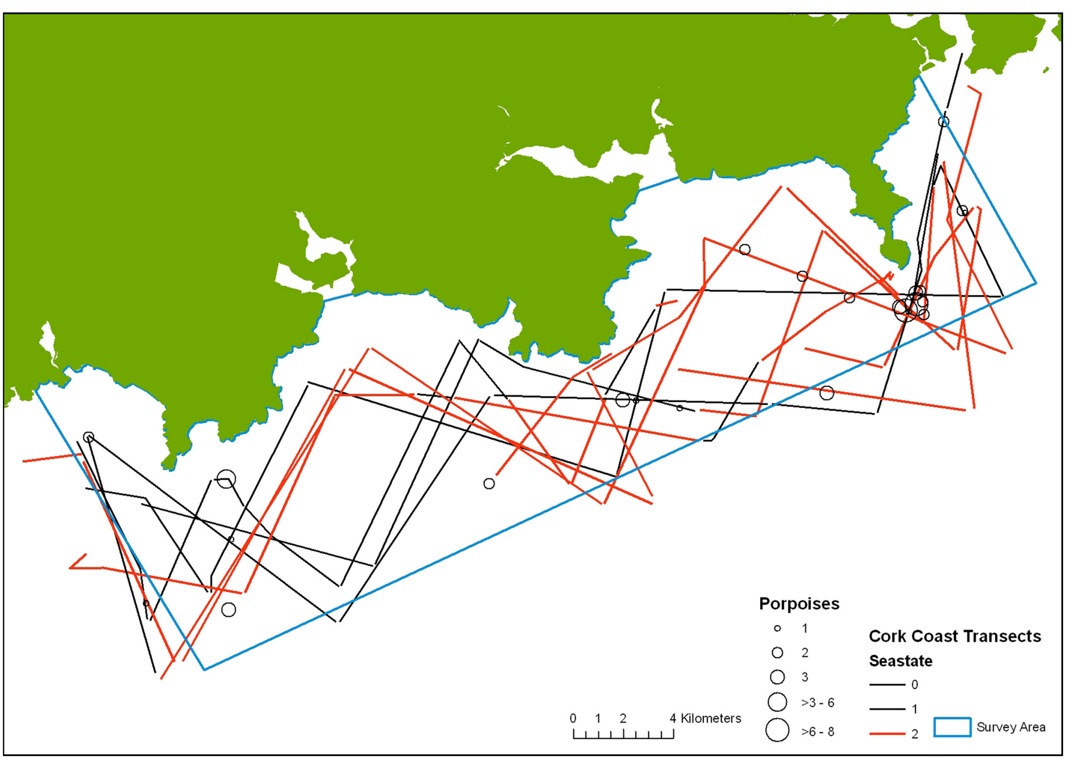

Fig. 6—Map showing location of all track lines surveyed and harbour porpoise observed in the Cork coast site.

