

# Relative abundance, density and distribution of the harbour porpoise (*Phocoena phocoena*) along the west coast of the UK

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*The harbour porpoise (Phocoena phocoena) is the most frequently sighted cetacean in the UK, yet there is a conservation need to assess both abundance and distribution for this species. During May–August, 2002–2004 a boat-based visual survey, employing effort-related line transect methodology was conducted for specified areas of the west coast of the UK. Estimates of relative abundance were made, with full DISTANCE analysis being carried out during 2004 for each of the areas surveyed. A generalized additive model (GAM) was constructed examining porpoise presence in relation to month, position (latitude and longitude), depth and sea surface temperature for all years and for each year of the study individually. Harbour porpoise density showed a significant decrease in the South West, with an increase for West Scotland over the study period, whilst the highest numbers for both Northern Ireland and the Firth of Clyde were recorded in 2003. The porpoise population in the south-west of England was estimated at 163 (67<sub>LCI</sub>–400<sub>UCI</sub>) individuals during the months of May and June, 387 (170<sub>LCI</sub>–877<sub>UCI</sub>) individuals were present off Northern Ireland during July, 1645 (823<sub>LCI</sub>–3289<sub>UCI</sub>) individuals around the Firth of Clyde in July and 3105 (2032<sub>LCI</sub>–4745<sub>UCI</sub>) off West Scotland during August and September. The GAM demonstrated that porpoise presence increased around the 100 m depth contour. Whilst further research is required in each of the areas throughout the year, this study provides important information on the distribution and habitat use of the harbour porpoise within UK waters.*

**Keywords:** harbour porpoise, abundance, density, distribution, UK.

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## INTRODUCTION

The harbour porpoise (*Phocoena phocoena*, Linnaeus, 1758) is a continental shelf species found throughout temperate waters of the northern hemisphere (Carwardine, 1995; Read, 1999; Reid *et al.*, 2003). As such it is the most frequently sighted cetacean in UK waters (Evans *et al.*, 2003).

A number of studies have been carried out to examine harbour porpoise abundance around the UK coastline, including the waters of south-west Ireland (Leopold *et al.*, 1992), the North Sea (Heide-Jørgensen *et al.*, 1993) and around south-east Shetland (Evans *et al.*, 1994). More recently the Whale and Dolphin Conservation Society (WDCS), in collaboration with Greenpeace carried out a winter survey off the south-western approaches to the UK, which considered all cetacean species encountered, including the harbour porpoise (WDCS, 2004). Additionally, both the Sea Mammal Research Unit (SMRU) and the Hebridean Whale and Dolphin Trust (HWDT) have conducted research on the harbour porpoise from the Scottish coast (Stockin *et al.*, 2001; Gordon & Northridge, 2003; Grellier & Wilson, 2003; Parsons *et al.*, 2003; MacLeod, 2004).

Whilst these published studies provided data on specific areas, none were sufficiently large or extensive to allow assessment of overall UK population status, though they provided important regional information. Covering a larger area, data have also been collated through the Seabirds at Sea Team (now Seabirds and Cetaceans Branch) of the UK Joint Nature Conservation Committee (JNCC). Between November 1979 and January 1997, surveys for seabirds were conducted in the North Sea, Danish waters, the north and west coast of Scotland, Irish Sea, south-west Ireland and the English Channel (Evans & Wang, 2002). These surveys, whilst primarily focused on distribution of seabirds, also collected information on cetaceans.

By far the most extensive surveys, in terms of area covered, are the SCANS (Small Cetacean Abundance in the North Sea) surveys, the first conducted in 1994 and the second in 2005. The former was the first large-scale survey of the area to address the status of small cetaceans, including the harbour porpoise (Hammond *et al.*, 2002). The harbour porpoise was found throughout most of the North Sea, Skagerrak and Kattegat and the Celtic Sea. More recently SCANS II, carried out in 2005, extended the survey area to include the west of the UK, Ireland and the inshore waters of Spain. Whilst for the study area as a whole harbour porpoise numbers were not found to vary significantly, with a total of 341,000 (coefficient of variation (CV) = 0.14) in 1994 and 386,000 (CV = 0.20) in 2005, clear differences in abundance

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were observed from the north to the south of the study area. This was particularly notable in the North Sea and English Channel where abundance figures were seen to decrease in the north (239,000 (1994)–120,000 (2005)) and increase in the south (102,000 (1994)–215,000 (2005)) (Hammond & MacLeod, 2006). The reasons for these differences remain unknown, although it is likely they relate, at least in part, to changes in the distribution and abundance of prey species.

The remaining existing information on numbers and distribution within the UK arises from volunteer observer schemes, such as Seaquest Southwest (Cornwall and Devon Wildlife Trusts) and a National Whale and Dolphin Watching Week, hosted by the Sea Watch Foundation. Within both schemes, members of the public are encouraged to report sightings with as much additional environmental detail as possible. Despite the possible errors (misidentification, group size estimates, behaviour etc.) in both schemes, the volunteer observer programmes are extensive and provide almost complete coverage of UK waters. As such they provide broad-based evidence of changes in relative abundance and distribution (Evans, 1992).

In addition to assessing abundance it is also important to consider distribution and any key areas for habitat conservation and wildlife protection. The UK is obliged under national, European and international agreements to investigate and monitor cetacean distribution and abundance (e.g. National Biodiversity Action Plans; EU Habitats Directive, 1992; EU Regulation No. 812/2004; OSPAR Convention, 1992). Accurately describing and understanding the distribution of cetaceans is a fundamental problem with important conservation and management implications (Redfern *et al.*, 2006). If conservation of wild cetacean populations is to be effective then relationships between species and their habitats need to be understood (Cañadas *et al.*, 2005). This should include examination of environmental characteristics of preferred habitats to enable an ecosystem-based approach to be taken to management.

