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Cetacean sightings and strandings: evidence for spatial and temporal trends?

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*Cetacean species and their habitats are under threat and effective marine management mitigation strategies require knowledge and understanding of cetacean ecology. This requires data that are challenging and expensive to obtain; incidental sightings/strandings data are potential underused resources. In this study, incidental cetacean sightings (N = 6631) and strandings (N = 1856) in coastal waters of Cornwall, south-west Britain (1991 to 2008) were analysed for evidence of spatial and temporal patterns or trends. Eighteen species were recorded sighted and/or stranded; key species were identified as bottlenose dolphin (*Tursiops truncatus*), harbour porpoise (*Phocoena phocoena*), common dolphin (*Delphinus delphis*), Risso's dolphin (*Grampus griseus*) and minke whale (*Balaenoptera acutorostrata*). There were significant decreases in bottlenose dolphin sightings and pod size but an increase in harbour porpoise and minke whale sightings. Cetacean strandings showed a recent decrease over time although there was a significant positive trend in harbour porpoise strandings that correlated with sightings. Incidence of sightings and strandings were both greater on the south coast than the north coast. When Marine Tour Operator data were analysed, distinct species-specific inshore and offshore habitat use was evident. With rigorous interrogation and editing, significant patterns and trends were gained from incidentally collected data, highlighting the importance of public engagement with such recording schemes and the potential of these underused resources.*

Keywords: conservation, habitat use, marine management, marine mammal

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INTRODUCTION

The world's oceans have suffered an abrupt decline in their capacity to provide crucial ecosystem goods and services (Crowder & Norse, 2008), all areas are affected by human influence and a large fraction (41%) strongly affected by multiple drivers of ecological change (Halpern *et al.*, 2008). Cetaceans face multiple threats (Bearzi, 2002; Bearzi *et al.*, 2004; Kelly *et al.*, 2004; MacLeod *et al.*, 2005; Weilgart, 2007). In European waters, cetaceans and their habitats are included in various conventions, treaties and agreements; many embrace creation of Marine Protected Areas (MPAs) (Evans, 2008) which are increasingly used as a management tool (Villa *et al.*, 2001; Lubchenco *et al.*, 2003; Palumbi, 2004). During the last decade, progress has been made in establishing MPAs but site identification, management and monitoring remains *ad hoc* (Evans, 2008). Knowledge of cetacean population ecology is fundamental for formulating conservation policy (Reid *et al.*, 2003) and effective policy depends on understanding relationships between species and habitats (Cañadas & Hammond, 2008) but for many cetacean species this information is largely non-existent (Reid *et al.*, 2003).

Monitoring spatial and temporal variation in cetacean abundance may determine if management action is required and helps identify remedial action (Evans & Hammond, 2004). Cetacean dispersion, determinants of patterns, habitat requirements and time-series data are also considered valuable in identifying changes to, or disruption of marine ecosystem processes (Reid *et al.*, 2003). Habitat modelling has predicted cetacean habitats in previously un-surveyed areas (Moses & Finn, 1997; Hamazaki, 2002) and predicted habitat shifts associated with oceanographic changes (Hamazaki, 2002). Spatial and temporal data for cetaceans have helped identify appropriate areas for MPAs (Hooker *et al.*, 1999; Cañadas *et al.*, 2002, 2005; Gomez De Segura *et al.*, 2006; Weilgart, 2006) and to develop conservation and management plans within protected areas (Hastie *et al.*, 2003; Cañadas & Hammond, 2008; Panigada *et al.*, 2008).

Collection of necessary data is difficult (Compton *et al.*, 2007; Kiszka *et al.*, 2007) as most cetacean species are highly mobile and spend substantial time below surface. This makes detection, identification, and group size estimation difficult (Redfern *et al.*, 2006). Weather and more specifically sea state also affects the detectability of cetacean species (Hammond *et al.*, 2002). A variety of approaches can be used dependent on species and available resources and these are reviewed in Evans & Hammond (2004). Environmental, biotic or anthropogenic factors can influence spatial and temporal patterns and correlation of environmental variables with sightings data can improve ecological understanding and highlight factors affecting distribution (Davis *et al.*, 1998). Findings are varied and frequently species-specific. However, bathymetry, specifically depth and seabed relief are often significant variables associated with cetacean

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distribution (e.g. Baumgartner, 1997; Cañadas *et al.*, 2002; Hastie *et al.*, 2003, 2004; MacLeod *et al.*, 2007) as well as sea surface temperature (e.g. Selzer & Payne, 1988), seasonality (e.g. Hooker *et al.*, 1999) and coastal currents (Tynan *et al.*, 2005). However, these may be secondary to environmental variables aggregating prey species (e.g. Baumgartner, 1997; Bearzi *et al.*, 2008) including tidal fronts, seabed and coastal topography, which can all influence cetacean distribution through aggregating prey (Reid *et al.*, 2003).

Historic sightings and catch data have helped define habitat areas for the North Pacific right whale (*Eubalaena japonica*) (Shelden *et al.*, 2005) and to identify previous summer feeding grounds of the North Atlantic right whale (*Eubalaena glacialis*) (Smith *et al.*, 2006). Historical literature, photographic records, osteological (bone) collections and strandings data have established past distribution and declines of common dolphin (*Delphinus delphis*) in various Mediterranean Sea areas (Bearzi *et al.*, 2003). Analyses of cetacean strandings data have identified changes in cetacean communities attributed to increased sea temperature (MacLeod *et al.*, 2005). Incidental sightings data have been seen to reflect effort corrected data (Camphuysen, 2004; Siebert *et al.*, 2006) and may constitute a valuable resource particularly in areas with limited or no specific survey work (Siebert *et al.*, 2006). Interpretation of incidental data is made difficult without quantification of sightability and effort (Evans & Hammond, 2004; Witt *et al.*, 2007a, b); nonetheless, with stringent data interrogation and filtering valuable patterns and trends can be identified (Witt *et al.*, 2007b; Tomás *et al.*, 2008).

SCANS, a large-scale line transect survey using ships and aircraft in the North Sea and adjacent waters determined abundance estimates as a basis for conservation strategy in European waters (Hammond *et al.*, 2002). SCANS-II aimed to update abundance estimates for the whole of the European Atlantic continental shelf, make recommendations for future monitoring and facilitate development of by-catch management models (Hammond & MacLeod, 2006). Such large-scale studies have a major role to play but there is also a need for an understanding of fine scale distribution and seasonal changes (Evans & Hammond, 2004).

In Cornwall and the Isles of Scilly a marine sightings scheme, Seaquest Southwest, and the Marine Strandings Network are hosted by the Cornwall Wildlife Trust (CWT) and run in conjunction with the Environmental Records Centre for Cornwall and the Isles of Scilly (ERCCIS). These allow members of the public and other interested parties to report cetacean sightings and strandings data. Here we undertake a comprehensive analysis of these data between 1991 and 2008 aimed at increasing knowledge of spatial and temporal ecology of cetaceans in the south-west of the UK.

MATERIALS AND METHODS

Sightings

The Seaquest Southwest database held 14,623 records, all non-cetacean sightings were removed (N = 6418). Cetacean sightings were recorded within seventeen species categories. Three further categories held sightings that had not been identified to species level. Each entry represented single or multiple animal sightings. A Geographical Information System (GIS) land map was created for the county of Cornwall using coordinates conforming to the British National Grid projection (metres). A 50 nautical mile (92.6 km) buffer shape was projected from the coast; the resulting polygon was deemed the study area. Formulae were used to determine the year and month of all sightings and to convert all sighting locations into decimal degree co-ordinates (longitude, latitude; WGS84). All sightings records prior to 1 January 1991 and subsequent to 31 December 2008 were removed (N = 214) together with cetacean strandings (N = 61). This date range represented the period that the sightings scheme had been running as a dedicated electronic database; records prior to 1991 were significantly sparser. Records that fell outside the study area (N = 1153) or that were not spatially locatable to a place name (N = 146) were removed; in total 6631 records were retained. In addition, a 12 nautical mile (22 km) buffer was projected from the Cornish coast and was edited to produce north and south sectors that excluded the Isles of Scilly. This buffer focused analysis on Cornish coastal waters and reduced the total number of sightings to 4991 for this part of the analysis. Three Marine Tour Operators (MTOs) were identified within the dataset who had contributed sightings data independently since 2003 from the areas of Land's End/Mount's Bay and Falmouth Bay (Figure 1). These sightings were recorded during marine wildlife tours and resulting data were analysed separate to sightings held in the Seaquest Southwest database.