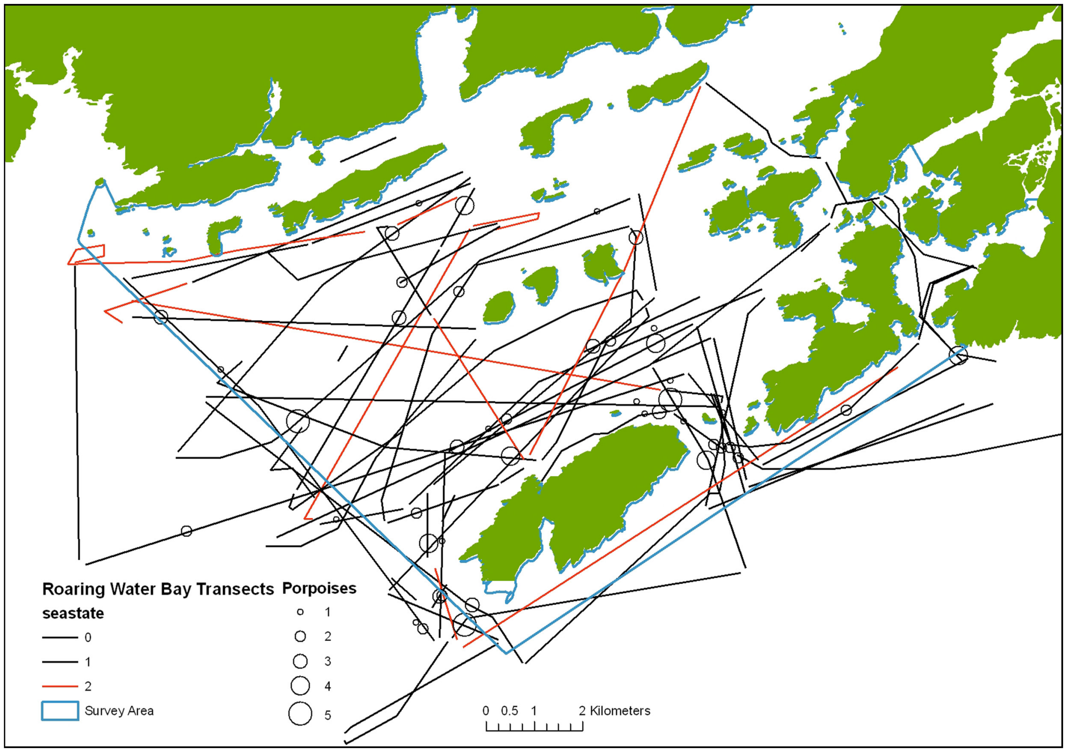

Fig. 7—Map showing location of all track lines surveyed and harbour porpoise observed in Roaringwater Bay cSAC.

group size was consistent at around two animals. The overall density estimate was 1.24 km^{-2} with a CV of 0.27. This gave an abundance estimate of 159 ± 42.

Blasket Islands cSAC

Three surveys were carried out within the Blasket Islands. The track-lines and position of each sighting are shown in Figure 8. Effort in sea-state 0 and 1 was distributed throughout the site though generally there was more effort in sea-state 2 (red lines). There were concentrations of harbour porpoises on the south side of Great Blasket and to a lesser extent in Blasket Sound (Figure 8). The number of sightings varied between five and 19 sightings and a total of seven and 37 individuals between the three survey days along the same track-lines. The distribution of sightings was consistent between survey days with most sightings to the south of Great Blasket, north of Inistooskert and in Blasket Sound (Fig. 8). A total of 54 track-lines and 31 sightings were used in the distance analysis. The detection function was not considered a good fit ($P = 0.50$) and thus estimates should be treated with caution. The mean group size also ranged greatly from 1.00 to 2.29. The overall density estimate was 1.65 km^{-2}, which gave an abundance of 372 ± 105.

Galway Bay

Six surveys were carried out in Galway Bay (Table 1). A total of 84 track-lines were surveyed covering 627km in sea-state ≤ 2 which resulted in 62 sightings of a total of 134 individuals. The track lines surveyed in Galway Bay are shown in Fig. 9. Effort in sea-state 0 and 1 and sea-state 2 is distributed throughout the survey area. Harbour porpoises were distributed throughout the survey area with concentrations off Black Head, Co. Clare, and towards the middle of the bay. The proportion of the variability accounted for by the encounter rate was 50.2%, with 34.3% attributed to detection probability and 15.3% due to group size. This is somewhat different to other sites where the variation due to encounter rate was higher due to smaller group sizes. This indicates there was more variability in the number of sightings recorded per track-line and a greater range in group size. This may reflect the larger area of this site. The overall density estimate was 0.73 km^{-2} giving an abundance $\pm$SE of 402 ± 84. Galway Bay is 547km^2 in area and even though the density estimate was low the overall abundance was high.

