ABUNDANCE ESTIMATE AND ACOUSTIC MONITORING OF HARBOUR PORPOISES (*PHOCOENA PHOCOENA* (L.)) IN THE BLASKET ISLANDS' CANDIDATE SPECIAL AREA OF CONSERVATION

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ABSTRACT

Visual surveys and acoustic monitoring of harbour porpoises were conducted between July and October 2007 within the Blasket Islands' candidate Special Area of Conservation (cSAC) to derive density estimates and acoustic-detection rates. A total of 44 sightings of 102 individual harbour porpoises were recorded on 74 tracks with a total distance of 389km. Density estimates ± SE, determined using DISTANCE software, ranged from 0.71 to 3.39 porpoises per km^2, giving abundance estimates ranging from 162 ± 120 to 768 ± 198, depending on the number of sightings per day. The most robust estimate of 303 ± 76 (coefficient of variation = 0.25; 95% confidence interval 186–494) was calculated using the combined data from each track line. There were indications of a seasonal increase in abundance from July through to September. Passive acoustic monitoring was carried out through the deployment of self-contained click detectors called T-PODs. One month's acoustic data were acquired from two sites, and data were extracted as Detection Positive Minutes per day and per hour for analysis. Detections were logged for every day of deployment at both sites. This survey provides the first information on the spatial distribution of harbour porpoises in the Blasket Islands' cSAC, as well as baseline data from which to monitor abundance and distribution.

INTRODUCTION

The Blasket Islands are comprised of a group of six main islands situated at the end of Dingle Peninsula in Co. Kerry. They are well known for their rich literary and archaeological heritage (Sayers 1974; O'Crohan 1978). The islands support one of the most important seabird colonies in Ireland, with at least eleven species of seabird breeding there regularly (Brazier and Merne 1989; Smiddy *et al.* 2000). They also provide one of the most important breeding sites for grey seals (*Halichoerus grypus* (Fabricius 1791)) in Ireland, with pup production in 2005 estimated at 185, giving a minimum population size of 648–833 (Ó Cadhla *et al.* 2008).

Published information on cetaceans around the Blasket Islands is limited. The presence of small cetaceans was known to the islanders who lived on Great Blasket, as O'Crohan (1978) described driving 'sea-hogs' ashore in 1890, where they were killed, and eaten during the winter. These could refer to harbour porpoises (*Phocoena phocoena* (Linnaeus 1758))—also known as *muc mhara* (sea pigs)—or small dolphins. Berrow (1993) carried out timed watches from 26 headlands around the Irish coast and recorded the highest sighting rate from Slea Head overlooking the Blasket Islands, where harbour porpoises and minke whales (*Balaenoptera acutorostrata* Lacépède 1804) were observed. Smiddy *et al.* (2000) reported a single sighting of two harbour porpoises in Blasket Sound in 1989 and a sighting of a single bottlenose dolphin (*Tursiops truncatus* (Montagu 1821)) in 2001. Five cetacean species were reported off Slea Head by Berrow *et al.* (2002). These species included harbour porpoises, bottlenose dolphins, common dolphins (*Delphinus delphis* Linnaeus 1758), Risso's dolphins (*Grampus griseus* (Cuvier 1812)) and minke whales.

The harbour porpoise is probably 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 the species is thought to be most abundant off the south-west coast (Reid *et al.* 2003). The harbour porpoise is also consistently the most frequently recorded species stranded on the Irish

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coast (Berrow and Rogan 1997). However, the life history of harbour porpoises in Irish waters is poorly understood. Rogan and Berrow (1996) reported that 95% of prey items recovered from the stomachs of stranded and bycaught harbour porpoises were either gadoids or clupeoids, with *Trisopterus* spp. and whiting (*Merlangius merlangus* (Linnaeus 1758)) contributing most of the prey items. Abundance estimates for harbour porpoises were determined for the Celtic Sea in 1994 (Hammond *et al.* 2002) and for all Irish waters, to the shelf edge, and the Irish Sea in 2005 (SCANS-II 2008).

EU member states are required to designate Special Areas of Conservation (SAC) for species listed under Annex II of the EU Habitats Directive (Council of the European Union 1992), which includes harbour porpoises and bottlenose dolphins. The Blasket Islands were designated as a candidate SAC (cSAC) in 2000 for the protection of a number of marine and terrestrial habitats, as well for the protection of the grey seal and harbour porpoise. Roaringwater Bay's cSAC in Co. Cork is also designated for the harbour porpoise, and the lower River Shannon is the only cSAC in Ireland designated for the bottlenose dolphin.

The objectives of the present survey were to calculate the density of harbour porpoises within the Blasket Islands' cSAC, in order to derive an abundance estimate, and to carry out passive acoustic monitoring of harbour porpoises.

MATERIAL AND METHODS

SIGHTING SURVEY

The Blasket Islands' cSAC covers an area of 227km^2. Conventional single-platform, line-transect surveys were carried out within the boundaries of the Blasket Islands' cSAC along predetermined routes (Fig. 1). Transect lines were chosen to cross depth gradients and to provide as close to equal coverage probability as possible, following the recommendations of Dawson *et al.* (2008), who suggested that systematic line spacing resulted in better precision than randomised line spacing. The lines were changed for each survey to ensure that there was full coverage of the cSAC over the study period and that no important porpoise concentrations were overlooked. Distance sampling was used to derive g(0)—a density estimate—and to calculate abundance estimates.

Fig. 1—Map of Ireland showing the location of the Blasket Islands' cSAC.

The 13m-long MV Blasket Princess was chartered for this survey. The boat travelled at a speed of 12km hr^{-1} (7kt), which was two to three times the typical average speed of the animal surveyed, as recommended by Dawson *et al.* (2008); travelling too fast will result in fewer sightings as there will be less time for the animals to surface within viewing range. Two observers were positioned on the flying bridge, which provided an eye height above sea level of 3.5m. They watched with the naked eye from dead ahead to 90° to port or starboard depending on which side of the vessel they were stationed. Observers were alternated between port and starboard between surveys. All sightings were recorded, but sightings involving distances of over 200m from the track line were not used in the distance model as these extreme values give little information and make it difficult to fit the detection function and to estimate g(0). Calves were defined as porpoises that had lengths less than or equal to half the length of the accompanying animal (adult) and that were travelling in very close proximity to this same animal.