Strandings

The strandings database held 1889 records of cetacean strandings in Cornish waters for the study period. Strandings were recorded within twelve species categories. Nine further categories held strandings that had not been identified to species level. Each entry represented a single animal stranding. A mass stranding event of common dolphins (N = 26) in 2008 on the south coast of Cornwall was reduced to one entry due to the potential for this to dominate subsequent statistical analyses. Validation of the spatial coordinates given with each stranding was carried out in accordance with the methodology described for sightings. Records that

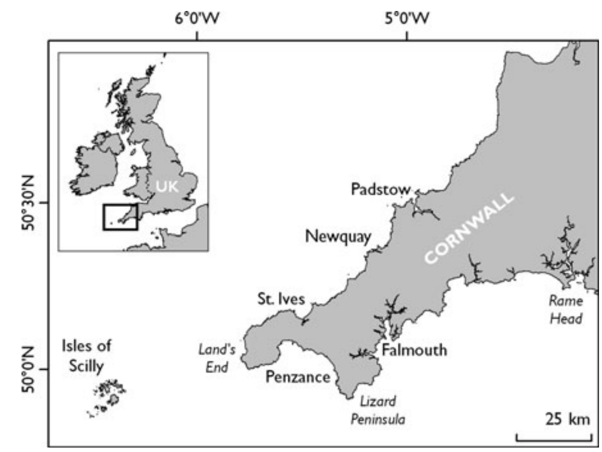

Fig. 1. Location map for Cornwall and the Isles of Scilly. Harbour areas are identified as Padstow, Newquay, St Ives, Penzance and Falmouth. The Land's End peninsula includes the headlands of Pendeen, Cape Cornwall and Gwennap Head.

fell outside the study area (N = 3) or that were not spatially referencable (N = 5) were removed; 1856 records were retained and 1786 of these records occurred within 12 nautical miles of land. All spatial analysis was undertaken using ArcView 9.2 (ESRI, Redlands, US, http://www.esri.com).

Statistical analysis

Statistical analysis was undertaken using R (R Development Core Team, 2008). Species-specific sightings as proportions of all sightings by year excluding MTO data, all sightings by year excluding MTO data and bottlenose dolphin (*Tursiops truncatus*) sightings and species-specific strandings as proportions of all strandings by year were analysed using generalized additive modelling (GAM) or general linear modelling (GLM) where the GAM suggested that the relationship was linear. GAM was undertaken using the package mgcv 1.4-1 utilizing integrated smoothness estimation. Results from GAM statistical modelling were validated using diagnostic plots, including qq plots, residuals versus linear predictor, distribution of residuals and response versus fitted values. Results from GLM statistical modelling were validated using diagnostic plots, including residuals versus fitted values and qq plots.

The spatial patterns and densities of all cetacean sightings and strandings (1991–2008; coastline to 50 nautical miles offshore), species-specific cetacean sightings and MTO species-specific sightings were determined using an interlaced grid of hexagonal polygons. This procedure was undertaken using custom written scripts in MATLAB (The MathWorks, v7.11).

RESULTS

Temporal analysis

SIGHTINGS: GENERAL TRENDS

Between 1991 and 2008, 6631 cetacean sightings were recorded in the study area. The most commonly sighted species, each representing >3% of the total sightings (which on average represents at least 10 records per year), were bottlenose dolphin (N = 2986), harbour porpoise (*Phocoena phocoena*) (N = 1519), common dolphin (N = 625), Risso's dolphin (*Grampus griseus*) (N = 252) and minke whale (*Balaenoptera acutorostrata*) (N = 182) (Table 1). Sightings that represented >0.5% but ≤3% of total sightings were killer whale (*Orcinus orca*) (N = 113), pilot whale (*Globicephala melas*) (N = 86) and fin whale (*Balaenoptera physalus*) (N = 49) (Table 1). There were also records for humpback whale (*Megaptera novaeangliae*) (N = 21), white-beaked dolphin (*Lagenorhynchus albirostris*) (N = 12), striped dolphin (*Stenella coeruleoalba*) (N = 7), sperm whale (*Physeter macrocephalus*) (N = 4), sei whale (*Balaenoptera borealis*) (N = 3), white-sided dolphin (*L. acutus*) (N = 3), Cuvier's beaked whale (*Ziphius cavirostris*) (N = 1), false killer whale (*Pseudorca crassidens*) (N = 1) and northern bottlenose whale (*Hyperoodon ampullatus*) (N = 1). Three further categories recorded sightings that had only been identified as dolphin spp. (N = 704), whale spp. (N = 49) or cetacean spp. (N = 13); these were considered as one category, 'unidentified species'. MTO data contributed 453 sightings. The number of these annual sightings increased from first appearing in the dataset from 53 in 2004 to 163 in 2008 (Figure 2A; see Supplementary Table 1 online).

Table 1. Most commonly sighted and stranded species as identified. Totals and percentages are given for sightings including and excluding Marine Tour Operator (MTO) data.

	Sightings including MTO data total sightings: N = 6631		**Sightings excluding MTO data total sightings: N = 6178**		**Strandings total strandings: N = 1856**	
Species	**Count**	**as %**	**Count**	**as %**	**Count**	**as %**
Bottlenose dolphin	2986	45	2851	46	14	1
Harbour porpoise	1519	23	1328	22	475	26
Common dolphin	625	9	546	9	823	44
Risso's dolphin	252	4	235	4	13	1
Minke whale	182	3	167	3	15	1
Killer whale	113	2	112	2	0	0
Pilot whale	86	1	84	1	63	3
Fin whale	49	<1	42	<1	3	<1
Striped dolphin	7	<1	7	<1	33	2

Annually, there was a broad increase in total recorded sightings (Figure 2A). However, when MTO data were removed, sightings remained relatively constant over the last eight years of the dataset (2001–2008). Sightings of bottlenose dolphin showed an absolute decline over the whole period, whereas, total sightings for all other species show a steady increase. Seasonality is evident in the sightings data with peak sightings being recorded in the summer months June to September (Figure 2B).

STRANDINGS: GENERAL TRENDS

Between 1991 and 2008, 1856 cetaceans were recorded stranded in the study area. Individual species that represented >0.5% of all strandings were common dolphin (N = 823), harbour porpoise (N = 475), pilot whale (N = 63), striped dolphin (N = 33), minke whale (N = 15), bottlenose dolphin (N = 14) and Risso's dolphin (N = 13) (Table 1). Species not recorded as stranded but sighted, were killer whale, humpback whale, sei whale, false killer whale and northern bottlenose whale. Supplementary Table 1 online details all stranded species, counts and percentages.

Annually, total recorded strandings had increased since 1991, peaking in 2003 but subsequently declined (Figure 2C). Peak years showed high levels of strandings for harbour porpoise and/or common dolphin. Seasonality was evident for strandings with peaks in winter and early spring (Figure 2D).

SIGHTINGS: SPECIES-SPECIFIC TRENDS

By year

Generalized additive modelling analysis highlighted significant negative trends in the number of bottlenose dolphin sightings as a proportion of total sightings ($F_{1,16} = 21.95$, $P < 0.001$; Figure 3A) and in pod size ($F_{1,16} = 23.66$, $P < 0.001$; Figure 3B). Analysis of pod size related to records where more than one individual was sighted.