Donegal Bay

Three surveys were carried out in Donegal Bay (Table 1). The track-lines and sightings are shown in Fig. 10. Sea-state ≤ 1 was distributed throughout

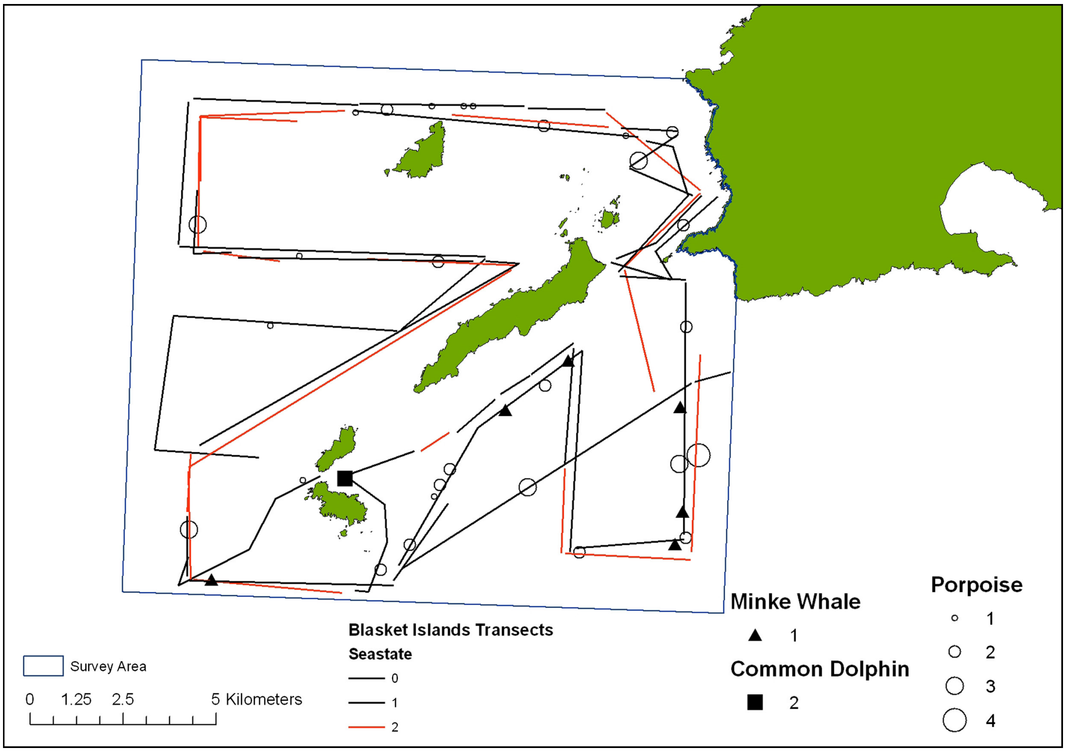

Fig. 8—Map showing location of all track lines surveyed and small cetaceans observed in the Blasket Islands cSAC.

the site but most harbour porpoise sightings were concentrated in the centre of the bay. The detection function was a poor fit (P = 0.66). The proportion of the variability accounted for by the encounter rate was 59.6%, with 23.8% attributed to detection probability and 16.7% due to group size. The