During each transect the position of the survey vessel was tracked continuously through a Global Positioning System receiver that was fed directly into a laptop, while survey effort, including environmental conditions (sea-state, wind strength and direction, glare, etc.), was recorded directly onto Logger software (©IFAW) every 15min. When a sighting was made, the position of the vessel was recorded immediately, along with the angle of the sighting from the track of the vessel and the angular distance of the sighting from the vessel. These data were communicated to the recorder in the wheelhouse via a VHF radio. The angle was recorded to the nearest degree via angle boards that were attached to the vessel, immediately in front of each observer. Accurate distance estimation is essential for distance sampling, so tests aimed at assisting distance estimation were carried out prior to the start of each survey. These tests involved the

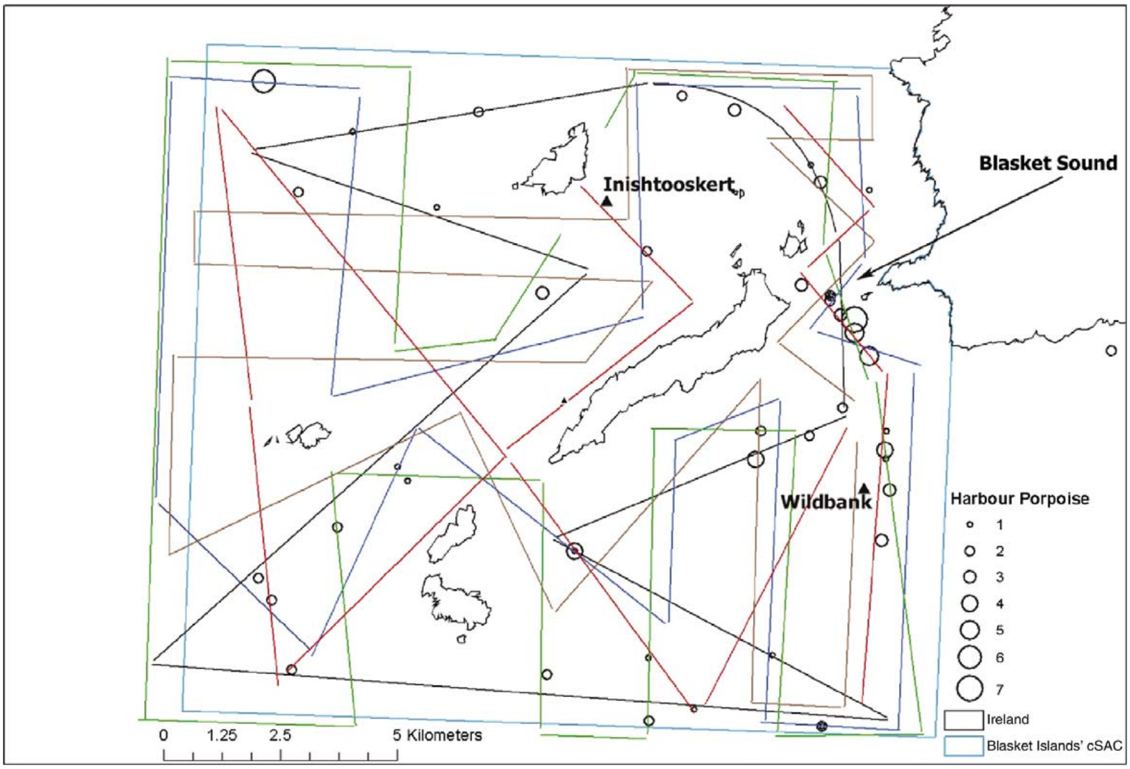

Fig. 2—Map showing the locations of all track lines surveyed and harbour porpoises observed. Each coloured line is a different survey day. Locations of T-POD deployments are shown as ▲.

estimation of distances that could be verified using a Leica Rangemaster 1200, which reports an accuracy to within ± 2m over 800m, or ± 0.5% over 600m. 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 distances could be estimated.

During this survey we assumed g(0) was equal to one, i.e. that all the harbour porpoises on the track line were observed. To address this assumption we carried out a double-platform survey on 27 August 2007. Two trackers, one on each side of the flying bridge (secondary platform), scanned ahead of the vessel and up to 30° on either side using 10 × 50 binoculars. Once one of these experienced cetacean surveyors observed harbour porpoises, the surveyors tracked them either until they were observed from the primary platform, as determined by hearing a confirmation of a sighting being called out to the recorder through the VHF, or until they passed beyond 90° to the track of the vessel.

ABUNDANCE ESTIMATE

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 lines in any given direction. In a relatively small survey area such as the Blasket Islands' cSAC there is a compromise between surveying enough track lines to obtain sufficient sightings to derive an abundance estimate and obtaining equal spatial coverage. Another assumption is that objects on the track line are always detected ($g(0) = 1$), and detected at their initial location prior to any movement in response to the observer. Finally, there is the assumption that if objects on or near the track line are missed, the density estimate will be biased downwards. To minimise the effect of movement it is recommended that the speed of the observer is at least twice the speed of the object; if this is the case, then movement of the object causes few problems in line-transect sampling (Buckland *et al.* 2001). Swimming speeds of harbour porpoises range from 0.5 to 4.2m s^{-1} (Otani *et al.* 2001), so a survey speed of 7kt, or 3.5m s^{-1}, is around twice their average speed.

The software programme DISTANCE (Version 5; University of St Andrews, Scotland) was used for calculating the density of harbour porpoises and for deriving abundance estimates. This software allows the user to select a number of models in order to identify the most appropriate one for the data. It also allows truncation of outliers when estimating variance in group size and testing for evasive movement prior to detection. There were two broad approaches to data analysis. Both 'survey day' and 'track line' were used as the sample, with 'sightings' as the observation. The advantage of using 'track line' was an increase in sample size, which should reduce the variance. However, one possible disadvantage is the high number of zero observations within each sample (i.e. no porpoise sighted on a track line). 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 intervals of 0–20 up to 180–200m, with data truncated over 200m. Cluster size was analysed using a size-bias regression method, with log(n) of cluster size plotted against estimated g(x). The variance was estimated empirically.