Previous research has demonstrated that cetacean species favour particular habitat areas (Gaskin, 1968; Hui, 1979; Au & Perryman, 1982; Cockcroft *et al.*, 1990; Palka, 1995; Johnston *et al.*, 2005). Investigations into the harbour porpoise have demonstrated seasonal and temporal variations in distribution, with further changes dependent on the area examined (Palka, 1995; Weir *et al.*, 2001; Hamazaki, 2002; Tynan *et al.*, 2005; Ballance *et al.*, 2006). A study by Hamazaki (2002) in the mid-western North Atlantic demonstrated seasonal shifts in harbour porpoise habitat use during June and August.

Gaskin (1968) indicated a relationship between bottlenose dolphin distribution and water temperature, something which has also been demonstrated for the harbour porpoise by both Palka (1995) and Tynan *et al.* (2005). The former study found harbour porpoises in waters ranging between 10 and 13.5°C. However, northern hemisphere waters can range from 0.5°C in the winter to 20°C during the summer months (Connor *et al.*, 2006), demonstrating that they have a much wider temperature tolerance than is indicated above. Given their small body size and high energetic demand it is probably favourable for them to maintain distribution in waters at the upper end of this temperature range. Sea surface temperature (SST) has been selected for analysis in this study as it will vary in regions of tidal fronts and upwelling, where Gaskin (1968) hypothesized that large numbers of prey would aggregate.

In the UK, few published reports relate specifically to harbour porpoise distribution and environmental variables. Weir *et al.* (2001) note that porpoises are occasionally found

off the continental shelf in deeper waters. Indeed they have been observed in waters as deep as 1502 m off the coast of Scotland, on the Rockall and Faroe Banks (MacLeod *et al.*, 2003). As bathymetry is known to influence cetacean distribution (MacLeod *et al.*, 2003), depth was included in the analysis in an attempt to explain the observed distribution with varying topographical features.

The primary aim of this study is to further our knowledge of abundance, density and distribution of the harbour porpoise in western UK waters. Habitat preferences and spatio-temporal patterns in distribution are quantified by analysing local abundance in relation to year, month, latitude, longitude, SST and depth. This study will also provide yearly population density estimates and an estimate of population size for each of the regions studied.

## MATERIALS AND METHODS

A boat-based survey of the west coast of the UK was undertaken between May and September, for three consecutive years, 2002, 2003 and 2004.

The UK seas are typically characterized by a complex coastal zone, with the edge of the continental shelf reached at a depth of approximately 200 m (Connor *et al.*, 2006). Within the South West few subtidal sediment banks exist, with largely coarse sediment interspersed with sandy and muddy sand. Moving up the west coast of the UK, Wales and Northern Ireland, the seabed substrate consists of coarse sediment and mud/sandy mud, and is relatively uniform at a large scale. The seabed off the coast of Scotland is interspersed with shelf troughs which have a considerably greater depth than the surrounding sea-floor. The sediment is heterogeneous with rock, coarse sediment and mud/sandy mud in between. The SST around the UK is on average 6–10°C during the winter, rising to 14–16°C during the summer months, although both lower and higher temperatures are recorded (Connor *et al.*, 2006).

The research vessel, SRV 'Forever Changes', was an 11.7 m Dufour sailing yacht, with a Perkins 4.108 auxiliary diesel engine, fitted with a Variprop feathering propeller. It was primarily involved in basking shark (*Cetorhinus maximus*) research, although cetacean, turtle, and marine wildlife surveys also took place onboard. The standard observation height from the platform was 3 m.

The survey, onboard what was effectively a platform of opportunity, began in May from Falmouth, surveying the South West peninsula and the Isles of Scilly before leaving for the north coast, Wales and Northern Ireland in July. In the middle of July the vessel sailed from Northern Ireland to the Clyde Sea, Scotland, for two weeks, before continuing onto the Sea of the Hebrides, returning to Cornwall at the end August. Essentially, the same route was undertaken in all years. However, during 2003 and 2004, the survey of the Welsh coast was omitted due to adverse weather conditions and there was an extra week of dedicated survey time off Northern Ireland during the journey south from Scotland to Cornwall towards the end of the season. As a result, the survey vessel did not return to Falmouth until the end of September in both the latter years.

Line transect surveys were carried out between fixed positions both inshore and offshore, using a standardized methodology. Transects were selected daily, taking into consideration the weather and sea state. It is rarely true that all animals on

the trackline are detected (i.e. that  $g(0) = 1$ ). Some cetaceans will be missed by the survey vessel as they may be submerged at the time of passing. In the present study it was not possible to estimate the probability of detection and hence  $g(0)$ , as there was only a single observation platform and one team of observers. As such  $g(0)$  was assumed to be equal to 0.769, calculated by Barlow (1987) for ship-board surveys of harbour porpoises (*Phocoena phocoena*).

Two observers were employed at all times, each scanning one side of the vessel, with a third crew member recording the vessel's position every half hour via a Furuno GP-32 GPS/WAAS Navigator interfaced with a DELL notebook computer operating SeaPro Pro navigational software and ARCS electronic charts. Observers were rotated every three hours to prevent misidentification or missed animals due to fatigue. Additional navigational and environmental data were recorded each half hour which included the vessel's heading, wind direction and speed, sea state, weather, cloud cover, depth and SST. A litter and marker buoy survey was also conducted onboard, as part of another research project. Distance estimation was always required in recording the location of all marker buoys and litter encountered. Following initial training, volunteer observers soon adapted to distance estimation and their recording was frequently calibrated by estimation of distance to known land marks (using information from the ship's radar or plotter) and checked by more experienced members of the crew. When harbour porpoises were encountered, the following data were recorded: time, GPS location, vessel heading, distance, radial angle to cetaceans, depth and SST. A hand-held sighting compass was used to measure the angle to the harbour porpoise, whilst distance was estimated by eye. A minimum estimate of group size was also made; this was defined as the maximum number of animals seen on the surface at any one time. A group was defined as two or more individuals in close contact, <20 m from each other and closer to one another than individuals belonging to another group (Slooten, 1994). Unfortunately, despite training, observers did not always record radial angle and distance to sightings during 2002 and 2003. This rendered the data inadequate to complete DISTANCE analysis for abundance estimates in those years. As DISTANCE methodology requires the perpendicular distance to the animal, or group (cluster) of animals, both angle and radial distance are required to permit the perpendicular distance to be calculated by simple trigonometry. The cluster size and distance from the track line are then used, in combination with the detection function, in this case 0.769, area surveyed and number/length of tracklines to calculate an estimate of both the density and total number of animals likely to be within each of the study areas. As some measurements were missing from the data collection in earlier years, only abundance estimates within each of the specified areas (Figure 1), for the most recent year, 2004 are presented.