Bottlenose dolphin sightings represented over 46% of all records; therefore, any temporal trend for this species could

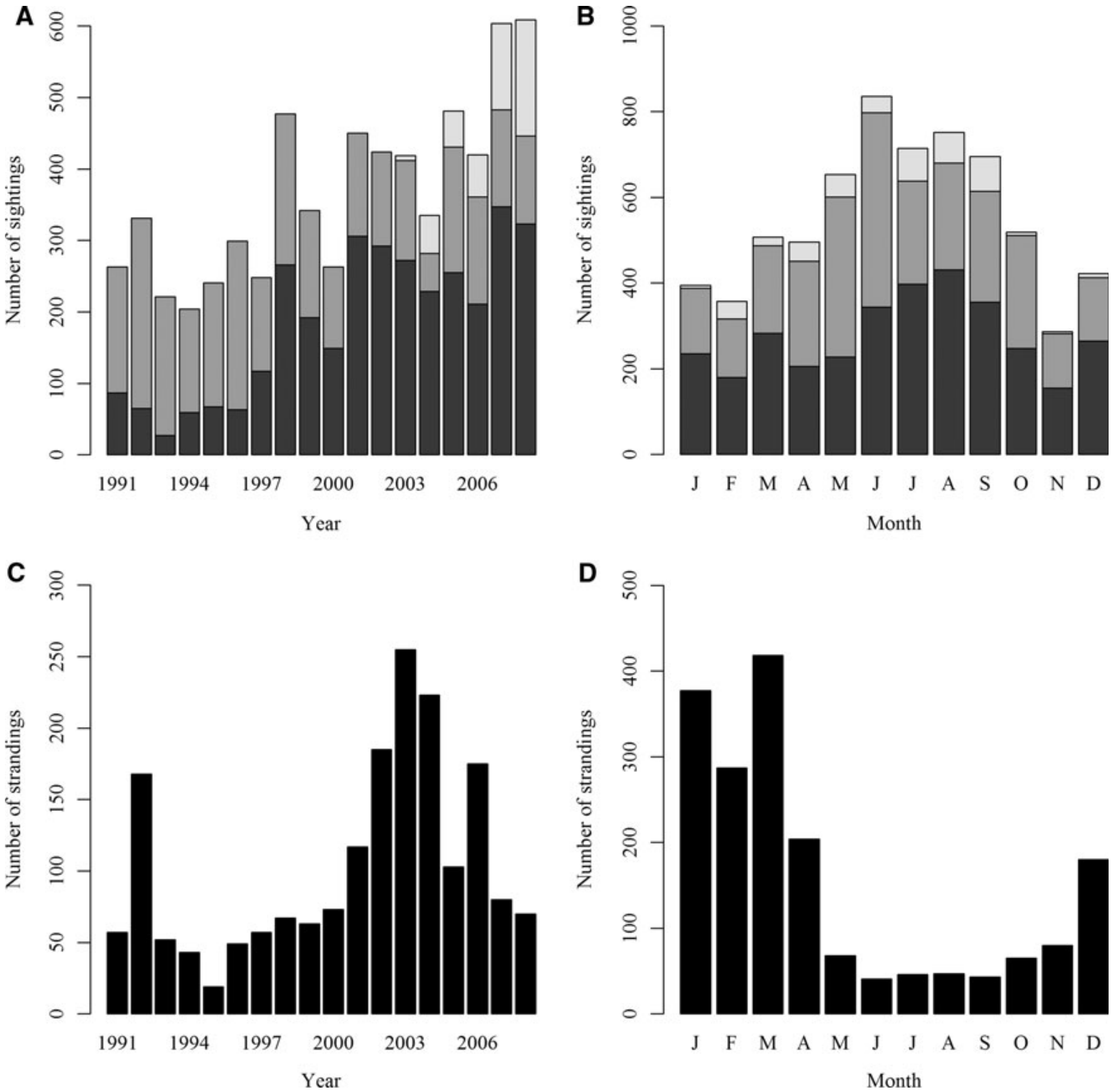

Fig. 2. (A) Number of sightings for all cetacean species by year from 1991 to 2008 (N = 6631). Marine Tour Operator (MTO) sightings 2003 to 2008 are shown as light grey caps (N = 453). Bottlenose dolphin sightings are shown as mid-grey (N = 2851). All other sightings are shown as black (N = 3327); (B) number of sightings for all cetacean species by month from 1991 to 2008. MTO sightings 2003 to 2008 are shown as light grey caps. Bottlenose dolphin sightings are shown as mid-grey. All other sightings are shown as black; (C) number of strandings for all cetacean species by year from 1991 to 2008 (N = 1856); (D) number of strandings for all cetacean species by month from 1991 to 2008.

have potentially skewed trends for other species. As a result, temporal trends for all other species were analysed without the inclusion of bottlenose dolphin data. When the significant decline in bottlenose dolphin over time was corrected for there remained a significant positive trend in the number of harbour porpoise sightings as a proportion of total sightings ($F_{1,16} = 7.43$, $P < 0.01$; Figure 3C) and a significant trend in minke whale sightings. Preliminary GAM analysis suggested a linear relationship for minke whale sightings as a proportion of total sightings; subsequent GLM analysis showed a significant positive trend ($F_{1,10} = 41.13$, $P < 0.001$; Figure 3D).

Minke whale sightings were absent for the first 5 years (1991 to 1995), therefore we felt it inappropriate to fit the GLM to these years, as such GLM analysis only included data from 1996 onwards. The proportion of minke whales sightings in 2001 represented 23% of all minke whale sightings (an exception for any species in the dataset), as such we chose to eliminate these data during GLM analysis given the likelihood that they would compromise the derivation of a meaningful linear relationship.

By month

Analysis of species-specific sightings as proportion of all cetacean sightings records by month was made to take account of the inherent flux in monthly sightings that was potentially attributable to survey effort. This allowed the contribution of a single species to the monthly patterns of sightings to be seen. Bottlenose dolphin showed twin peaks in sightings in late spring and autumn (see Supplementary Figure 1A online). Harbour porpoise showed a peak in winter (see Supplementary Figure 1B online). Common dolphin, Risso's dolphin, minke whale and pilot whale generally showed main seasonal peaks in late summer, though common dolphin also displayed spikes in April and December and pilot whale in November (see Supplementary Figure 1C, D,