Maps were created using the Irish National Grid (TM65/Irish Grid) with ArcView 3.2; the map of the SAC was obtained from the National Parks and Wildlife Service (NPWS). Data used in the creation of the maps of transects, effort, abundance and density estimates were stored in a single Microsoft Access database, which was queried from within the geographic information system to produce maps.

ACOUSTIC MONITORING

Acoustic monitoring was carried out through the deployment of two Version 5 T-PODs in the study area. These T-POD units, manufactured by Chelonia Ltd, Cornwall, UK, consist of a self-contained computer and hydrophone, which can log the times and durations of clicks that resemble the echolocation clicks produced by porpoises. T-PODs were set to log only harbour porpoise clicks, using generic harbour porpoise settings. The T-PODs detect clicks using two band-pass filters: one filter is called the target filter (A), while the other filter (B) is the reference filter. Thus, the target filter A was set to 130kHz (peak frequency of harbour porpoises), while the B filter was set to 92kHz (since at this frequency there is very little or no energy from the porpoise sonar signal). Harbour porpoises are known to produce narrowband, high-frequency clicks within 110–150kHz (Møhl and Andersen 1973). During the analysis the filter CETACEAN-ALL was used, as this enables the same settings to be used across all conditions and avoids having to manually inspect all doubtful click trains (Ingram *et al.* 2004). Data were analysed using T-POD.exe Version 8.21 (Chelonia Ltd 2007).

In order to allow comparison of acoustic data collected by different T-PODs, it was necessary to calibrate units to assess any variability in sensitivity. Trials were carried out in Galway Bay between 12 June and 10 July 2007. Two T-PODs (nos 642 and 658) were strapped together, and both T-PODs were set to detect only harbour porpoises. Potential for masking was minimised by the long deployment period and the high number of detections, with detections recorded on 100% of days from both T-PODs. Upon recovery, data were extracted as total Detection Positive Minutes (DPM) per day. The results showed that T-POD 658 detected 4,243 more clicks (56 more DPM) than T-POD 642. A correction factor (C) from Leeney (2007) was calculated using the following equation:

$$C = X^{658}/X^{642} = 15.3/13.3 = 1.15$$

where X is equal to the mean number of DPM per hour recorded by each unit during calibration trials.

The unit with the most DPM recorded during these trials was used as the reference against which the other unit was corrected. Thus, the mean DPM

Table 1—Date, sea-state and number of sightings of harbour porpoises within the Blasket Islands' cSAC during 2007.

Sample	*Date*	*No. of track lines*	*Total distance (km)*	*Sea-state (% of total survey time)*				*Number of sightings*	*Total animals*
				0	1	2	3		
1	16 July	8	65.947	0.0	81.4	12.2	6.4	10	20
2	24 July	17	83.045	0.0	55.7	35.3	9.0	5	12
3	11 August	19	92.380	0.0	69.2	24.8	6.0	4	8
4	27 August	18	83.180	7.1	57.0	24.0	11.9	9	26
5	11 September	12	64.675	53.0	44.4	1.0	1.6	16	36
6	1 October	8	67.429	0.0	15.8	66.7	17.5	0	0
Total		**82**	**456.656**					**44**	**102**

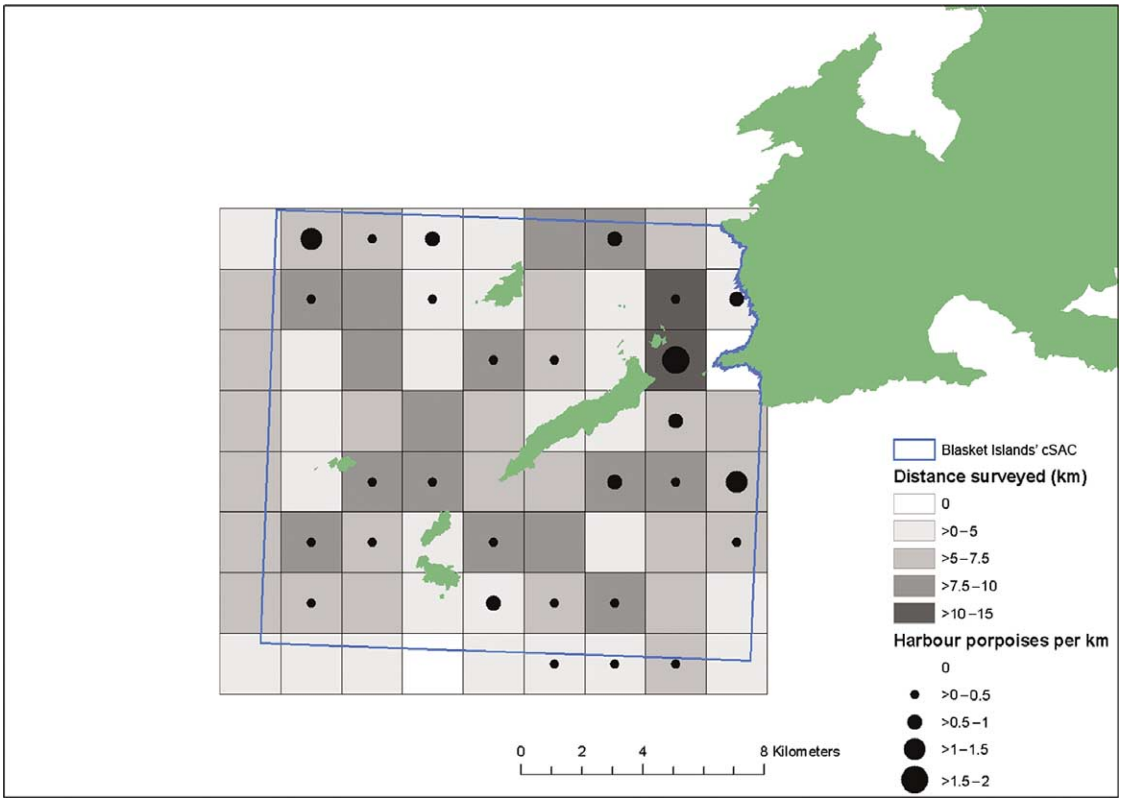

Fig. 3—Map of Blasket Islands' cSAC with effort and harbour porpoise sightings shown within a 2-km grid.

recorded by T-POD 642 during the acoustic survey was multiplied by 1.15 to enable comparison with T-POD 658. After the correction factor was applied to T-POD 642, a non-parametric Kruskal–Wallis test was carried out in order to test for significant differences between the corrected data. No significant difference was found in DPM per day ($P = 0.401$). A repetition of this trial was planned for the end of the study, to determine whether there were any changes in sensitivity over the duration of the study, but, due to loss of T-PODS during the survey, this task could not be carried out.