Surveys in all years encompassed the summer season, ranging from May to September. The time at which a transect was begun on any given day varied due to a number of factors, primarily weather and tides. However, when conditions permitted, transects were completed during daylight hours on almost all days. The Friday of every week was a crew change-over day, which also allowed for the vessel to be restocked and any minor technical problems to be addressed. Whilst all hours of the day were covered, the majority of data were collected between 1000 and 1800. A greater number of hours

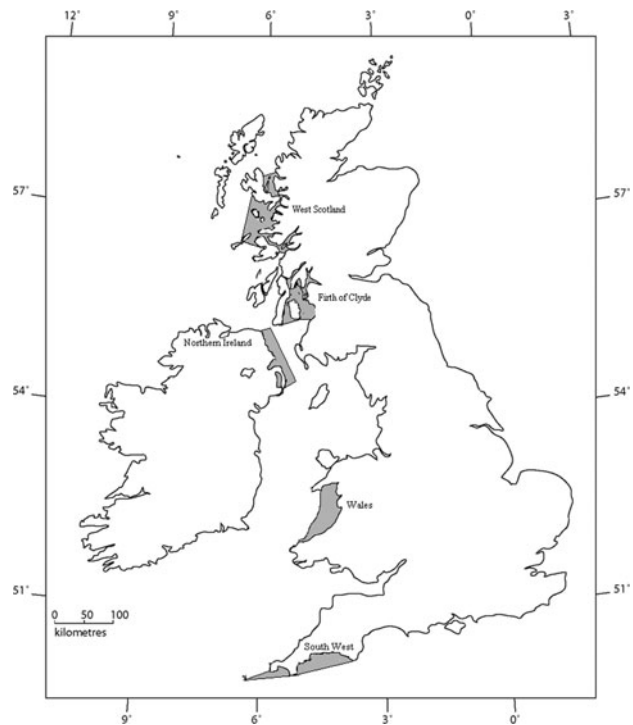


Fig. 1. Map of the UK showing the regions surveyed, the South West, Wales, Northern Ireland, Firth of Clyde, West Scotland.

were spent on survey during 2003, compared with 2002 and 2004, largely because of unfavourable weather conditions in those years. It may also be assumed that a greater proportion of harbour porpoises are seen in calmer conditions. Therefore, in line with previous studies (Jefferson *et al.*, 2002; Hammond *et al.*, 2002), only data points recorded in a sea state  $\leq 3$  were included in the subsequent analyses.

Relative abundance estimates were calculated for all years, expressed as number of porpoises per 100 km. Data were divided into the following regions: south-west England ( $49^{\circ}30' - 50^{\circ}30'N$   $04^{\circ} - 06^{\circ}W$ ), Wales ( $52^{\circ} - 53^{\circ}N$   $04^{\circ} - 05^{\circ}W$ ), Northern Ireland ( $54^{\circ}30' - 55^{\circ}30'N$   $05^{\circ} - 06^{\circ}W$ ), Firth of Clyde ( $55^{\circ}30' - 56^{\circ}30'N$   $04^{\circ}30' - 06^{\circ}W$ ) and west Scotland ( $56^{\circ}30' - 58^{\circ}N$   $05^{\circ}30' - 07^{\circ}W$ ) (here Kintyre was used as a dividing landmark, which also serves to delineate the two survey legs that were completed there) (Figure 1). Regions were chosen through a combination of time and effort constraints and also served to divide the whole coast into temporally independent blocks. As the same northward movement of the survey vessel through the course of the year occurred each time, each survey area was statistically examined separately to avoid temporally confounding the results through either seasonal variation in abundance and/or calving periods. The coefficient of variation (CV) has been calculated for all density estimates. A one-way analysis of variance (ANOVA) has been carried out on harbour porpoise density for each region sampled to examine variation across years. A density estimate and approximate number of individuals has been calculated using DISTANCE 4.1 software for 2004. The effective search width has been calculated for the survey as a whole after pooling all observations during 2004.

Generalized additive modelling (GAM) is an exploratory data analysis tool for elucidating functional forms of relationships between observations and predictor variables (Hastie