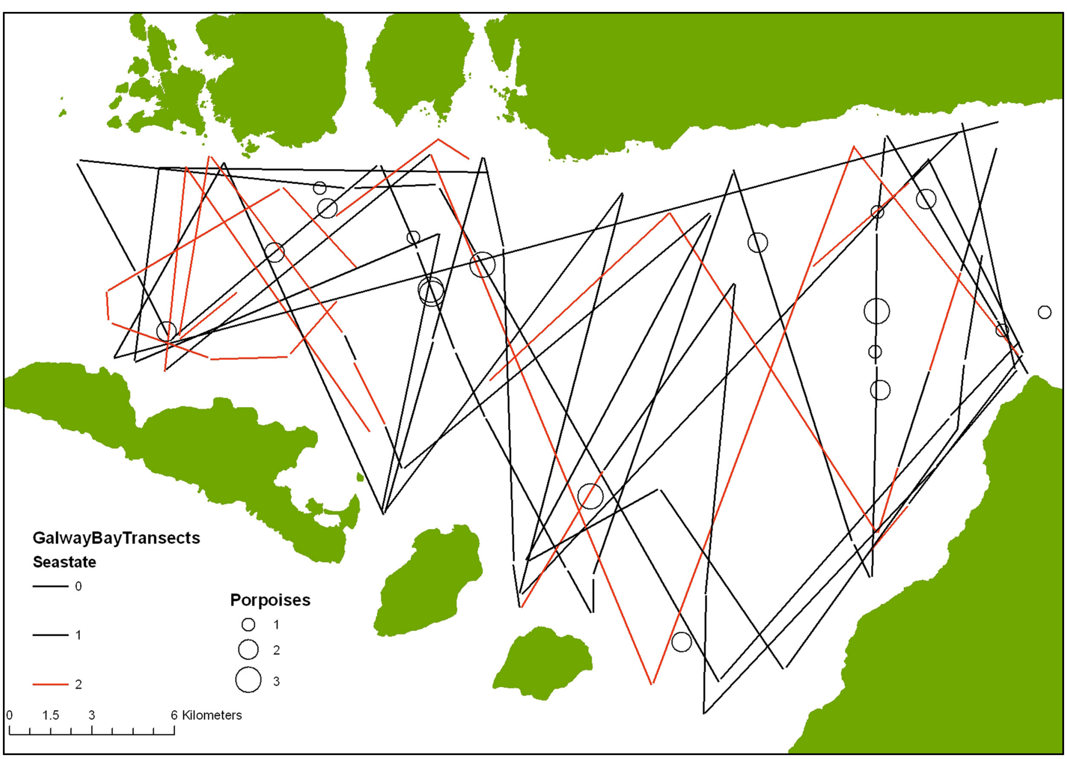

Fig. 9—Map showing location of all track lines surveyed and harbour porpoise observed in Galway Bay.

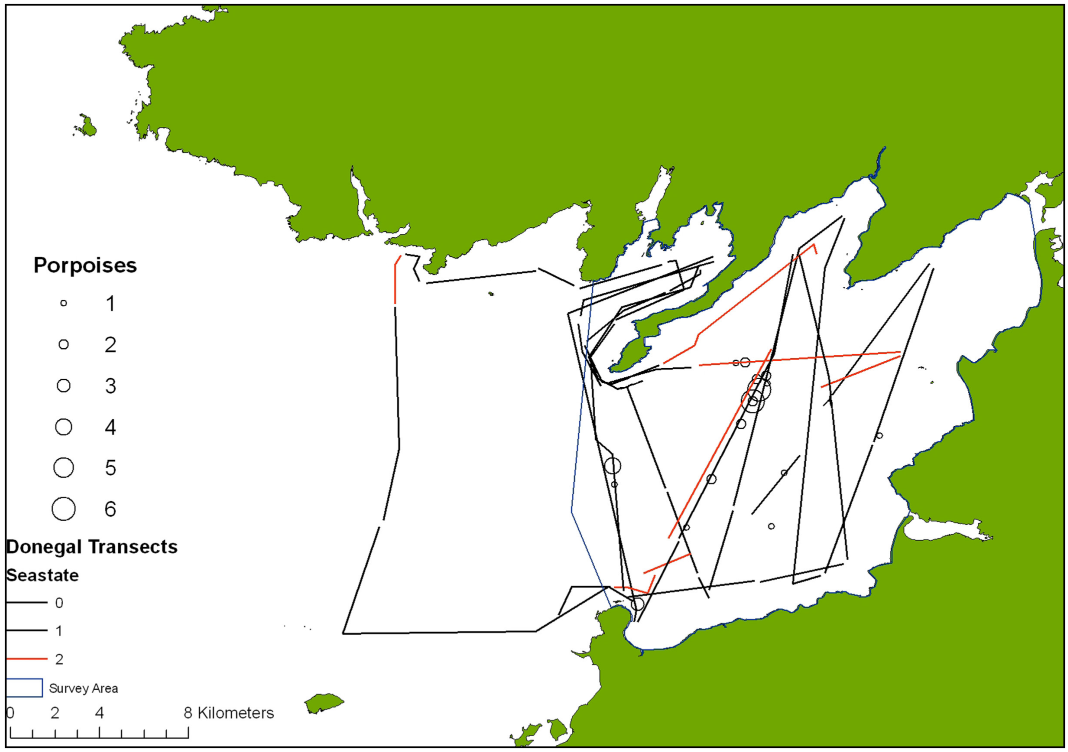

Fig. 10—Map showing location of all track lines surveyed and all small cetaceans observed in Donegal Bay.

variability attributed to the encounter rate was relatively low with a higher proportion attributed to group sizes, which reflects the large range in group size recorded. The overall estimate was 0.88 km^{-2} giving an abundance of 249 $\pm$ 111.5.