One T-POD was deployed at each of two locations (Inishtooskert and Wildbank, Fig. 2), with both units deployed at the same time. T-PODs were deployed on moorings at 30-m water depth. Each main mooring weighed 60kg and had a large yellow mooring buoy attached. Each T-POD was attached to a line running along the seabed, 40m from the main mooring at a depth of 5m off the bottom. Attached to the end of this line was a second mooring (20kg), which had a line rising to the surface that was attached to a smaller orange buoy. This enabled the smaller moorings and the T-PODs to be recovered without having to lift the main moorings, as the distance between the moorings was greater than the depth of the water. A small ecobuoy, with 2kg buoyancy, was attached to the hydrophone end of the T-PODs to ensure they remained vertical in the water and to facilitate recovery should the moorings be lost, as they leave a distinctive mark on an echo sounder. T-PODs were to be recovered and downloaded each month, but the gear was lost after one month.

RESULTS

SIGHTING SURVEYS

Harbour porpoise surveys were carried out on six days between July and October 2007 (Table 1). The whole cSAC was covered on each survey day to enable individual abundance estimates for each survey day to be calculated. No track line was surveyed more than once (apart from in restricted areas such as Blasket Sound), providing good coverage of the whole cSAC (Fig. 2). Transect surveys were carried out within the cSAC boundary, but on two occasions the route passed a maximum of 830m to the west of the western boundary (Fig. 2). A total of 456km of track line were surveyed, ranging in length from 66km on 16 July to 92km on 11 August. Forty-four sightings of harbour porpoises, consisting of 102 individual animals, were recorded (Table 1). Sea conditions varied during each survey (Table 1). Although sea-state was less than 3 for over 88% of the track lines

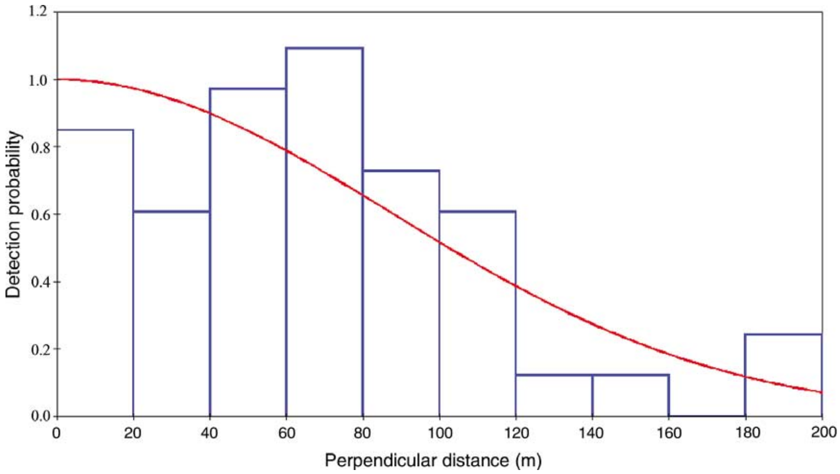

Fig. 4—Detection function for harbour porpoises in the Blasket Islands' cSAC ($\chi^2 = 3.39$, d.f. = 6, $p = 0.76$).

surveyed during five of the six days, only during the fifth transect on 11 September was a high proportion of survey effort carried out in sea-state 0. Sea-state 1 or less was recorded on 97.4% of track lines surveyed on 11 September, and on more than 55% of track lines surveyed on five of the six transect days. Sea-state was 2 or greater on 84.2% of the track lines surveyed on 1 October, and no cetacean sightings were recorded; data from this survey day were removed from all the subsequent analyses.

HARBOUR PORPOISE DISTRIBUTION AND ABUNDANCE

Harbour porpoises were distributed throughout the cSAC, with highest densities (harbour porpoises per km travelled) recorded in Blasket Sound (Fig. 3). High concentrations were also recorded to the south of Great Blasket, to the east of Inishvickillane and to the north-west of the cSAC (Fig. 3). Only two calves were reported, both in September, equating to an adult:calf ratio of 50:1, or 2% of total harbour porpoises recorded.

The detection function is shown in Fig. 4 (goodness of fit of $\chi^2 = 3.39$, d.f. = 6, $p = 0.76$). The data were spiked at 40–80m, which was most likely caused by evasive movement of harbour porpoises from the track of the vessel prior to detection—this will cause the density estimate to be biased low. The component of the variation of the density estimate (D) that was contributed by the detection probability was 12.3%, and the component contributed by the encounter rate was 80.0%, with the remaining 7.7% contributed by variability in the cluster size. This is typical of line-transect data and shows that the variability in encountering harbour porpoises on each track line contributes to most of the overall variability. Results from the double-platform survey on 27 August showed that all harbour porpoise sightings made from the secondary platform were also reported by the primary platform. On two of the nine sightings the primary platform actually recorded the sighting before the tracker platform. These findings suggest that few harbour porpoises within 200m of the vessel were not recorded by the observers.

Using this detection function, we derived density estimates for each sampling day (Table 2). The estimates for sample days 2 and 3 were the lowest, as the number of sightings and the total number of animals observed were low. This also

Table 2—Mean density and abundance of harbour porpoises per sample day.