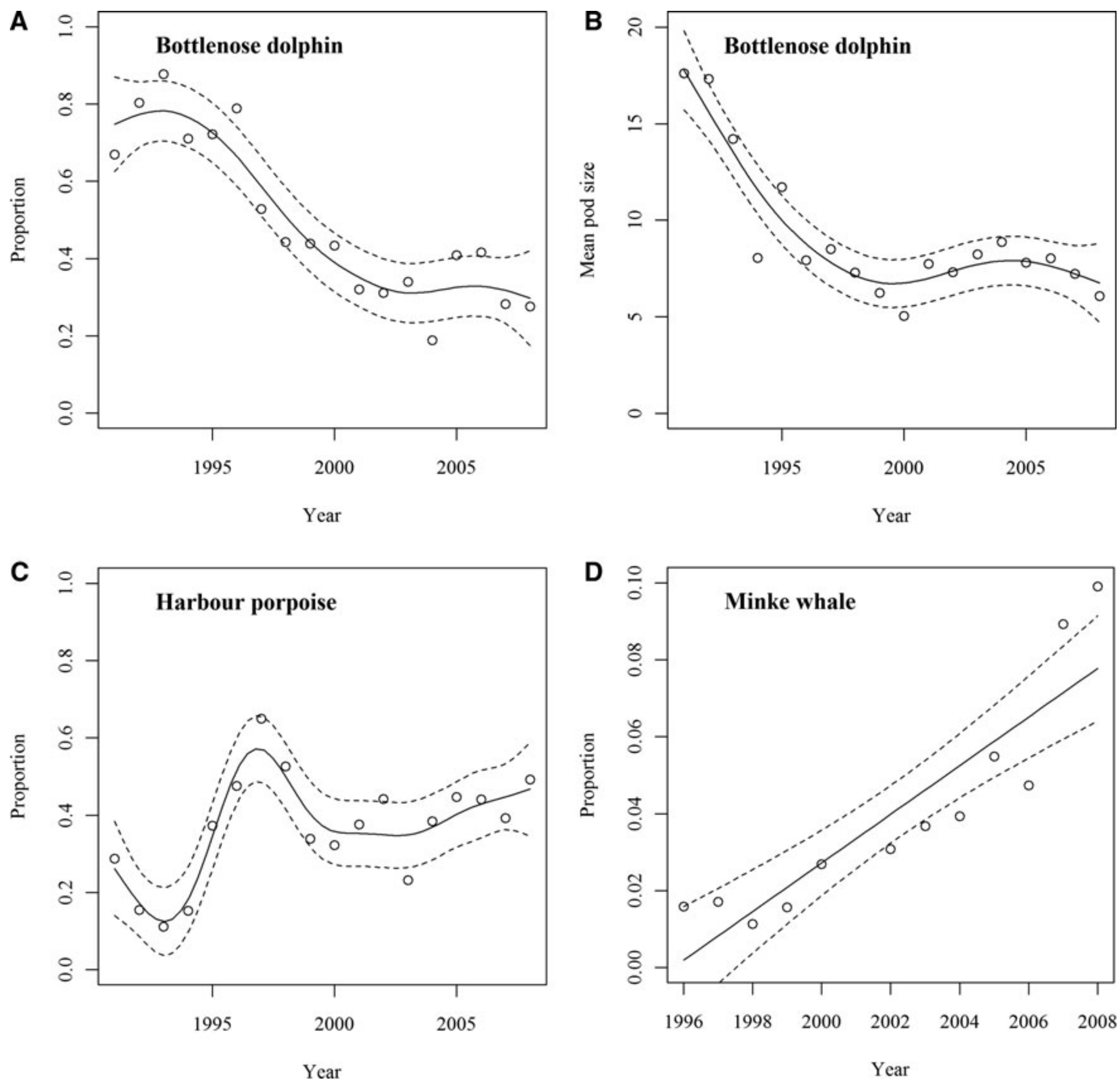

Fig. 3. (A) Bottlenose dolphin sightings as proportion of all sightings excluding Marine Tour Operator (MTO) data by year 1991 to 2008 (N = 2851; generalized additive modelling (GAM): $F_{1,16} = 21.95$, $P < 0.001$); (B) bottlenose dolphin mean pod size (N = 2596; GAM: $F_{1,16} = 23.66$, $P < 0.001$); (C) harbour porpoise sightings (N = 1328; GAM: $F_{1,16} = 7.43$, $P < 0.01$) as proportion of all sightings excluding MTO and bottlenose dolphin data by year 1991 to 2008; (D) minke whale sightings (N = 167; GLM: $F_{1,10} = 41.13$, $P < 0.001$) as proportion of all sightings excluding MTO and bottlenose dolphin data by year 1996 to 2008. All figures show 95% confidence intervals (broken lines).

E, & G online). Killer whale sightings peaked in May (see Supplementary Figure 1F online); however, this was driven by a cluster of sightings during 1998. Fin whale showed a winter peak (see Supplementary Figure 1H online).

STRANDINGS: SPECIES-SPECIFIC TRENDS

Preliminary GAM analysis suggested a linear relationship for harbour porpoise strandings as a proportion of total strandings, subsequent GLM analysis showed a significant positive trend for this species ($F_{1,16} = 17.01$, $P < 0.001$; See Supplementary Figure 2B,C online). Harbour porpoise strandings were significantly correlated by year with sightings ($F_{1,16} = 10.3$, $P < 0.01$; Figure 4B).

Evidence for seasonality of strandings was mixed. The most frequently stranded species, harbour porpoise and common dolphin both showed clear winter peaks (see Supplementary Figure 2B, C online). Total numbers of strandings for the other four species were low and therefore patterns may not be truly representative but are included for completeness (see Supplementary Figure 2A & D–F online).

Spatial analysis

SIGHTINGS

Spatial distribution mapping (hexagonal polygonal binning) gave clear indication of a high density of sightings around the Land's End peninsula and to a lesser extent around several north and south coast headlands and in some bay areas on the south coast. There was a lower density of sightings to the north-east of the county (Figure 5A). Bottlenose dolphin sightings were concentrated around north and south coast harbour areas as well as Land's End (Figure 6A). There was a low (relative) density of sightings for this species off the Isles of Scilly. There was a greater density of harbour porpoise sightings around Land's End, the Lizard and the Isles of Scilly (Figure 6B). Common dolphin had a greater density of sightings off the south coast than the north; this species also demonstrated an increased density of sightings off the Isles of Scilly (Figure 6C).

Analysis of records occurring up to 12 nautical miles from the north and south coasts of Cornwall further highlighted

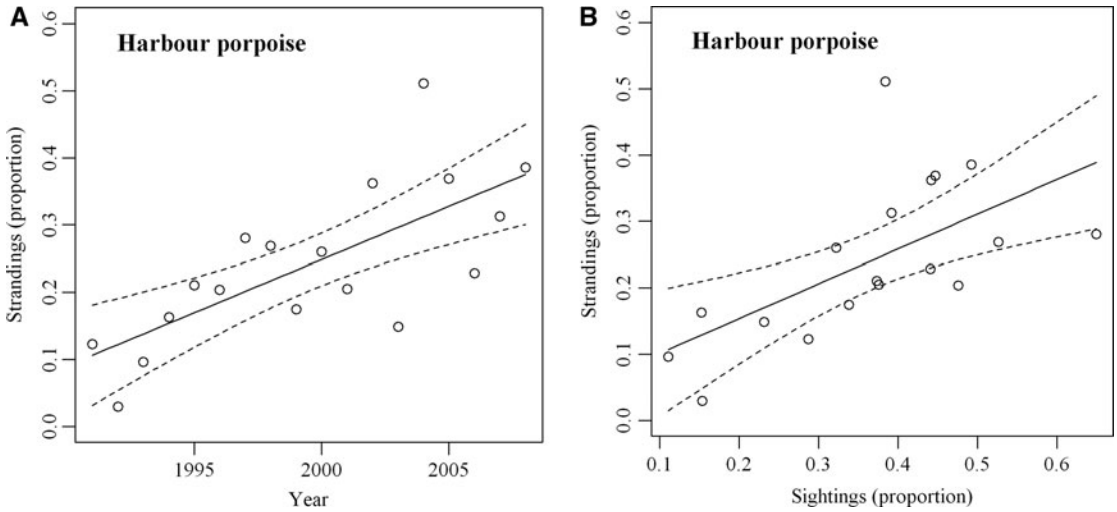

Fig. 4. (A) Harbour porpoise strandings as proportion of all strandings by year 1991 to 2008 (N = 475; generalized linear model (GLM): $F_{1,16} = 17.01$, $P < 0.001$); (B) linear regression between harbour porpoise sightings and strandings by year (GLM: $F_{1,16} = 10.3$, $P < 0.01$). All figures show 95% confidence intervals (broken lines).

species-specific spatial distribution patterns. This analysis focused on coastal waters and excluded the Isles of Scilly. The reduced area of this spatial analysis reduced total numbers of sightings analysed to N = 4991. Neither bottlenose dolphin nor harbour porpoise showed specific bias between north and south coasts. The greatest variation was seen with minke whale: 22% north/78% south, pilot whale 24% north/76% south and common dolphin: 27% north/73% south.

STRANDINGS

There was evidence for an increased density of strandings on the south coast compared to the north coast with strandings particularly associated with coastal embayments (Figure 5B) thus supporting the observations made by Leeney *et al.* (2008). Harbour porpoise strandings were mainly concentrated in south coast bays. Common dolphin showed greater range in their spatial patterns with higher density along the south coast and at St Ives. Minke whale strandings were concentrated along the south coast. Pilot whale, bottlenose dolphin and Risso's dolphin showed no specific strong north/south bias. Analysis of records occurring within 12 nautical miles of land further highlighted species-specific spatial patterns. The total numbers of analysed strandings reduced to N = 1786. All species showed a notable division of strandings between north and south coasts. Bottlenose dolphin and Risso's dolphin showed a split 38% north/62% south and 40%/60% respectively. The greatest variations were seen with common dolphin: 17% north/83% south, minke whale 20% north/80% south, harbour porpoise: 25% north/75% south and pilot whale 31% north/69% south. There were clear similarities between species-specific sightings and strandings patterns for north and south coasts.