PROPORTION OF ADULT TO YOUNG

We calculated the proportion of adults to young (combining records of those animals described as juveniles or calves) for each site. No calves or juveniles were observed off the Cork coast. The proportions of juveniles and calves in sites, excluding Cork Coast which recorded no calves, were consistent with a percentage of 6–8% (Table 4).

DISCUSSION

Statistical inference using distance sampling rests on the validity of several assumptions (Buckland et al. 2001). These include that objects are spatially distributed according to some stochastic process. If transect lines were randomly placed within the study area one can safely assume that objects are uniformly distributed with respect to the perpendicular distance from the line in any given direction. Another assumption is that objects on the track-line are always detected (i.e. $g(0) = 1$) and are detected at their initial location prior to any movement in response to the observer. If objects on or near to the track-line are missed then the density estimate will be biased low. To minimise the effect of movement

Table 4—Proportion of adult to young for all sites surveyed in 2008.

Site	*No. of sightings*	*No. of animals*	*No. of Adults*	*No. of Juveniles*	*No. of calves*	*Proportion of young (%)*
North County Dublin	82	111	102	1	8	8
Dublin Bay	56	69	65	1	3	6
Carnsore Point	12	22	19	3	0	14
Cork Coast	28	72	72	0	0	0
Roaringwater Bay	47	110	102	8	0	7
Galway Bay	62	134	124	2	8	7
Blasket Islands	30	55	45	0	10	18
Donegal Bay	18	40	37	0	3	8

it is recommended that the speed of the observer is at least twice the speed of the object (Buckland et al. 2001).

Typically for surveys of harbour porpoise $g(0) = 0.4$ or 0.5, i.e. only one-half of the animals on the track-line are detected (Buckland et al. 2001). If this was the case with the present survey, then we should double the density estimates. Without a double-platform methodology it is not possible to accurately determine the numbers missed on the track-line. This methodology would require an increase in the number of surveyors and a larger vessel, which may restrict how close to shore the vessel could survey as well as considerably increasing costs. This is a major constraint of single-platform methods and this can only be used for between site comparison if the same method and analysis is used between surveys and sites. This may realistically only provide a relative rather than absolute abundance estimate. The detection functions for most sites suggested there was some evasive movement from the boat. The model can be but the effect of this evasive behaviour was not consistent between days and sites so no account was taken of this reaction to boats for consistency. This factor will also cause the density estimates to be under-estimated. We have attempted to keep the survey methodology and treatment of the data consistent at all sites, throughout the present survey. Survey methodology and data analysis were also consistent with that used by Berrow et al. (2009), which facilitates comparison of the data between, and within, surveys. It is interesting to note that the results of the survey of the Blasket Islands cSAC in 2007 and 2008 were quite similar giving some confidence in the methodology. Only additional surveys will see if this similarity in estimates is consistent.

The ability to detect harbour porpoise visually at sea and thus the accuracy of density and abundance estimates is extremely dependent on sea-state. During the present study, transects were carried out, whenever possible, in sea-state 2 or less as the ability to detect harbour porpoise decreases significantly in sea-state ≥ 3 (Teilmann 2003). Berrow et al. (2009) recommended that all harbour porpoise surveys should be carried out in sea-state 0 or 1 to ensure all animals are detected and $g(0) = 1$. This is rarely possible and given the poor weather throughout the summer in 2008 we were fortunate to be able to carry out as many surveys as we did in relatively good sea-state (sea-state ≤ 2). The data could be stratified by sea-state within each site if necessary if subsequent surveys record any significant changes in densities but the number of sightings available for the model will decrease.