Sample day	*N (95% CI)*	*SE*	*CV*	*Density (per km^2)*	*Mean group size (95% CI)*	*Effective strip width (m)*
1	265 (120–586)	102	0.39	1.17	2.00 (1.37–2.91)	166
2	162 (29–909)	120	0.74	0.71	2.40 (1.00–6.76)	102
3	185 (45–763)	105	0.56	0.82	1.75 (1.00–4.11)	78
4	764 (451–1,294)	200	0.26	3.37	3.15 (2.33–4.26)	88
5	768 (457–1,291)	198	0.26	3.38	2.25 (1.62–3.12)	80
Overall	303 (133–691)	107	0.35	1.33	2.29 (1.89–2.78)	106

influenced the confidence of the abundance estimate, resulting in a high coefficient of variation (CV) and wide confidence intervals (CI). The CV for sample day 5 was the lowest (CV = 0.26), as the total track length sampled (64.7km) was relatively short compared to other days, and the number of sightings was high. This resulted in the highest density estimate (D = 3.38 per km^2) during the present survey and, thus, the highest abundance estimate of 768 harbour porpoises (95% CI = 457–1,291). The abundance estimate for sample day 4 was also high due to a large mean group size of 3.15 compared to 2.25 on survey day 5 (11 September). The overall abundance estimate, using data from all surveys combined, was 303 ± 107 (95% CI 133–691).

Due to the low number of sightings per day, the track line was the preferred sample, as the sample size and CV were higher, and the estimate and confidence intervals more robust. The data collected using track line as the sample are shown in Table 3. A total of 74 track lines ranging from 1.54 to 14.39km in length, with a total length of 389km, were used. For 45 (60.8%) of these track lines there were no sightings. One sighting occurred on eighteen (24.3%) track lines, two sightings occurred on seven (9.5%), and three and four sightings occurred on two each (2.7%). The overall density estimate was the same as that in the previous analysis (D = 1.33), resulting in a similar abundance estimate (303), with a lower CV (0.25) and a smaller CI of 186–494 (Table 3). The overall abundance estimate using data from all survey days combined was 303 ± 76 (95% CI 186–494). Thus, although we can see that the number of sightings and the group size estimation can have a strong influence on the density estimate, the overall density and abundance estimate is consistent between the two different samples (day or track line).

INFLUENCE OF SEA-STATE ON DENSITY ESTIMATES

The DISTANCE programme was run again with the data stratified by sea-state to explore the influence of sea-state on density and abundance estimates. There were no sightings in the 37km surveyed in sea-state 3, so the density estimate was zero. There were only seven sightings in sea-state 0, which provided an abundance estimate with the highest SE and a CV of 0.52 (Table 4). The estimate with the lowest CV came from sea-state 1, where 30 sightings were made during 45 track lines with a total length of 203km. The density estimates in sea-state 0 and 1 were similar, suggesting that the detection rate was similar in these sea-states. However, the density estimate declined by 49% in sea-state 2 compared with the mean of sea-states 0 and 1. Thus, the data support previous studies (e.g. Teilmann 2003) that suggest that, if possible, surveys should be carried out in sea-state 0–1.

ACOUSTIC DETECTIONS

During the study we acquired nearly two months of acoustic data, one month from each T-POD (Table 5). Data were extracted from both units as total DPM per day (Fig. 5). Detections were logged on every day of deployment at both sites. T-POD 642 at Inishtooskert detected only 44% of the total DPM logged by T-POD 658 at Wildbank. After the correction factor of 1.15 was applied to data from Inishtooskert, there was a significant difference (Kruskal–Wallis, $P = 0.002$) between total DPM logged between the two sites.

In order to compare this study with previous work carried out in Roaringwater Bay's cSAC, we then extracted the data as DPM per hour (including the 1.15 correction factor), in a similar way to that of Leeney (2007). Meridians were calculated by assessing the times of sunrise and sunset over the deployment period, and these were used to set day- and night-time parameters. The software WXTide32 (WXTide32 2007) was used to calculate meridians for Dingle Harbour, Co. Kerry. Daylight was classified as between 05.00 and 20.00GMT, and night-time as between 20.00 and 05.00GMT. The data were then summed over these day- and night-time periods. In order to select an appropriate statistical test, a Levene test was carried out to examine the homogeneity of variance between data from Inishtooskert and Wildbank. This showed that

Table 3—Mean density and abundance of harbour porpoises per track line per day.

Sample day	*N (95% CI)*	*SE*	*CV*	*Density (per km^2)*	*Mean group size (95% CI)*	*Effective strip width (m)*
1	265 (77–910)	167	0.63	1.17	2.00 (1.37–2.91)	166
2	162 (28–938)	154	0.95	0.71	2.40 (1.00–6.76)	102
3	205 (50–832)	155	0.76	0.90	2.05 (1.05–3.80)	78
4	356 (144–876)	165	0.46	1.57	2.89 (1.81–4.59)	113
5	769 (329–1,799)	330	0.42	3.39	2.25 (1.62–3.12)	81
Overall	303 (186–494)	76	0.25	1.33	2.32 (1.92–2.79)	107

the variances between the two sites were not equal ($P < 0.05$), therefore, a non-parametric Mann–Whitney U test was chosen to test for significant differences between the two sites. Diel variation was examined in order to assess if animals were using a site more often during the day or night. Random day and night samples (DPM per hour) were chosen from each site (using random number tables) to maintain independence of samples by ensuring that each minute analysed was not influenced by the preceding minute. Twelve samples were taken from the day and from the night. This analysis showed that harbour porpoises were more active during the day at Wildbank ($P = 0.02$) when compared to night-time data from the same site. Porpoises were found to be more active during the night at Inishtooskert ($P = 0.0005$) when compared to day-time samples. Non-parametric Mann–Whitney U tests were carried out to determine if there were any differences in the DPM logged during daylight between sites. Again a random sample of DPM per hour from twelve day and twelve night samples was used, revealing a significant difference between sites, with more detections during the day ($P = 0.0014$) and night ($P = 0.0001$) at Wildbank compared to Inishtooskert.

When DPM per hour was analysed over a tidal cycle, no trends were found for Wildbank, while off Inishtooskert there was some variation between low and high water, with the highest peaks occurring during the ebbing tide; however, these were not significant (Kruskal–Wallis test, $P = 0.234$, n.s.).