MTO sightings: distance and depth

Only two of the MTOs held data spatially referenced 'at sea'. Spatial density mapping used for both sets of MTO sightings data showed an increase in density of cetacean sightings eastward of significant bathymetric features at Gwennap Head and Manacle Point as well as increased density in sightings near harbour areas (Figure 7). Increased sightings near harbours may however be artefacts of MTOs operating from their home port. Maps of species-specific distributions (see Supplementary Figure 3 online) show bottlenose dolphin in shallow coastal waters generally ≤20 m depth and ≤2 km (approximately 1 nautical mile) from shore. Harbour porpoise were seen across a wide spectrum of depths but generally 20–60 m <5 km (approximately 2.5 nautical miles) from shore. Common dolphin favoured deeper water with depths between 50 and 70 m up to 9 km (approximately 5 nautical miles) from shore.

DISCUSSION

The sightings and strandings databases held records for a broad range of cetacean species, predominately toothed cetacean. The top three species recorded sighted were bottlenose dolphin, harbour porpoise and common dolphin. As the sightings data were collected with a greater effort from the coast and in near-shore waters, relative proportionality highlights species habitat use rather than species abundance with inshore species being sighted more often. This is supported through the MTO data.

Marine Tour Operator data showed distinct species-specific spatial patterns. Bottlenose dolphins were found in shallow near-shore coastal waters. The spatial density mapping for all data for this species showed sightings concentrated in harbour and bay areas often within or close to estuary mouths as well as around Land's End headlands. The existence of separate coastal and offshore populations of bottlenose dolphin has been documented throughout its range (Würsig & Würsig, 1979; Hoelzel *et al.*, 1998). River estuaries, headlands and sand banks with uneven seabed relief and/or strong tidal currents are often favoured in coastal waters (Reid *et al.*, 2003). MTO data showed harbour porpoise and common dolphin were distributed across a broad range of depths and distance but with harbour porpoise also closer inshore in shallower depths than common dolphin. Kiszka *et al.* (2007) found harbour porpoises to show a preference for the shallow waters of the western English Channel with common dolphins being

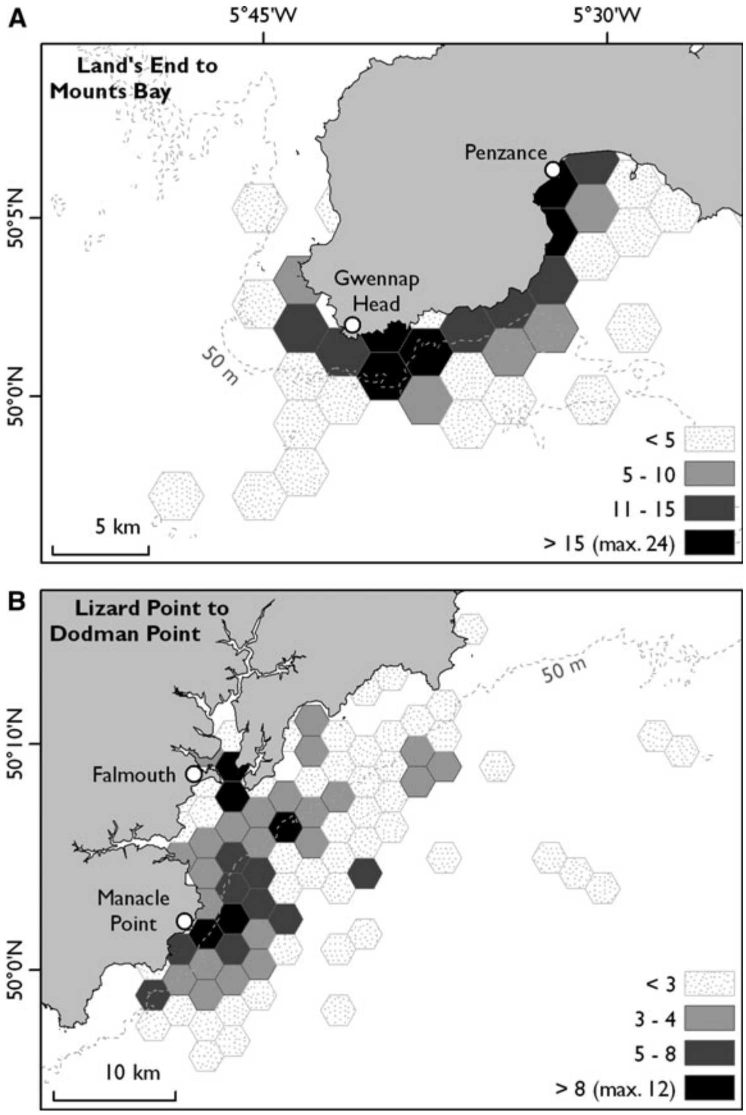

Fig. 5. Hexagonal polygon binning density estimates for (A) cetacean sightings with Marine Tour Operator data removed 1991 to 2008 (N = 6178) and (B) cetacean strandings 1991 to 2008 (N = 1856).

sighted in deeper shelf and oceanic waters. Spatial density mapping suggests an increase in density of cetacean sightings eastward of pronounced bathymetric features. Localized conditions such as tidal fronts, uneven bottom topography, narrow channels and eddies downstream of headlands and islands can favour biological productivity and aggregate prey, thereby influencing cetacean distribution (Reid *et al.*, 2003).

The overall increase in sightings records potentially reflects increased awareness and use of the sightings scheme as opposed to actual increase in cetacean occurrence. Similarly, the overall seasonality of sightings could indicate effort related bias. However, the shifts seen in species patterns over time, specifically those associated with proportionality of bottlenose dolphin, harbour porpoise and minke whale sightings may indicate changes in species occurrence. Such shifts could also reflect an increase in public education or awareness of species identification but, if so, one would also expect a decreasing trend of non-categorized species, which was not evident.

Reid *et al.* (2003) describes several resident bottlenose dolphin populations in UK waters. Wood (1998) discussed the residency pattern in Cornish waters of a group of approximately 25 to 30 animals between 1993 and 1996. Field studies and photo-identification suggested an emigration or loss of individuals from the area in 1994 and 1996. This reflects the trends seen in this study with a reduction in pod numbers to between 5 and 10 since 1996. The associated reduction in the proportion of bottlenose dolphin sightings may reflect a decrease in the potential for smaller pod sizes to be sighted from shore. The model of sudden population drop-off appears to fit these data better than one of a gradual decline. In 2005, SCANS-II (Hammond & MacLeod, 2006) reported an increase in harbour porpoise and minke whale abundance in the areas of the Channel and Celtic Sea over the previous 1994 SCANS survey (Hammond *et al.*, 2002). MacLeod *et al.* (2009) have also observed an increase in harbour porpoise occurrence in the English Channel albeit during winter months. These regional increases in species abundance