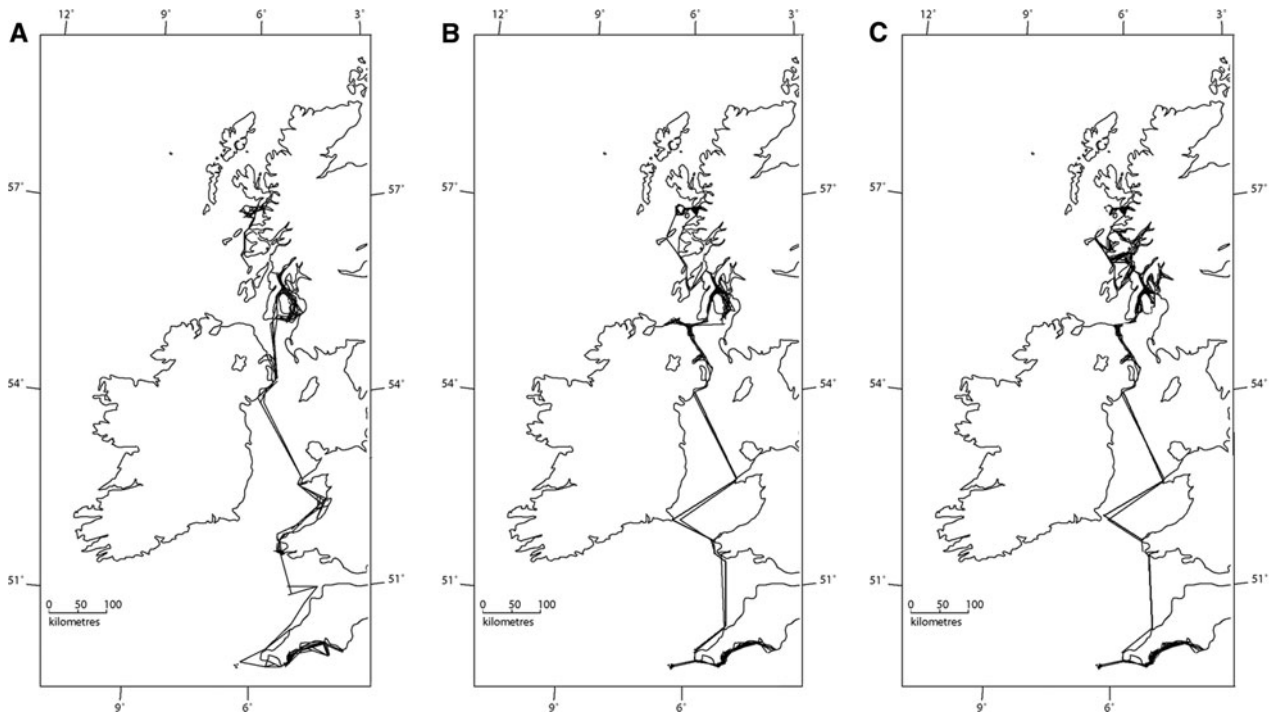


Fig. 2. Effort related survey tracks completed onboard the research vessel 'Forever Changes' between (A) May and August, 2002; (B) May and September, 2003; and (C) May and September, 2004 for the west coast of the UK.

& Tibshirani, 1990). The GAMs are very useful for interpreting ecological interactions as they are able to fit non-parametric functions to estimate the relationship between response and predictor variables without imposing limitations on any underlying relationships (Hastie *et al.*, 2005). They can be used to assess how each environmental variable relates to presence or absence of the harbour porpoise. Using a binomial logistic function with the 'mgcv' package within the statistical program 'R' (Wood, 2004), GAMs have been used to model the effects of month, position (latitude (Lat), longitude (Lon)), SST and depth on the presence/absence of harbour porpoises for the entire west coast of the UK. The significance of each smoothed term was estimated using a  $\chi^2$ -test, comparing the full model and the model omitting the respective predictor. Initially, smoothing functions were applied to all variables, with position (Lat, Lon) being presented in a two-dimensional surface, rather than two separate variables. Month was represented by a factor in the model as opposed to a variable. Any smoother which was approximately linear ( $df = 1$  or thereabouts) was replaced by a parametric (linear) term. A GAM was run on the entire data set to assess the relationships between porpoise presence and environmental variables. To assess between-year variability the GAM was then run using individual years of data: 2002, 2003, and 2004. In each case, the optimal GAM was identified as the model with the lowest Akaike information criterion, provided that all explanatory variables included were individually statistically significant and there were no obvious patterns in the residuals.

## RESULTS

During 2002, a total of 20 weeks was spent at sea, with approximately 333.5 h on survey. During this time, a total of

3137 km was surveyed (Figure 2). In 2003, the survey was repeated but with increased coverage of Northern Ireland and almost no coverage of Wales (Figure 2). A total of 22 weeks was spent on survey, comprising 501 h, over 3736 km. In 2004, again 22 weeks were spent at sea, with 385 h over 3892 km (Figure 2).

Comparison of relative abundance estimates has only been made between years, as opposed to between regions due to the seasonal differences relating to when each region was surveyed. Whilst there does not appear to have been much change across the years (Table 1), in each region, an ANOVA has demonstrated statistically significant differences in porpoise density for all regions across the three years surveyed (Table 2). It is clear that relative abundance estimates over the course of the three years have declined in the South West (Table 1), whilst there has been a slight increase in numbers for the west of Scotland (Figure 3). The greatest density of harbour porpoises (*Phocoena phocoena*) for both Northern Ireland and the Firth of Clyde was seen in 2003. Pooling the data over all years provided estimates of relative abundance for each study area.

Analysis of the most recent data (2004) using DISTANCE 4.1 provided the following estimates of population size

Table 1. Relative abundance estimates (number of porpoises per 100 km) and coefficient of variation (CV) for each sub-area sampled during 2002, 2003 and 2004.

Area	2002	CV	2003	CV	2004	CV	All years	CV
South West	1.8	0.388	0.58	0.524	0.41	0.500	0.81	0.439
Wales	2.5	0.503	-	-	-	-	2.5	0.503
Northern Ireland	5.8	0.508	8.75	0.659	6.04	0.783	6.91	0.775
Firth of Clyde	10.6	0.834	15.25	0.579	10.76	0.639	12.19	0.662
West Scotland	2.4	0.521	23.65	0.629	29.75	0.624	26.67	0.603

**Table 2.** Analysis of variance testing for annual differences in the number of porpoises per 100 km (porpoise density) for each sub area sampled during 2002, 2003 and 2004.

Area	F	df	P
South West	5.203	44	<0.05
Wales	-	-	-
Northern Ireland	7.206	29	<0.05
Firth of Clyde	12.279	239	<0.05
West Scotland	12.984	380	<0.05

(Table 3). Whilst these estimates appear to present an increase with increasing distance north it must be remembered that the sampling for each region occurred in different months throughout the year and so each region should be examined in isolation from the other selected areas. Additionally, each of the regions surveyed were of different sizes.