DISCUSSION

The ability to detect harbour porpoises visually at sea and, thus, the accuracy of density and abundance estimates are extremely dependent on sea-state. During the present study transect surveys were carried out, whenever possible, in sea-state 2 or less, as the ability to detect harbour porpoises decreases significantly in sea-state 3 or above (Teilmann 2003). Palka (1996) found that the sighting rates for this species decreased by 20% from Beaufort 0 to 1 and by 75% from Beaufort 0 to 2–3. We have shown that the differences in abundance estimates with sea-state can vary as much as 100% between sea-state 0–1 and 2, but no difference was detected between sea-state 0 and 1, although sample sizes were very low for sea-state 0. Harbour porpoise surveys should only be carried out in sea-state 0 or 1 to ensure all animals are detected ($g(0) = 1$). Acoustic monitoring is much less weather dependent.

Little was known about the spatial distribution of harbour porpoises within the Blasket Islands' cSAC prior to this study. The results suggest that most of the study area was used by harbour porpoises. Concentrations were recorded that might indicate important foraging areas, particularly in Blasket Sound, where currents are very strong. Other concentrations may correlate with reefs (e.g. Wildbank) or other bathymetric or oceanographic features that might concentrate prey items.

The mean harbour porpoise group size recorded during this study ranged from 1.75 to 3.15 (actual: 1–7 individuals). Hastie *et al.* (2003) reported mean group sizes for harbour porpoises in the Moray Firth, Scotland, of 1.33–2.00, and Teilmann (2003) reported a mean of 2.2 (CV = 0.07) in Danish waters. Thus, the group sizes recorded were typical for this species.

HARBOUR PORPOISE DENSITY AND ABUNDANCE ESTIMATES

Typically for surveys of harbour porpoises, $g(0) = 0.4$ or 0.5, i.e. only one-half of the animals on the track line are detected. If this was the case with the present survey, then we could double the density estimate. Without a consistent double-platform methodology, it was not possible to accurately determine the numbers missed on the track line. An attempt to test this assumption was carried out during the survey, and all animals that were tracked by the secondary platform were also detected by the primary platform, though some groups were not detected immediately, and some demonstrated evasive movement from the boat. This is also indicated by the detection function. These factors will reduce the density estimates. However, as density estimates were similar in sea-state 0 and 1, we can be more confident that they are relatively accurate. There are a number of important constraints in this survey.

Table 4—Mean density and abundance of harbour porpoises per track line in different sea-states.

Sea-state	*Distance surveyed (km)*	*N (95% CI)*	*SE*	*CV*	*Density (per km^2)*	*Mean group size (95% CI)*
0	46	320 (115–890)	166	0.52	1.41	1.28 (1.00–1.82)
1	203	369 (194–701)	122	0.33	1.62	2.27 (1.78–2.88)
2	107	179 (49–656)	126	0.70	0.78	2.40 (1.02–3.80)
3	37	–	–	–	0.00	–

The total number of sightings was low. Ideally around 60–80 sightings are required to achieve a good fit to the distance model, and 20–30 sightings should be considered a minimum (Dawson *et al.* 2008). The number of sightings on each day was insufficient (maximum 16 sightings) to derive robust density estimates, thus, data from all survey days were pooled to derive a mean density estimate. Density estimates might be inflated by the small survey area and uneven survey coverage. The site could have been stratified by habitat, as determined by bathymetry or distance to land, but this stratification would have been constrained by the low number of sightings. We have provided minimum density estimates for harbour porpoises within the Blasket Islands' cSAC and a baseline from which to monitor changes in the population.

We compared the density estimate from the present survey to those recorded by other harbour porpoise surveys in Irish and other European waters (Table 6). Most of these surveys were of much larger areas, up to ten times the present survey area, and used double-platform or aerial methodologies. However, the comparison does provide a useful overview of harbour porpoise surveys and their methodology in EU waters, as well as of variations in density estimates. The density estimate recorded in the present study (1.33 harbour porpoises per km^2) was higher than those found in the more extensive surveys in Irish waters. Only Leopold *et al.* (1992) reported densities greater than 0.5 harbour porpoises per km^2 in Irish waters. However, we might expect estimates to be high in the Blasket Islands' cSAC given that densities of harbour porpoises are thought to be greater off the south-west coast compared to other parts of Ireland (Rogan and Berrow 1996; Reid *et al.* 2003). The highest densities in European waters were reported by Teilmann (2003), who found up to 3.7 harbour porpoises per km^2 in the Great Belt, Denmark.

The overall abundance estimate from this study suggests that an average of around 303 harbour porpoises occurred within the cSAC between July and September 2007. The data also suggest that there was an increase in the abundance of harbour porpoises from July through to September: densities increased about three fold from around 1 porpoise per km in July and early August to 3 per km during late August and September. Immigration into the site may have occurred throughout the summer and into the autumn, increasing abundance to a maximum recorded in September. This is an important factor in the design of monitoring protocols, as abundance estimates would have to be stratified by season to ensure that any recorded changes in abundance were not due to shifts in seasonal changes rather than long-term trends.

In the NPWS Conservation Assessment, recently submitted to the EU as part of the government's reporting requirements, the total population estimate for harbour porpoises in Irish waters was around 100,000 individuals (NPWS 2008). This suggests that around 0.005% (0.003–0.007%) of the total Irish population of harbour porpoises occurs within the Blasket Islands' cSAC.

ACOUSTIC DETECTIONS

To complement the boat-based surveys, which could only be carried out during daylight hours, static acoustic monitoring (SAM) was used through the use of T-PODs. This provided an alternative way to explore factors such as site usage and diurnal and tidal factors that might influence the distribution of harbour porpoises within the cSAC. The detection distance of harbour porpoises by T-PODs is limited, with most detections received within 100m, and very few beyond 250m (Tougaard *et al.* 2006), demonstrating the importance of site selection for deployment of T-PODs.

These data showed that there were significant differences in detections between the two sites surveyed. A significant difference was also found in the number of detections during day-time and night-time. This study showed that harbour porpoises were more vocally active at Inishtooskert during the night, but more active during the day at Wildbank. There were more detections during both day and night at Wildbank than at Inishtooskert. Carlström (2005) showed that harbour porpoises increased their echolocation rate and/or visited the depth of the T-POD more often at night than during the day, and this was attributed to

Table 5—Summary of acoustic data from T-PODs recovered from Wildbank and Inishtooskert.