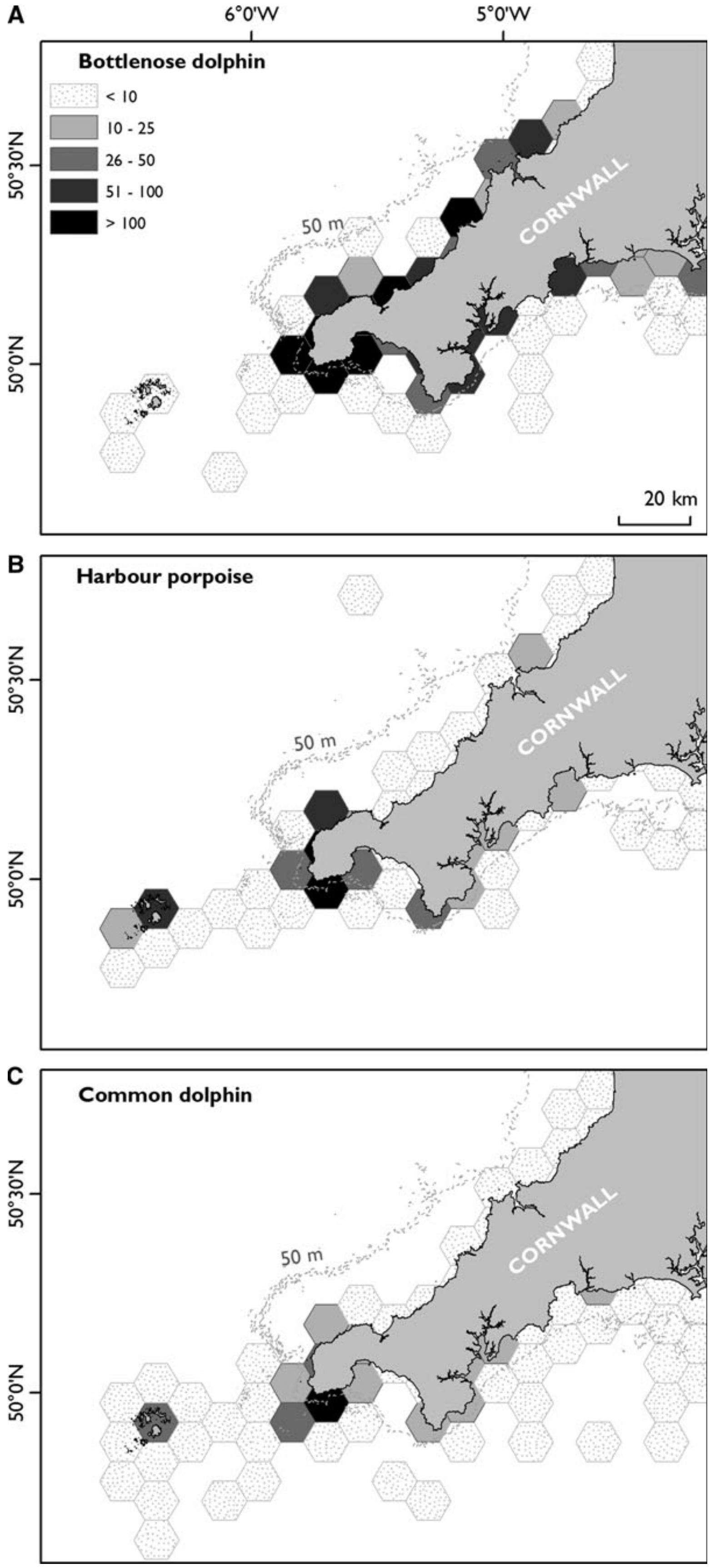

Fig. 6. Hexagonal polygon binning density estimates for species-specific cetacean sightings with Marine Tour Operator data removed 1991 to 2008 for (A) bottlenose dolphin (N = 2851), (B) harbour porpoise (N = 1328) and (C) common dolphin (N = 546).

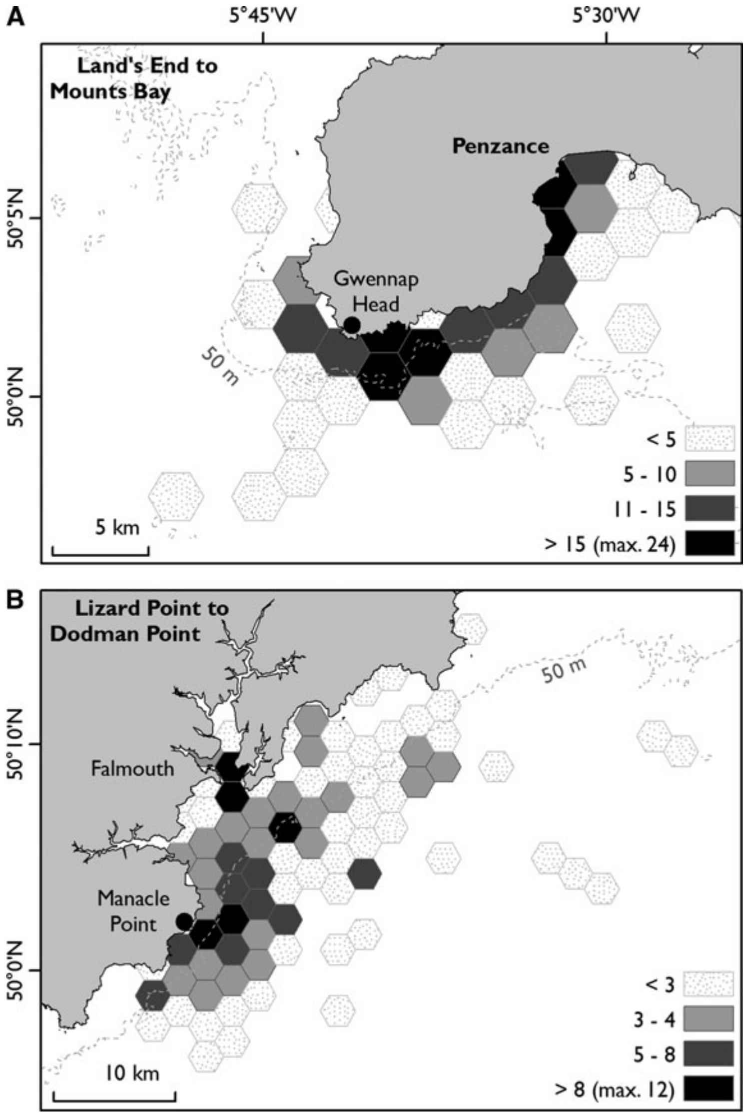

Fig. 7. Hexagonal polygon binning density estimates for Marine Tour Operator (MTO) sightings for all species: (A) Land's End to Mount's Bay (N = 234); (B) Lizard Point to Dodman Point (N = 253). For MTO species-specific plots see Supplementary Figure 3 online.

reflect trends for harbour porpoise and minke whale seen in this study. Camphuysen (2004) reported similar trends for harbour porpoise in Dutch coastal waters. It was suggested that prey availability had triggered a shift in distribution and that the observed trend should not be interpreted as a population recovery.

Both harbour porpoise and fin whales showed seasonal trends in sightings that did not mirror patterns that could be attributed to seasonal effort related bias. Harbour porpoise held winter/early spring peaks; these again replicate the findings of Camphuysen (2004). Fin whale held a winter peak in sightings, specifically December. This species mainly occur off the coast of the UK between June and December with part of the population overwintering and breeding south of Ireland and in the Western Channel Approaches (Reid *et al.*, 2003). This may account for the seasonal pattern of these sightings.

Overall density of sightings was greater at headlands and in some bay areas. This may reflect increased effort. Pelagic species, common dolphin, Risso's dolphin, minke whale and pilot whale had a greater number of sightings off the south coast. Greater recreational boat use here may increase sightings of these species. Coastal bathymetry could also exaggerate this trend; depth contours run significantly closer to the south coast than the north, which may result in pelagic species staying a greater distance from the north coast. Bottlenose dolphin and harbour porpoise showed no notable north/south bias. This may reflect habitat use with these species being more readily sighted from the coast and therefore showing an even north/south distribution of sightings. It is also possible that a combination of bathymetry, specifically depth and seafloor relief (e.g. Baumgartner, 1997; Cañadas *et al.*, 2002; Hastie *et al.*, 2004; Azzellino *et al.*, 2008) and coastal currents or tidal fronts (Reid *et al.*, 2003; Tynan *et al.*, 2005), are influencing cetacean distribution between north and south coasts.