The effective search width (ESW) was calculated for the survey as a whole after pooling the data, (ESW ± SE) 190.28 ± 13.42 m.

**Generalized additive modelling (GAM)**

On inspection of the diagnostic plot for SST, the relationship was a straight line, demonstrating an increase in sightings with increasing SST and so the smoothing function was replaced with a linear term. The overall GAM explained 45.1% of the deviance in porpoise presence/absence. The model was significant ( $P < 0.05$ ) and explained a greater amount of deviance (64.7%) when run using data from 2004 only, whereas only 30.2% of deviance was explained using data from 2002 (not significant) and 59.7% ( $P < 0.05$ ) during 2003 (Table 4).

The results of the full GAM suggest that position (Lat, Lon) depth and SST were significantly related ( $P < 0.05$ ) to the presence of harbour porpoises (Table 5), with the highest abundance of harbour porpoises occurring in West Scotland. The SST had a positive effect on porpoise presence but this was found to be significant only during 2003 ( $P < 0.05$ ) and 2004 ( $P < 0.05$ ). The relationship with depth ( $P < 0.05$ ) for the full GAM, depicted an increase in porpoise presence around the 100 m depth contour (Figure 4). The presence of porpoises during the month of June was also highlighted as being significantly higher than in the months of May, July, August and September, in all years ( $P < 0.01$ ) after testing all pairs of months.

**DISCUSSION**

It is clear from the data collected that the west coast of the UK represents an important area for the harbour porpoise

**Table 3.** DISTANCE analysis for 2004. Estimated population size (N), density (D), area size (km<sup>2</sup>), with upper (UCI) and lower confidence intervals (LCI) for population size and the coefficient of variation (CV) for each region.

Area	N	D	Km <sup>2</sup>	LCI	UCI	CV
South West	163	0.148	1100	67	400	0.443
Northern Ireland	387	0.387	1000	170	877	0.406
Firth of Clyde	1645	0.823	2000	823	3289	0.351
West Scotland	3105	1.071	2900	2032	4745	0.208

**Table 4.** Results of generalized additive models (GAMs) of presence/absence of harbour porpoises, including model significance and percentage of overall deviance explained. Full, data for 2002, 2003 and 2004 combined.

GAM	P	R <sup>2</sup>	Deviance explained (%)
Full	0.013	0.461	45.1
2002	0.102	0.246	30.2
2003	0.034	0.606	59.7
2004	0.123	0.656	64.7

(*Phocoena phocoena*) during the summer months. Harbour porpoises were observed throughout the surveys along the west coast of the UK, being seen around the South West in May and June, throughout waters in Northern Ireland and Wales in July and around the Firth of Clyde and the west of Scotland during July, August and September.

Population estimates have been given for each region studied during 2004; however, these should be examined with caution, as each estimate refers to the time of survey. Only through repeat surveys in additional years and through year-round monitoring of the sites can accurate estimates of the population within these areas be given. The South West was found to have an estimated population of 163 (67<sub>LCI</sub>-400<sub>UCI</sub>) individuals during the months of May and June. This estimate is undoubtedly smaller than the actual population for the entire region, as survey observations have only been made on the south coast. Nevertheless, as no porpoises were observed within the English Channel on the SCANS survey during 1994 and only a small number of observations made in this region in 2005 it may be assumed that this is a small population, or one which is dispersed over a large area. An alternative suggestion is that the South West population exists largely offshore. The findings of the joint WDCCS and Greenpeace 2004 winter survey demonstrated a number of sightings of harbour porpoises in offshore waters in the south-western approaches to the UK (WDCCS, 2004). Indeed research has demonstrated their presence in waters as deep as 1502 m off the shelf waters off the coast of Scotland, on the Rockall and Faroe

**Table 5.** Contribution and significance (P) of smoothed and parametric environmental predictor variables for overall and yearly generalized additive models (GAMs). Full, data for 2002, 2003 and 2004 combined.

Variable	Estimated df (for smoothers) or direction of effect	χ <sup>2</sup> (for smoothers) or z value	P
<b>Full GAM</b>			
Lat, Lon	9.630	43.74	0.0016
Depth	3.348	14.71	0.0399
SST	+	3.839	<0.001
Month	Jun > other months		
<b>2002</b>			
Lat, Lon	8.27	28.089	0.0439
<b>2003</b>			
Depth	3.441	13.47	0.0615
SST	+	2.469	0.0135
<b>2004</b>			
Lat, Lon	1.546	11.290	0.0235
Depth	1.000	6.621	0.0101
SST	+	2.285	0.0223

Lat, latitude; Lon, longitude; SST, sea surface temperature.