Location	*Deployment date*	*Deployment duration*	*Total clicks (CETACEAN-ALL)*	*Clicks per hour*	*Total DPM*	*Mean DPM per h*
Inishtooskert (642)	12 July	28d 14h 49min	33,389	46	619	0.9
Wildbank (658)	12 July	29d 6h 28min	89,984	120	1394	1.99

Data presented with correction factor applied to T-POD 642.

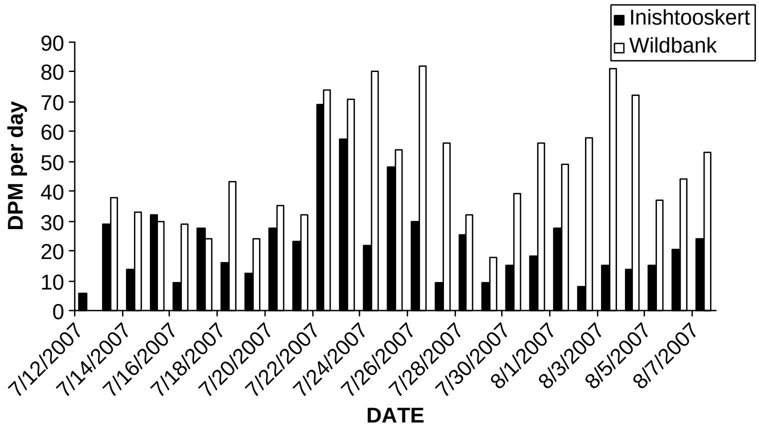

Fig. 5—Total DPM per day from Inishtooskert and Wildbank (the Inishtooskert data have been corrected).

Table 6—Density estimates of harbour porpoises in Irish and EU waters, as determined from dedicated sighting surveys.

Location	*Year*	*Area (km²)*	*Method*	*Density (per km²)*	*CV*	*Reference*
Irish waters						
Galway–Cork[1]	1989	—	SPL	0.77	0.34	Leopold *et al.* (1992)
Celtic Sea	1994	201,490	DPL	0.18	0.57	Hammond *et al.* (2002)
Celtic Sea	2005	197,400	DPL	0.41	0.50	SCANS-II (2008)
Irish Sea	2005	45,417	Aerial	0.34	0.35	SCANS-II (2008)
Coastal Ireland	2005	31,919	Aerial	0.28	0.37	SCANS-II (2008)
Offshore shelf edge[2]	2005	149,637	DPL	0.07	1.24	SCANS-II (2008)
Blasket Islands	2007	227	SPL	1.33	0.25	this study
Other EU waters						
Great Belt, Denmark	1994	326	DPL	3.2–3.7	0.16	Teilmann (2003)
Northern North Sea	1994	118,985	DPL	0.78	0.25	Hammond *et al.* (2002)
East Danish coast	1994	7,278	Aerial	0.81	0.27	Hammond *et al.* (2002)
Coastal north-west Denmark	2005	20,844	Aerial	0.56	0.43	SCANS-II (2008)

SPL = single-platform line transect; DPL = double-platform line transect; Aerial = aerial survey.

[1] Not a dedicated survey but a platform of opportunity.

[2] Includes offshore waters to the west of Scotland.

Table 7—Comparison between acoustic indices from similar studies in Irish waters.

County	*General area*	*Location*	*Deployment duration (d)*	*Mean DPM per hour*	*Reference*
Kerry	Blasket Islands	Wildbank	29	1.99	this study
Kerry	Blasket Islands	Inishtooskert	29	1.04	this study
Galway	Galway Bay	Spiddal	22	0.20	O'Brien (unpublished)
Mayo	Clare Island	Clare Island	93	0.68	O'Brien (unpublished)
Cork	Roaringwater Bay	Calf Islands	66	0.63	Leeney (2007)
Cork	Roaringwater Bay	Sherkin Island	71	3.58	Leeney (2007)
Cork	Roaringwater Bay	Long Island	55	0.23	Leeney (2007)

increased foraging activity. Thus, Wildbank may be a more important foraging site than Inishtooskert, with Inishtooskert used more during the night and Wildbank used more during the day. Wildbank is a reef, while Inishtooskert is one of the large islands in the site, and these results might reflect how porpoises utilise the cSAC. There was no significant effect of tidal cycle on the number of DPM per hour at either site. However, a longer data set is required to determine whether this relationship is consistent throughout the year or perhaps due to the seasonal occurrence of potential prey.

In this study we present a brief acoustic snapshot of harbour porpoise activity in the Blasket Islands' cSAC. Although there are difficulties comparing static SAM studies using different T-POD units and versions, it is useful to place the results of the acoustic monitoring from the Blasket Islands' cSAC into context (Table 7). When compared with sites within Roaringwater Bay's cSAC (Leeney 2007), the number of detections at the Blasket Islands was greater than the numbers off Long and Calf Islands but lower than the mean value from Sherkin Island. There was a large difference in the mean DPM per hour from the Blasket Islands when compared with Galway Bay (O'Brien, unpublished data) for the same month. However, there was less of a difference when the data were compared to Clew Bay in Co. Mayo (Table 7). Given the strong influence of sea-state on visual surveys, SAM should also be an integral component of a monitoring programme. This would be especially beneficial during the winter, when sea conditions rarely support boat-based observations. A long-term monitoring scheme in the Blasket Islands' cSAC would greatly increase our knowledge of the use of the site, and of any seasonal variation in abundance or changes in behaviour, as well as provide a good reference for other sites where acoustic monitoring may take place during assessment for future designations. Consideration should be given to the location of SAM sites, as T-PODs only have a small spatial resolution.

The EC Habitats Directive (Council of the European Union 1992) states that a site that 'corresponds to the ecological requirements of the species' may be designated as a SAC. In relation to the selection of sites eligible for identification as of community importance, the directive states 'for aquatic species which range over wide areas, such sites shall be proposed only where there is a clearly identifiable area representing the physical and biological factors essential to their life and reproduction'. It has proved difficult for member states to identify sites based on these criteria due to the harbour porpoise being widely distributed and the densities being quite consistent, and other criteria have been proposed. Elevated population density (in relation to neighbouring areas) is one of the recent criteria recommended for SAC selection according to Johnston *et al.* (2002). This study shows that densities of harbour porpoises within the Blasket Islands' cSAC were high, supporting its designation as a cSAC. These elevated density estimates are also supported by acoustic data, which, although limited, yielded high detection rates that were generally greater than those found in other sites in Ireland. The limited time-series presented here suggests there could be a strong seasonal component to the abundance of harbour porpoises within the Blasket Islands' cSAC. We recommend that this factor is fully investigated through a replicated, seasonally stratified sampling programme for at least one year. This would then inform the design of a long-term monitoring protocol.