SURVEY TRAINING

The use of a team of surveyors contributed to the successful completion of the survey as this enabled full advantage to be taken of favourable weather conditions. Having a large pool of observers meant that a team could be put together at short notice and more than one site could be surveyed on the same day. However, having such a large number of observers, with different experience and abilities, could lead to large variability in the accuracy of parameters recorded such as distance to sightings and in estimations of group size. O'Brien (2009) explored these variables in more detail and showed that experienced observers were good at recording sightings and estimating distance consistently. Variability in estimation of group size could potentially be significant during surveys of small cetaceans (O'Brien 2009), but harbour porpoise in the present survey generally only occurred in small groups so the effect should be limited. We have shown that if using a large team of experienced observers, heterogenity in the data caused by different observers could be minimised especially if training and observer trials are carried out at the start of the survey.

COMPARISON OF HARBOUR PORPOISE DENSITY ESTIMATES

There are a number of variables in the data collected during a survey which may contribute to large standard errors and wide confidence intervals that should be considered when presenting results and interpreting the data. The mean group sizes of harbour porpoise varied considerably between sites with larger groups recorded on the south and west coasts compared to the east coast. The number of sightings, and thus density estimates, during each visit to the same site can vary considerably over relatively short time periods. For example, 48 sightings of a total of 67 harbour porpoises were recorded on 29 August in North County Dublin followed by only 15 sightings and 21 individuals 14 days later on the 12 September, despite sea-state ≤ 1 for 88% and 96% of the survey effort. The high number of sightings recorded on 29 August in North County Dublin suggests immigration into the site may have occurred. This violates one of the assumptions made for this survey methodology, namely that there were no changes in distribution within each site during the survey period. North County Dublin and Roaringwater Bay cSAC sites are small in area, which makes them sensitive to even small local movements of harbour porpoises in the adjacent area and this should be considered when determining the size of a site to be monitored. Strong short-term or seasonal patterns in abundance of harbour porpoise have been shown elsewhere (e.g. Marubini et al.

2009;; Gilles et al. 2011) which suggests that by moving the date of a survey by only a few weeks can produce large differences in density estimates. Ideally survey day should be randomised but as suitable weather conditions dictate when a survey can be carried out this is not possible. However if effort is consistent with a defined period, such as six survey days within the same three month period, then this variable may not be too influential.

The coefficients of variation (CV) at five of the eight sites surveyed were between 0.22 and 0.28. However, Englund et al. (2007) recommended that the CV of abundance estimates, if used for monitoring the population status of bottlenose dolphins in the Shannon Estuary, should be as low as 0.12 if changes in abundance were to be detected within reasonable time-frames. To achieve lower CVs for harbour porpoise density estimates more surveys will be required at each site to increase the number of sightings. The data on detection rates from the present survey could be used in a power analysis to predict the number of surveys required to reduce these CVs. This could inform managers on the effort and cost required to monitor harbour porpoise densities. Large inter-annual fluctuations in the densities of harbour porpoises within a site may occur and data should be collected over a number of years before sites are assessed for site designation. For example, porpoise densities in the Cork Coast site were lower than might have been expected. This site was chosen as concentrations of harbour porpoise sightings have been reported off the Old Head of Kinsale and Galley Head (Berrow et al. 2010). This suggests 2008 was a poor year for harbour porpoise at this site and the results from the present survey may not reflect the importance of this site for this species. The presence of other cetacean species within a site may influence the distribution and densities of harbour porpoise. Bottlenose dolphins are regularly recorded in Donegal Bay (Ingram et al. 2003; Berrow et al. 2008) and the density of harbour porpoises in the bay might vary depending on their presence as this species is known to attack and kill harbour porpoises (Ross and Wilson 1996). However as the dolphins in Donegal Bay are known to be transient (O'Brien et al. 2009), harbour porpoise densities may increase when dolphins are absent. Habituation to ships may also be a factor with porpoises less likely to show evasive behaviour in areas exposed to heavy boat traffic. This would negatively bias estimates at sites with les traffic as porpoises may react more to the survey vessel.