Conspecific stranding patterns were in inverse proportion to sightings for bottlenose dolphin, harbour porpoise and common dolphin, supporting the suggestion that sightings numbers do not reflect abundance. Strandings trends and patterns for these data to 2006 have been discussed at length in Leeney *et al.* (2008). However, with the inclusion of data for 2007 and 2008, strandings overall, have shown a recent decline. This is principally due to a decrease in the absolute number of strandings of common dolphin and partly of harbour porpoise. Harbour porpoise strandings as a proportion of all strandings showed a significant positive trend that was significantly correlated by year to the increase in the proportion of sightings for this species. This lends credence to the proposition that changes in abundance and distribution may in part have led to an increase in recorded strandings for this species (Jepson, 2005; Sabin *et al.*, 2006). Leeney *et al.* (2008) reported a significant trend in common dolphin strandings between 1973 and 2006. With the inclusion of more recent data, this trend was no longer significant.

Seasonality of strandings was evident. Leeney *et al.* (2008) noted that patterns in strandings do not reflect the seasonal pattern of recreational coastal use. Similarly, these strandings patterns do not reflect the patterns of seasonality in sightings attributable to survey effort. It was therefore considered that these strandings patterns were not affected by effort. Common dolphin and harbour porpoise were the most frequently recorded stranded species. Both species held clear winter peaks. It is acknowledged that by-catch has been the major cause of death in UK stranded harbour porpoise and common dolphin since 1990 (Jepson, 2005) and that the south-west of England (Cornwall and Devon) represents a hotspot for such strandings. Leeney *et al.* (2008) highlight the potential for various fisheries to affect cetacean populations through by-catch. Locally, concern has been raised over the potential impact of inshore gill/tangle net fisheries on cetaceans in south-west waters (CWT, 2006). With the sustained positive trend in harbour porpoise strandings and sightings combined with the seasonal trend for inshore sightings, the potential for this interaction should not be dismissed.

Spatial patterns for strandings broadly support those reported by Leeney *et al.* (2008) with greater density of strandings on the south coast than north. Interestingly, this pattern was also seen with bottlenose dolphin and harbour porpoise: species recognized by this study as having no specific north/south bias in sightings. This lends support to the observation by Leeney *et al.* (2008) that local prevailing winds and/or currents may in part drive strandings distribution.

Mindful of the inherent temporal and spatial bias within incidentally collected data (Evans & Hammond, 2004; Witt *et al.*, 2007a, b) with rigorous and methodical interrogation and editing together with cautious interpretation, significant temporal/spatial patterns have been shown for the species bottlenose dolphin, harbour porpoise, common dolphin, minke whale and fin whale. Further dedicated work using effort corrected line transect surveys or fixed passive acoustic monitoring using C-PODS (Carstensen *et al.*, 2006) may corroborate the seasonal patterns observed in this study and assemblage of time-series data will identify trends. This study particularly highlights the potential resource held within publicly driven recording schemes. Providing data are gathered without causing disturbance to the animals, engaging with collectors and enhancing the quality of data collected, particularly spatial referencing and recording effort, may prove a worthwhile consideration.

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Supplementary materials and methods

The Supplementary material referred to in this article can be found online at journals.cambridge.org/mbi.

REFERENCES

Azzellino A., Gaspari S., Airoldi S. and Nani B. (2008) Habitat use and preferences of cetaceans along the continental slope and adjacent pelagic waters of the western Ligurian Sea. *Deep-Sea Research Part I* 55, 296–323.

Baumgartner M.F. (1997) The distribution of Risso's dolphin (*Grampus griseus*) with respect to the physiography of the northern Gulf of Mexico. *Marine Mammal Science* 13, 614–638.

Bearzi G. (2002) Interactions between cetaceans and fisheries in the Mediterranean Sea. In Notarbartolo di Sciara G (ed.) (2002) *Cetaceans of the Mediterranean and Black Seas: state of knowledge and conservation strategies.* A report to the ACCOBAMS secretariat, Monaco, February 2002.

Bearzi G., Reeves R.R., Notarbartolo di Sciara G., Politi E., Cañadas A., Frantzis A. and Mussi B. (2003) Ecology, status and conservation of short-beaked common dolphins *Delphinus delphis* in the Mediterranean Sea. *Mammal Review* 33, 224–252.

Bearzi G., Holcer D. and Notarbartolo di Sciara G. (2004) The role of historical dolphin takes and habitat degradation in shaping the present status of northern Adriatic cetaceans. *Aquatic Conservation: Marine and Freshwater Ecosystems* 14, 363–379.

Bearzi G., Fortuna C.M. and Reeves R.R. (2008) Ecology and conservation of common bottlenose dolphins *Tursiops truncatus* in the Mediterranean Sea. *Mammal Review* 39, 92–123.

Camphuysen K.C.J. (2004) The return of the harbour porpoise (*Phocoena phocoena*) in Dutch coastal waters. *Lutra* 47, 113–122.

Cañadas A. and Hammond P.S. (2008) Abundance and habitat preferences of the short-beaked common dolphin *Delphinus delphis* in the southwestern Mediterranean: implications for conservation. *Endangered Species Research* 4, 309–331.

Cañadas A., Sagarminaga R. and García-Tiscar S. (2002) Cetacean distribution related with depth and slope in the Mediterranean waters off southern Spain. *Deep-Sea Research I* 49, 2053–2073.

Cañadas A., Sagarminaga R., De Stephanis R., Urquiola E. and Hammond P.S. (2005) Habitat preference modelling as a conservation tool: proposals for marine protected areas for cetaceans in southern Spanish waters. *Aquatic Conservation: Marine and Freshwater Ecosystems* 15, 495–521.

Carstensen J., Henriksen O.D. and Teilmann J. (2006) Impacts of offshore wind farm construction on harbour porpoise: acoustic monitoring of echolocation activity using porpoise detectors (T-PODs). *Marine Ecology Progress Series* 321, 295–308.

Compton R., Banks A., Goodwin L. and Hooker S.K. (2007) Pilot cetacean survey of the sub-Arctic North Atlantic utilizing a cruise-ship platform. *Journal of the Marine Biological Association of the United Kingdom* 87, 321–325.

Crowder L. and Norse E. (2008) Essential ecological insights for marine ecosystem-based management and marine spatial planning. *Marine Policy* 32, 772–778.

CWT (2006) *Cetacean by-catch analysis: a report on the mortality of cetaceans stranded on the coast of Cornwall in January 2006*. Truro: Cornwall Wildlife Trust, 24 pp.

Davis R.W., Fargion G.S., May N., Leming T.D., Baumgartner M., Evans W.E., Hansen L.J. and Mullin K. (1998) Physical habitat of cetaceans along the continental slope in the north-central and western Gulf of Mexico. *Marine Mammal Science* 14, 490–507.

Evans P.G.H. (ed.) (2008) *Selection criteria for marine protected areas for cetaceans. Proceedings of the ECS/ASCOBANS/ACCOBAMS workshop. ECS (European Cetacean Society). Special Publication Series, no. 48*, 13 pp.

Evans P.G.H. and Hammond P.S. (2004) Monitoring cetaceans in European waters. *Mammal Review* 34, 131–156.

Gomez De Segura A., Crespo E.A., Pedraza S.N., Hammond P.S. and Raga J.A. (2006) Abundance of small cetaceans in waters of the central Spanish Mediterranean. *Marine Biology* 150, 149–160.

Halpern B.S., Walbridge S., Selkoe K.A., Kappel C.V., Micheli F., D'Agrosa C., Bruno J.F., Casey K.S., Ebert C., Fox H.E., Fujita R., Heinemann D., Lenihan H.S., Madin E.M.P., Perry M.T., Selig E.R., Spalding M., Steneck R. and Watson R. (2008) A global map of human impact on marine ecosystems. *Science* 319, 948–952.

Hamazaki T. (2002) Spatio-temporal prediction models of cetacean habitats in the mid-western North Atlantic Ocean (from Cape Hatteras, North Carolina, U.S.A. to Nova Scotia, Canada). *Marine Mammal Science* 18, 920–939.