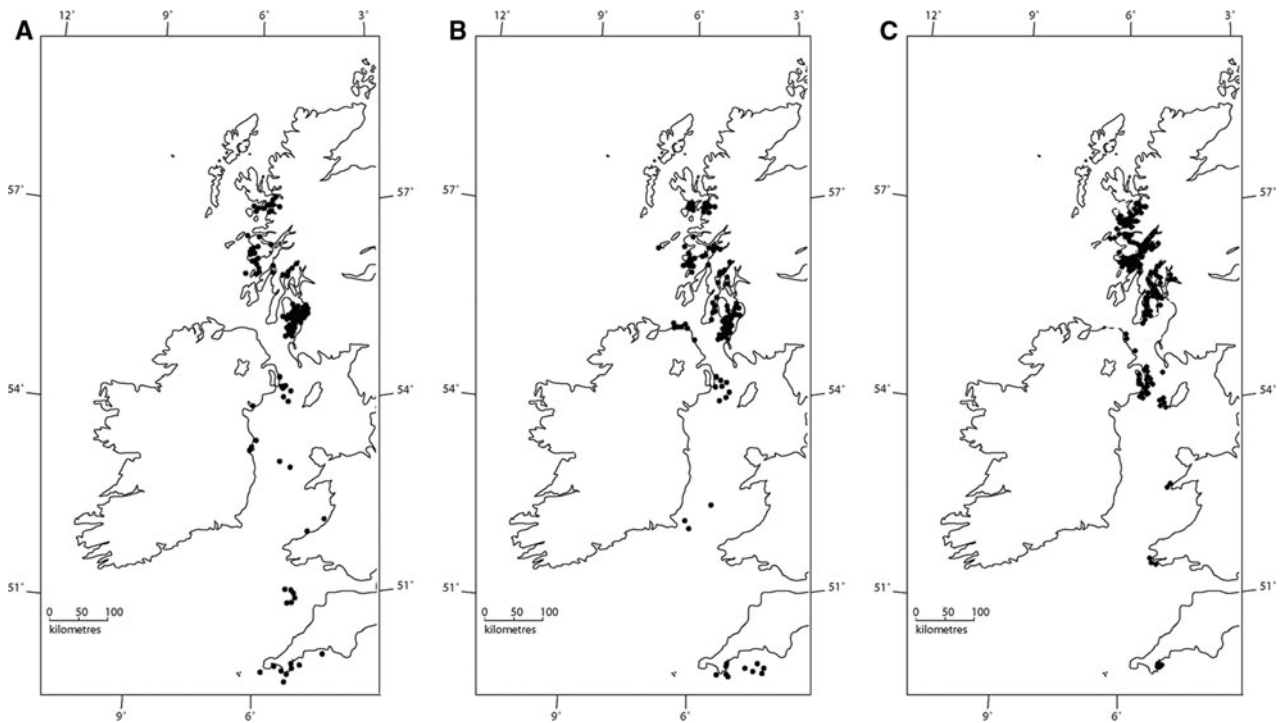


Fig. 3. Location of observed harbour porpoise (*Phocoena phocoena*) groups during (A) May and August, 2002; (B) May and September, 2003; and (C) May and September, 2004 for the west coast of the UK.

Banks (MacLeod *et al.*, 2003). This highlights the importance of research into new or as yet un-surveyed waters. A lack of research does not indicate a lack of animals, just as high effort in some areas does not necessarily indicate an area of critical importance for the species (Kenney & Winn, 1986).

Whilst the SCANS II survey in 2005 only identified a small number of porpoises for the South West, a north to south movement of animals since the original survey conducted in 1994 has been speculated upon (Hammond & MacLeod, 2006). The South West population therefore may have the potential to increase further, however, as the region is also known to have high levels of harbour porpoise by-catch

(Goodwin & Edwards, 2007), this population may only increase if adequately protected.

Harbour porpoises also utilize coastal waters off Wales (Weir *et al.*, 2001). As data collection in this area was not possible beyond the first year of study, no estimate of population size for this region has been given. It is noted however, that the region has been classified by Evans & Wang (2002) as a location where porpoises have been recorded over several years, with a presence in every month of the year and concentrations in at least four months during April–September, warranting further attention as a protected area (Category 1).

To date harbour porpoises off the coast of Northern Ireland have received little attention. This research identifies the presence of porpoises in the region and estimates the population to be approximately 387 ( $170_{LCI}$ – $877_{UCI}$ ) individuals, during the month of July. Whilst time spent on survey within the region is less than that required for a Category 3 classification, under the site classification criteria produced by Evans & Wang (2002) (locations where porpoises have been recorded over several years, with a presence in at least three months and concentrations in at least two months), personal communication with both local people, fishermen and the Ulster Wildlife Trust would indicate that this may be a key area for the species, where they are sighted on a regular basis.

The coast of Scotland is renowned for its sightings of cetacean species (Evans *et al.*, 2003; Scott & Parsons, 2004), with both the SMRU and the HWDT conducting research from the coast (Stockin *et al.*, 2001; Gordon & Northridge, 2003; Grellier & Wilson, 2003; Parsons *et al.*, 2003; MacLeod, 2004). Despite this, however, few detailed assessments of harbour porpoise population or distribution in this region have been published. This study indicates that a population of 1645 ( $823_{LCI}$ – $3289_{UCI}$ ) exists around the Firth of Clyde and its associated waters in July, with approximately 3105

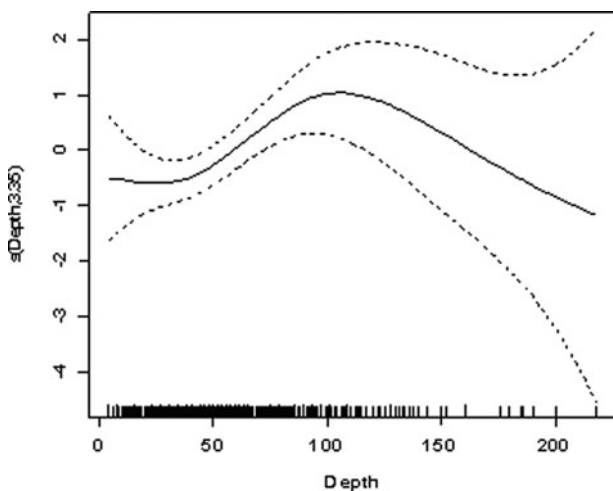


Fig. 4. Generalized additive model (GAM) plot for the years, 2002, 2003 and 2004 combined (full GAM) for harbour porpoise presence in relation to depth.

(2032<sub>LCI</sub>–4745<sub>UCI</sub>) further north around the Western Isles, and potentially extending out into the Hebrides during August and September. The area from Mallaig up to the far north of Scotland has received a Category 1 classification (Evans & Wang, 2002), however, no classification has been made for the region around the Firth of Clyde, where the numbers recorded in this study would indicate high use by porpoises.

It must be remembered that information on porpoise use of each of these areas is seasonally restricted by the nature of the survey undertaken. The areas surveyed from June onwards are likely to have an increased sighting rate due to calving within this period. Indeed Bannon (2006) and Weir *et al.* (2001) also found increasing numbers of harbour porpoises during these months due to the presence of calving females. Additionally, Hamazaki (2002) notes a seasonal shift in habitat use during the months of June and August, indicating that the increasing numbers observed further north, as the survey progressed up the coast may have been additionally confounded by seasonal variation in habitat use.