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REFERENCES

Berrow, S. 1993 Constant effort cetacean sighting survey of Ireland. *Irish Naturalists' Journal* **24** (8), 344.

Berrow, S.D. and Rogan, E. 1997 Cetaceans stranded on the Irish coast, 1901–1995. *Mammal Review* **27** (1), 51–76.

Berrow, S.D., Whooley, P. and Ferriss, S. 2002 *Irish Whale and Dolphin Group cetacean sighting review (1991–2001).* Clare. Irish Whale and Dolphin Group.

Brazier, H. and Merne, O.J. 1989 Breeding seabirds on the Blasket Islands, Co. Kerry. *Irish Birds* **4**, 43–64.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L. 2001 *An introduction to distance sampling: estimating abundance of biological populations*. Oxford. Oxford University Press.

Carlström, J. 2005 Diel variation in echolocation behavior of wild harbor porpoises. *Marine Mammal Science* **21** (1), 1–12.

Chelonia Ltd 2007 *T-POD.exe*, available at http://www.chelonia.co.uk/tpod_downloads.htm (25 February 2009).

Council of the European Union 1992 Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. *Official Journal of the European Union* **L206**, 7–50.

Dawson, S., Wade, P., Slooten, E. and Barlow, J. 2008 Design and field methods for sighting surveys of cetaceans in coastal and riverine habitats. *Mammal Review* **38** (10), 19–49.

Hammond, P.S., Benke, H., Berggren, P., Borchers, D.L., Buckland, S.T., Collet, A., Heide-Jorgensen, M.P., Heimlich-Boran, S., Hiby, A.R., Leopold, M.F. and Oien, N. 2002 Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. *Journal of Applied Ecology* **39**, 361–76.

Hastie, G.D., Barton, T.R., Grellier, K., Hammond, P.S., Swift, R.J., Thompson, P.M. and Wilson, B. 2003 Distribution of small cetaceans within a candidate Special Area of Conservation. *Journal of Cetacean Research and Management* **5** (3), 261–6.

Ingram, S.N., Englund, A. and Rogan, E. 2004 Methods of best practice for the use of T-POD passive acoustic detectors for cetacean research in Irish waters. Report to the Heritage Council, Ireland.

Johnston, C.M., Turnbull, C.G. and Tasker, M.L. 2002 *Natura 2000 in UK offshore waters*. JNCC report no. 325. Peterborough. Joint Nature Conservation Committee.

Leeney, R. 2007 Distribution and abundance of harbor porpoises and other cetaceans in Roaringwater Bay, Co. Cork. Report to the National Parks and Wildlife Service, Dublin.

Leopold, M.F., Wolf, P.A. and Van de Meer, J. 1992 The elusive harbour porpoise exposed: strip transect counts off southwestern Ireland. *Netherlands Journal of Sea Research* **29** (4), 395–402.

Møhl, B. and Anderson, S. 1973 Echolocation: high-frequency component in the click of the harbour porpoise (*Phocoena ph.* L.). *Journal of the Acoustical Society of America* **54** (5), 1368–72.

NPWS 2008 *The status of EU protected habitats and species in Ireland*. Dublin. NPWS, Department of the Environment, Heritage and Local Government.

Ó Cadhla, O., Strong, D., O'Keeffe, C., Coleman, M., Cronin, M., Duck, C., Murray, T., Dower, P., Nairn, R., Murphy, P., Smiddy, P., Saich, C., Lyons, D. and Hiby, A.R. 2008 *An assessment of the breeding population of grey seals in the Republic of Ireland, 2005. Irish wildlife manual no. 34.* Dublin. National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government.

O'Crohan, T. 1978 *The islandman*. Oxford. Oxford University Press.

Otani, S., Naito, Y., Kato, S. and Kawamura, A. 2001 Oxygen consumption and swim speed of the harbour porpoise. *Fisheries Science* **67** (5), 894–8.

Palka, D. 1996 Effects of Beaufort Sea State on the sightability of harbour porpoises in the Gulf Of Maine. *Report of the International Whaling Commission* **46**, 575–82.

Reid, J.B., Evans, P.G.H. and Northridge, S.P. 2003 *Atlas of cetacean distribution in north-west European waters*. Peterborough. Joint Nature Conservation Committee.

Rogan, E. and Berrow, S.D. 1996 Review of harbour porpoises *Phocoena phocoena* L. in Irish waters. *Report of the International Whaling Commission* **46**, 595–605.

Sayers, P. 1974 *Peig: the autobiography of Peig Sayers of the Great Blasket Island*. Dublin. Talbot Press.

SCANS-II 2008 *Small cetaceans in the European Atlantic and North Sea. Final report to the European Commission under project LIFE04NAT/GB/000245.* Fife, UK. SMRU, Gatty Marine Laboratory, University of St Andrews.

Smiddy, P., O'Halloran, J. and O'Mahony, B. 2000 The birds and mammals of Beginish and Young's Island (Blaskets), Co Kerry (1988–2001). *Irish Birds* **6** (4), 593–6.

Teilman, J. 2003 Influence of sea state on density estimates of harbour porpoises (*Phocoena phocoena*). *Journal of Cetacean Research and Management* **5** (1), 85–92.

Tougaard, J., Poulsen, L.R., Amundin, M., Larsen, F., Rye, J. and Teilman, J. 2006 Detection function of T-PODs and estimation of porpoise densities. In R. Leeney and N.J.C. Tregenza (eds), *Static acoustic monitoring of cetaceans. European Cetacean Society newsletter no. 46—special issue*, 7–14.

WXTide32 2007 *WXTide32*, available at http://www.wxtide32.com/ (25 February 2009).