All these variables should be taken into account if short-duration surveys are to be conducted in a single season and year. Results from a similar survey of the Blasket Islands cSAC in 2007 were used to compare density estimates from 2008. It was encouraging that the estimate in 2008 (1.65) was similar to 2007 (1.33) with similar CVs (0.28 compared to 0.25). As this site was already designated for harbour porpoise it was considered to provide good habitats for harbour porpoise and thus the density recorded there (1.33) may represent an upper range for coastal sites in Ireland. During the present survey only North County Dublin (2.03) had a higher overall density than the Blasket Islands cSAC. Density estimates in Roaringwater Bay cSAC (1.24), which is also designated for harbour porpoises, was very similar to that recorded in the Blasket Islands cSAC during 2008. Dublin Bay, which is around 20km south of the North County Dublin site at 1.19 harbour porpoises per km^2 was only slightly lower again. Densities at the other four sites were less than 1.0 harbour porpoises per km^2 with densities at some sites (Carnsore Point and the Cork Coast) were around 0.50–0.60, nearly one-third of the densities recorded in the two cSACs and may reflect relatively poor habitat for this species.

Comparing the results from the present survey to harbour porpoises surveys elsewhere is difficult as different methods were used (single v double-platform, dedicated v opportunistic surveys) and over very different spatial scales. Most density estimates reported in the present study were higher than that recorded during SCANS-II (2008), where the highest reported density was 0.81 harbour porpoises km^{-2} off the east Danish coast (Table 5). This is to be expected as the survey areas in SCANS II were very large and included offshore waters. If densities of harbour porpoises are greater closer to the coast (say within 12 nmls) then this will result in higher overall estimates in the small coastal sites surveyed during the present study. Thus it is not reasonable to compare the present study with results from SCANS-II: line transect surveys, which cover the whole range of a species, are less likely to be strongly influenced by this than small-scale surveys.

PROPORTION OF ADULTS TO YOUNG

The proportion of adults to young at the four sites reported with young, was remarkably consistent, at between 6% and 8%. Given the large differences in the number of sightings and numbers of individual porpoises recorded between sites, it was surprising that the proportion of calves was so consistent. This proportion was consistent for both small (North County Dublin, $104km^2$ = 8%) and relatively large sites (Galway Bay, $547km^2$ = 7%). Sonntag *et al.* (1999) summarised data on the proportion of calves from 13 aerial surveys and 10 ship-based surveys throughout the North Sea and Kattegat area, including data from SCANS (Hammond *et al.* 2002). The proportion of calves ranged from 5.1% (Inner Danish waters) to 17.9% (Isle of Sylt) from aerial surveys and 2.2%–6.7% from ship-based

Table 5—Density estimates of harbour porpoise during dedicated sighting surveys in Ireland and elsewhere in the EU.

Location	*Year*	*Area* (km^2)	*Density* (km^{-2})	*Abundance* ± *SE* (*95% Confidence Intervals*)	*CV*	*Reference*
North County Dublin	2008	104	2.03	211 ± 47.1 (137–327)	0.23	This study
Dublin Bay	2008	116	1.19	138 ± 33.2 (86–221)	0.24	This study
Carnsore Point	2008	151	0.58	87 ± 36.3 (39–196)	0.42	This study
Cork Coast	2008	326	0.53	173 ± 56.6 (92–326)	0.33	This study
Roaringwater Bay	2008	128	1.24	159 ± 42 (95–689)	0.27	This study
Blasket Islands	2008	227	1.65	372 ± 105.3 (216–647)	0.28	This study
Galway Bay	2008	547	0.73	402 ± 84.1 (267–605)	0.21	This study
Donegal Bay	2008	281	0.88	249 ± 111.5 (106–586)	0.45	This study
Blasket Islands	2007	227	1.33	303 ± 76 (186–494)	0.25	Berrow *et al.* (2009)
Northern North Sea	1994	118,985	0.78	–	0.25	Hammond *et al.* (2002)
Orkney and Shetland	1994	31,059	0.78	–	0.34	Hammond *et al.* (2002)
East Danish Coast	1994	7,278	0.81	–	0.27	Hammond *et al.* (2002)
South Central North Sea	2005	156,972	0.56	–	0.23	SCANS-II (2008)
Coastal NW Denmark	2005	20,844	0.56	–	0.43	SCANS-II (2008)