The generalized additive model, when run with a smoothing function on SST found an increasing relationship between harbour porpoise presence and SST. As the survey progressed through the summer, so the SST had increased. Due to the time of the year and possible calving periods, as SST was seen to increase so the numbers of porpoises will also have increased. It is not surprising therefore that this relationship was seen in the diagnostic plots and found to be statistically significant even after the smoothing function was replaced with a linear term. The relationship with depth is perhaps more interesting, with an increasing number of porpoise sightings around the 100 m depth contour. Previous research has demonstrated significant relationships with depth for the harbour porpoise, thought to be related to the distribution of prey species (MacLeod *et al.*, 2003; Hastie *et al.*, 2005; Molina-Schiller *et al.*, 2005; Tynan *et al.*, 2005). Indeed Johnston *et al.* (2005) note that distribution patterns of harbour porpoises are usually the result of foraging decisions made at a meso-scale (10's to 100 km) and fine scale (1–10 km), based on the assumption that these animals, requiring a high energy consumption, will remain near a prey patch until it becomes energetically profitable to move on (Molina-Schiller *et al.*, 2005). Given their small size, energetic requirements and reliance on prey availability, their patterns of movement are likely to be highly correlated with prey distribution (Johnston *et al.*, 2005).

These data provide a three year analysis of density and distribution of the harbour porpoise for sites along the west coast of the UK. Whilst the study is limited by the seasonal nature of the survey course, considering different areas, at different times of the year, it provides inter-annual comparison of sites from 2002 to 2004. Comparing the estimated porpoise density in each region for each year of the survey highlights inter-annual variation. Whilst the SCANS surveys indicate a general increase in the last ten years, the results of this survey indicate a potential decline in numbers from 2002 to 2004 for the South West. As this is only based on three years of data, collected from the south coast alone however, caution must be applied in interpreting these figures further. In the case of Northern Ireland these results are some of the first quantitative analysis of the harbour porpoise within the region. The GAM depicts a statistically significant relationship with depth and in particular the 100 m depth contour, which

is interesting to note in relation to further understanding habitat use by this species.

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## REFERENCES

- Au D. and Perryman W.** (1982) Movement and speed of dolphin schools responding to an approaching ship. *Fishery Bulletin* 80, 371–379.
- Ballance L.T., Pitman R.L. and Fiedler P.C.** (2006) Oceanographic influences on seabirds and cetaceans of the eastern tropical Pacific: a review. *Progress in Oceanography* 69, 360–390.
- Bannon S.M.** (2006) Diversity and relative abundance of cetaceans in three areas off the west coast of Scotland. In Evans P.G.H. (ed.) *European Research on Cetaceans—20. Proceedings of the 20th Annual Conference of the European Cetacean Society, Gdynia, Poland*. Cambridge: European Cetacean Society, in press.
- Barlow J.** (1987) *Abundance estimation of harbour porpoise (Phocoena phocoena) based on ship surveys along the coasts of California, Oregon and Washington*. Administrative Report LJ-87-05. National Marine Fisheries Service. Southwest Fisheries Center.
- Cañadas A., Sagarminaga R., De Stephanis R., Urquiloa E. and Hammond P.S.** (2005) Habitat preference modelling as a conservation tool proposed for marine protected areas for cetaceans in southern Spanish waters. *Aquatic Conservation: Marine and Freshwater Ecosystems* 15, 495–521.
- Carwardine M.** (1995). In Evans P. and Weinrich M. (eds) *Whales, dolphins and porpoises*. London: Dorling Kindersley Handbooks, pp. 242–243.
- Cockcroft V.G., Ross G.J.B. and Peddemors V.M.** (1990) Bottlenose dolphin *Tursiops truncatus* distribution in Natal's coastal waters. *South African Journal of Marine Science* 9, 1–10.
- Connor D.W., Gilliland P.M., Golding N., Robinson P., Todd D. and Verling E.** (2006) *UK SeaMap: the mapping of seabed and water column features of UK seas*. Peterborough: Joint Nature Conservation Committee.
- Evans P.G.H.** (1992) *Status Review of Cetaceans in British and Irish Waters*. Report to UK Department of Environment. Sea Watch Foundation, Oxford.
- Evans P.G.H., Anderwald P. and Baines M.E.** (2003) *UK Cetacean Status Review*. Report to English Nature and Countryside Council for Wales. Sea Watch Foundation, Oxford.
- Evans P.G.H., Fisher Q.C.P., Jordon W., Limer R. and Rees I.** (1994) A study of the reactions of harbour porpoises to various boats in the coastal waters of Southeast Shetland. In Evans P.G.H. (ed.) *European Research on Cetaceans—8. Proceedings of the 8th Annual Conference*