Hammond P.S. and MacLeod K. (2006) *Progress report on the SCANS-II project*. A report to the ASCOBANS Advisory Committee, Finland, April 2006, 6 pp.

Hammond P.S., Berggren P., Benke H., Borchers D.L., Collet A., Heide-Jorgensen 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.

Hastie G.D., Wilson B. and Thompson P.M. (2003) Fine-scale habitat selection by coastal bottlenose dolphin: application of a new video montage technique. *Canadian Journal of Zoology* 81, 469–478.

Hastie G.D., Wilson B., Wilson L.J., Parsons K.M. and Thompson P.M. (2004) Functional mechanisms underlying cetacean distribution patterns: hotspots for bottlenose dolphins are linked to foraging. *Marine Biology* 144, 397–403.

Hoelzel A.R., Potter C.W. and Best P.B. (1998) Genetic differentiation between parapatric 'nearshore' and 'offshore' populations of the bottlenose dolphin. *Proceedings of the Royal Society of London B* 265, 1177–1183.

Hooker S.K., Whitehead H. and Gowans S. (1999) Marine protected area design and the spatial and temporal distribution of cetaceans in a submarine canyon. *Conservation Biology* 13, 592–602.

Jepson P.D. (ed.) (2005) *Cetaceans Strandings Investigation and Co-ordination in the UK. Report to Defra for the period 1st January 2000–31st December 2004. Trends in cetacean strandings around the UK coastline and cetacean and marine turtle post-mortem investigations 2000 to 2004 inclusive (Contract CRO 238).* NHM Consulting, 142 pp. http://www.defra.gov.uk/wildlifecountryside/resprog/findings/cetaceanar/index.htm (accessed 23 March 2007).

Kelly C., Glegg G.A. and Speedie C.D. (2004) Management of marine wildlife disturbance. *Ocean and Coastal Management* 47, 1–19.

Kiszka J., Macleod K., Van Canneyt O., Walker D. and Ridoux V. (2007) Distribution, encounter rates, and habitat characteristics of toothed cetaceans in the Bay of Biscay and adjacent waters from platform-of-opportunity data. *ICES Journal of Marine Science* 64, 1033–1043.

Leeney R.H., Amies R., Broderick A.C., Witt M.J., Loveridge J., Doyle J. and Godley B.J. (2008) Spatio-temporal analysis of cetacean strandings and by-catch in a UK fisheries hotspot. *Biodiversity and Conservation* 17, 2323–2338.

Lubchenco J., Palumbi S.R., Gaines S.D. and Andelman S. (2003) Plugging a hole in the ocean: the emerging science of marine reserves. *Ecological Applications* 13, 3–7.

MacLeod C.D., Bannon S.M., Pierce G.J., Schweder C., Learmonth J.A., Herman J.S. and Reid R.J. (2005) Climate change and the cetacean community of north-west Scotland. *Biological Conservation* 124, 477–483.

MacLeod C.D., Weir C.R., Pierpoint C. and Harland E.J. (2007) The habitat preferences of marine mammals west of Scotland (UK). *Journal of the Marine Biological Association of the United Kingdom* 87, 157–164.

MacLeod C.D., Brereton T. and Martin C. (2009) Changes in the occurrence of common dolphins, striped dolphins and harbour porpoise in the English Channel and Bay of Biscay. *Journal of the Marine Biological Association of the United Kingdom* 89, 1059–1065.

Moses E. and Finn J.T. (1997) Using Geographical Information Systems to predict North Atlantic right whale (*Eubalaena glacialis*) habitat. *Journal of Northwest Atlantic Fishery Science* 22, 37–46.

Palumbi S.R. (2004) Marine reserves and oceans neighbourhoods: the spatial scale of marine populations and their management. *Annual Review of Environment and Resources* 29, 31–68.

Panigada S., Zanardelli M., MacKenzie M., Donovan C., Mélin F. and Hammond P.S. (2008) Modelling habitat preferences for fin whales and striped dolphins in the Pelagos Sanctuary (Western Mediterranean Sea) with physiographic and remote sensing variables. *Remote Sensing of Environment* 112, 3400–3412.

R Development Core Team (2008) *R: A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing. ISBN 3-900051-07-0, URL http://www.R-project.org

Redfern J.V., Ferguson M.C., Becker E.A., Hyrenbach K.D., Good C., Barlow J., Kaschner S.K., Baumgartner M.F., Forney K.A., Ballance 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 modelling. *Marine Ecology Progress Series* 310, 271–295.

Reid J.B., Evans P.G.H. and Northridge S.P. (eds) (2003) *Atlas of cetacean distribution in north-west European waters*. Peterborough: Joint Nature Conservation Committee, 77 pp.

Sabin R.C., Chimonides P.D.J., Spurrier C.J.H., Evans-Jones E.L., Jepson P.D., Deaville R., Reid R.J., Patterson I.A.P., Penrose R. and Law R. (2006) *Consultancy report to Defra: trends in cetacean strandings around the UK coastline and cetacean and marine turtle post-mortem investigations 2005*. NHM Consulting, 47 pp. http://www.defra.gov.uk/wildlife-countryside/resprog/findings/cetacean05/index.htm (accessed 23 March 2007).

Selzer L.A. and Payne P.M. (1988). The distribution of white sided (*Lagenorhynchus acutus*) and common dolphin (*Delphinus delphis*) vs. the environment features of the continental shelf of the northeastern United States. *Marine Mammal Science* 4, 141–153.

Shelden K.E.W., Moore S.E., Waite J.M., Wade P.R. and Rugh D.J. (2005) Historic and current habitat use by North Pacific right whales (*Eubalaena japonica*) in the Bering Sea and Gulf of Alaska. *Mammal Review* 35, 129–155.

Siebert U., Gilles A., Lucke K., Ludwig M., Benke H., Kock K.H. and Scheidat M. (2006) A decade of harbour porpoise occurrence in German waters—analyses of aerial surveys, incidental sightings and strandings. *Journal of Sea Research* 56, 65–80.

Smith T.D., Barthelmess K. and Reeves R.R. (2006) Using historical records to relocate a long-forgotten summer feeding ground of North Atlantic right whales. *Marine Mammal Science* 22, 723–734.

Tomás J., Gozalbes P., Raga J.A. and Godley B.J. (2008) Bycatch of loggerhead sea turtles: insights from 14 years of stranding data. *Endangered Species Research* 5, 161–169.

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 Californian Current System. *Deep-Sea Research II* 52, 145–167.

Villa F., Tunesi L. and Agardy T. (2001) Zoning marine protected areas through spatial multiple-criteria analysis: the case of the Asinara Island national marine reserve of Italy. *Conservation Biology* 16, 515–526.

Weilgart L.S. (2006) *Managing noise through Marine Protected Areas around global hot spots.* Paper presented to the 58th Annual Meeting of the International Whaling Commission Scientific Committee, 11 May 2006, 12pp. http://www.iwcoffice.org/_documents/sci_com/SC58docs/SC-58-E25.pdf (accessed 3 June 2009).

Weilgart L.S. (2007) The impacts of anthropogenic ocean noise on cetaceans and implications for management. *Canadian Journal of Zoology* 85, 1091–1116.

Witt M.J., Broderick A.C., Johns D.J., Martin C.S., Penrose R., Hoogmoed M.S. and Godley B.J. (2007a) Prey landscapes help identify potential foraging habitats for leatherback turtles in the northeast Atlantic. *Marine Ecology Progress Series* 337, 231–244.

Witt M.J., Penrose R. and Godley B.J. (2007b) Spatio-temporal patterns of juvenile marine turtle occurrence in waters of the European continental shelf. *Marine Biology* 151, 873–885.

Wood C.J. (1998) Movement of bottlenose dolphins around the south-west coast of Britain. *Journal of Zoology* 246, 155–163.

and

Würsig B. and Würsig M. (1979). Behaviour and ecology of the bottlenose dolphin (*Tursiops truncatus*), in the South Atlantic. *Fishery Bulletin* 77, 399–412.

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