surveys. Irish Sea records were 5.1% calves and only 3.3% in British coastal waters. The 6%–8% presented in this survey (Table 4) is likely to be higher than the data from the SCANS surveys as the sites are all small and coastal compared to much larger areas surveyed during the SCANS surveys. Sonntag *et al.* (1999) suggested the high proportion of calves of the Isle of Sylt in Germany (9.6%–17.9%) indicated that it was a preferred calving ground for harbour porpoise in the southern North Sea. Our data do not suggest such elevated levels but proportions are probably typical of Irish coastal waters (Table 5).

USEFULNESS OF METHODOLOGY FOR MONITORING HARBOUR PORPOPOISES

Estimating densities and abundance of harbour porpoises in Irish coastal waters presents many difficulties. These are mainly associated with difficulties in observing this species in high sea-states and swell. We have attempted to use conventional single platform line-transect sighting surveys to record densities of harbour porpoises for identifying important habitats and monitoring abundance. Small vessels can be chartered at short notice to take advantage of suitable weather. We also designed the survey methodology to obtain full coverage of the site in one day again to take full advantage of suitable weather windows. We have demonstrated that this method can be used to estimate densities providing suitable vessels, observer training and appropriate weather windows are fully considered. A number of surveys of the entire area over a number of days are preferable to incomplete surveys of the study site during a single day.

Sources of variability are many and are difficult to stratify for unless there are a large number of sightings. Given that each survey was carried out on a single day it is unlikely that the number of sightings per survey will be large enough to satisfy the requirements of the model (40–60 sightings) for robust estimates. The low number of sightings may result in a poor fit of the model to the data. It may be best to ignore these results or ideally use them to carry out a power analysis to determine how many track-lines or days are required to provide enough sightings for a good fit and a low CV of the density estimates. However, providing surveyors only use data collected in sea-state ≤ 2, use experienced observers and make the same assumptions when analysing or modelling the data then similar surveys may be used to quantify porpoise densities and make comparison between sites, providing a similar methodology is adopted. Changes in prey type (benthic or pelagic fish species), their distribution and abundance may occur and thus the use of habitats by porpoises may change considerably. This can cause significant changes between seasons. We have attempted to survey sites in a three month period in the summer but a greater time series of data will be required to explore the scale of this variability between seasons and years within sites.

The density estimates presented here could be used as a reference with which to compare results of similar surveys elsewhere, in order to assess the importance of these sites for harbour porpoise. In addition to these baselines, more surveys during the same period are required to determine if estimates are consistent or show large inter-annual variability. This includes identification of sites with elevated densities for designation as protected areas. This methodology could also be used in impact studies in Irish coastal waters, such as those associated with offshore wind and wave-farms and other major developments, where an assessment of the importance of the site for harbour porpoises and other species of small cetacean are required. In time, with more surveys this method may be suitable, especially when combined with acoustic monitoring techniques, to monitor population dynamics and status.

ACKNOWLEDGEMENTS

We would like to thank all those surveyors who made this survey possible: John Brophy, Eileen Diskin, Bojana Ferjan, Brian Glanville, Sophie Hansen, Eugene McKeown, Dana Miller, Fiacc O'Brolchain, Joanne O'Brien, Mick O'Connell, Tracey O'Shea, Debbie Pedreschi, Conor Ryan, Dave Wall, Faith Wilson, Peter Wilson and Pádraig Whooley. We would like to thank all the boat operators: Colin Barnes, Joe Brady, Jeff Brownlee, William van Dyke, Declan Kilgannon, Séan McDonogh, Ruairi O'Brien, Edmund O'Byrne, Micháel O'Chonneile and Fachtna O'Driscoll, Mick Sheeran, and Richard Timony, who have been extremely tolerant of late changes to plans and some early starts. This survey was funded by the Department of Environment, Heritage and Local Governments' National Parks and Wildlife Service, and we thank Dr David Lyons for his support during this project.

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