- of the European Cetacean Society, Montpellier, France. Cambridge: European Cetacean Society, pp. 60–64.
- Evans P.G.H. and Wang J.** (2002) *Re-examination of distribution data for the harbour porpoise around Wales and the UK with a view to site selection for this species*. Oxford: Sea Watch Foundation.
- Gaskin D.E.** (1968) Distribution of Delphinidae (Cetacea) in relation to sea surface temperatures off eastern and southern New Zealand. *New Zealand Journal of Marine and Freshwater Research* 2, 527–534.
- Goodwin L. and Edwards J.** (2007) *The South West Dolphin Report*. A joint publication produced by Marine Connection and the Wildlife Trusts.
- Gordon J. and Northridge S.P.** (2003) *Potential impacts of acoustic deterrent devices on Scottish marine wildlife*. Contract Report to Scottish Natural Heritage.
- Grellier K. and Wilson B.** (2003) Bottlenose dolphins using the sound of Barra, Scotland. *Aquatic Mammals* 29, 378–382.
- Hamazaki T.** (2002) Spatiotemporal prediction models of cetacean habitats in the mid-western North Atlantic Ocean (from Cape Hatteras, North Carolina, USA to Nova Scotia, Canada). *Marine Mammal Science* 18, 920–939.
- Hammond P.S., Berggren P., Benke H., Borchers D.L., Collet A., Heide-Jørgensen M.P., Heimlich S., Hiby A.R., Leopold M.F. and Øien N.** (2002) Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. *Journal of Applied Ecology* 39, 361–376.
- Hammond P.S. and MacLeod K.** (2006) *SCANS II—Report on Progress*. Document for ASCOBANS Meeting of Parties, Egmond aan Zee, The Netherlands.
- Hastie G.D., Swift R.J., Slesser G., Thompson P.M. and Turrell W.R.** (2005) Environmental models for predicting oceanic dolphin habitat in the Northeast Atlantic. *ICES Journal of Marine Science* 62, 760–770.
- Hastie G.D. and Tibshirani R.J.** (1990) *Generalized additive models. Monographs on Statistics and Applied Probability*. London: Chapman & Hall, 335 pp.
- Heide-Jørgensen M.P., Teilmann J., Benke H. and Wulf J.** (1993) Abundance and distribution of harbour porpoises *Phocoena phocoena* in selected areas of the western Baltic and the North Sea. *Helgoländer Meeresunters* 47, 335–346.
- Hui C.A.** (1979) Undersea topography and distribution of dolphins of the genus *Delphinus* in the Southern California Bight. *Journal of Mammalogy* 60, 521–527.
- Jefferson T.A., Hung S.K., Law L., Torey M. and Treganza N.** (2002) Distribution and abundance of finless porpoises in Hong Kong and adjacent waters of China. *Raffles Bulletin of Zoology* 10, 43–55.
- Johnston D.W., Westgate A.J. and Read A.J.** (2005) Effects of fine scale oceanographic features on the distribution and movements of harbour porpoises *Phocoena phocoena* in the Bay of Fundy. *Marine Ecology Progress Series* 295, 279–293.
- Kennedy R.D. and Winn H.E.** (1986) Cetacean high-use habitats of the Northeast United States Continental Shelf. *Fishery Bulletin* 84, 345–357.
- Leopold M.F., Wolf P.A. and Meer J. van der** (1992) The elusive harbour porpoise exposed: strip transect counts off southwestern Ireland. *Netherlands Journal of Sea Research* 29, 395–402.
- MacLeod K.** (2004) Abundance of the Atlantic white-sided dolphin (*Lagenorhynchus acutus*) during summer off northwest Scotland. *Journal of Cetacean Research and Management* 6, 33–40.
- MacLeod K., Simmonds M.P. and Murray E.** (2003) Summer distribution and relative abundance of cetacean populations off north-west Scotland. *Journal of the Marine Biological Association of the United Kingdom* 83, 1187–1192.
- Molina-Schiller D., Rosales S.A. and De Freitas T.R.O.** (2005) Oceanographic conditions off coastal South America in relation to the distribution of Burmeister's porpoise, *Phocoena spinipinnis*. *Latin American Journal of Aquatic Mammals* 4, 141–156.
- Palka D.** (1995) Influences on spatial patterns of Gulf of Maine harbour porpoises. In Blix A.S. *et al.* (eds) *Whales, seals, fish and man*. Amsterdam: Elsevier Science, pp. 69–76.
- Parsons E.C.M., Warburton C.A., Woods-Ballard A., Hughes A. and Johnston P.** (2003) The value of conserving whales: the impacts of whale-watching on the economy of rural West Scotland. *Aquatic Conservation: Marine and Freshwater Ecosystems* 13, 23–36.
- Read A.** (1999) *Porpoises*. Grantown-on-Spey, Scotland: Colin Baxter Photography.
- Redfern J.V., Ferguson M.C., Becker E.A., Hyrenbach K.D., Good C., Barlow J., Kaschner K., Baumgartner M.F., Forney K.A., Balance L.T., Fauchald P., Halpin P., Hamazaki T., Pershing A.J., Qian S.S., Read A., Reilly S.B., Torres L. and Werner F.** (2006) Techniques for cetacean-habitat modeling. *Marine Ecology Progress Series* 310, 271–295.
- Reid J.B., Evans P.G.H. and Northridge S.** (2003) *Atlas of cetacean distribution in north-west European waters*. Peterborough: Joint Nature Conservation Committee.
- Scott N.J. and Parsons E.C.M.** (2004) A survey of public awareness of the occurrence and diversity of cetaceans in south-west Scotland. *Journal of the Marine Biological Association of the United Kingdom* 84, 1101–1104.
- Slooten E.** (1994) Behaviour of Hector's dolphin: classifying behaviour by sequence analysis. *Journal of Mammalogy* 75, 956–964.
- Stockin K.A., Fairbairns R.S., Parsons E.C.M. and Sims D.W.** (2001) Effects of diel and seasonal cycles on the dive duration of the minke whale (*Balaenoptera acutorostrata*). *Journal of the Marine Biological Association of the United Kingdom* 81, 189–190.
- Tynan C.T., Ainley D.G., Barth J.A., Cowles T.J., Pierce S.D. and Spear L.B.** (2005) Cetacean distributions relative to ocean processes in the northern California Current System. *Deep-Sea Research. Part II—Tropical Studies in Oceanography* 52, 145–167.
- Weir C.R., Pollack C., Cronin C. and Taylor S.** (2001) Cetaceans of the Atlantic Frontier, north and west of Scotland. *Continental Shelf Research* 21, 1047–1071.
- Whale and Dolphin Conservation Society (WDCS)** (2004) *Cetaceans and pelagic trawl fisheries in the Western Approaches of the English Channel*. A WDCS Scientific Report: The Report of the 2004 WDCS/Greenpeace Winter Survey.
- and
- Wood S.N.** (2004) Stable and efficient multiple smoothing parameter estimation for generalized additive models. *Journal of the American Statistical Association* 99, 673–686.

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