J. Mar. Biol. Ass. U.K. (2005), **85**, 1083–1088
Printed in the United Kingdom

Spatial distribution patterns of basking sharks on the European shelf: preliminary comparison of satellite-tag geolocation, survey and public sightings data

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Current concerns about the population levels of the basking shark (*Cetorhinus maximus*) in the north-east Atlantic have prompted a need to understand population distribution, habitat preference and centres of abundance. In this study, spatial distribution maps derived from satellite-tag geolocations, boat surveys and public sightings data were compared. The broad distribution patterns revealed by these different methods are similar, but there are considerable differences in density distributions. Surface sightings data show high densities, or 'hotspots' in the Hebridean Sea, Clyde Sea, Irish Sea and close inshore around Devon and Cornwall. Tag geolocations, in contrast, identified two areas where individuals spent considerable time outside the distributions indicated by surveys and public sightings: the Celtic Sea and Western Approaches of the English Channel. The reason for this disparity and its implications for population estimates for the species are discussed.

INTRODUCTION

Populations of large-bodied, predatory shark species have declined precipitously in recent years with some arguably approaching collapse as a consequence of increased human exploitation (Jackson et al., 2001; Baum et al., 2003). It is thought plankton-feeding sharks have also been affected, although the scale and persistence of the problem for these little known species at present remains unclear (Sims & Reid, 2002). Historically, the basking shark (*Cetorhinus maximus*) was hunted by surface-harpoon fisheries that often expanded and declined rapidly in particular localities (McNally, 1976). Anecdotal observations of the disappearance of basking sharks from former hunting grounds on the European continental shelf (e.g. Isle of Skye, Scotland; Achill Island, Ireland) have been proposed as evidence for their broad-scale decline due to fishing (Anderson, 1990). Consequently, there is current concern that the population levels of basking shark have yet to recover from at least two hundred years of targeted hunting in the north-east Atlantic (Pawson & Vince, 1998). Apparent declines have resulted in measures for their protection under the precautionary principle, and the hunting of basking sharks was prohibited by several countries, including within UK territorial waters in 1998 under the Wildlife and Countryside Act (1981). More recently, *C. maximus* was listed on Appendix II of the Convention on International Trade in Endangered Species (CITES), indicating that concerns about reduced populations due to human exploitation are now of global significance.

It has not proved possible to assess the effects of past fishing mortality on basking shark populations in the north-east Atlantic because no reliable estimates of population size have been made. Without scientifically-based population assessment, it is impossible to determine current population trends and to monitor stocks effectively for conservation purposes. One reason for the lack of knowledge regarding population status is that distribution patterns and stock boundaries of this species within European seas are not known with any certainty. There is some evidence that *C. maximus* is highly migratory and tracks seasonal zooplankton aggregations closely (Sims & Quayle, 1998; Sims et al., 2003), including interannual shifts in zooplankton distribution (Sims & Reid, 2002). These shifts may explain the disappearance of basking sharks from areas where they were formerly abundant, rather than apparent declines being due exclusively to fishing mortality. Therefore, there is a need to identify the spatial distribution of basking sharks on the European shelf, to determine geographical areas of special significance to this species, and to determine whether current survey methods are able to provide indices of abundance in these areas.

Methods for assessing patterns of spatial distribution of animals range from tracking individual movements through to large-scale surveys. A major problem associated with visual surveys for basking sharks (e.g. ship, aerial or land-based) is that these methods rely on individual sharks spending sufficient time at the sea surface where they can be observed. Because it is not known whether all individuals within a population 'bask', how often this behaviour is exhibited, or whether they undertake it in all habitats occupied, there may be significant bias associated with such assessments of distribution pattern. Clearly, when basking sharks do not appear at the sea surface, their presence in some habitats may go unrecorded.

In this study we compare the spatial distributions of basking sharks derived from three datasets: (1) individual shark geolocations determined from satellite-linked archival telemetry; (2) effort-corrected counts from ship surveys; and (3) sightings of sharks reported by the UK public over a 15-y period. Archival telemetry theoretically provides a non-biased, independent means of assessing spatial distribution patterns, whereas public sightings and survey data may be biased towards identifying basking shark habitat only where sharks occur on the surface in areas accessible to study. Therefore, the purpose of this paper was to compare the spatial distribution of basking sharks between the methods employed, and identify whether surface sightings alone reflect adequately the habitat usage of basking sharks.

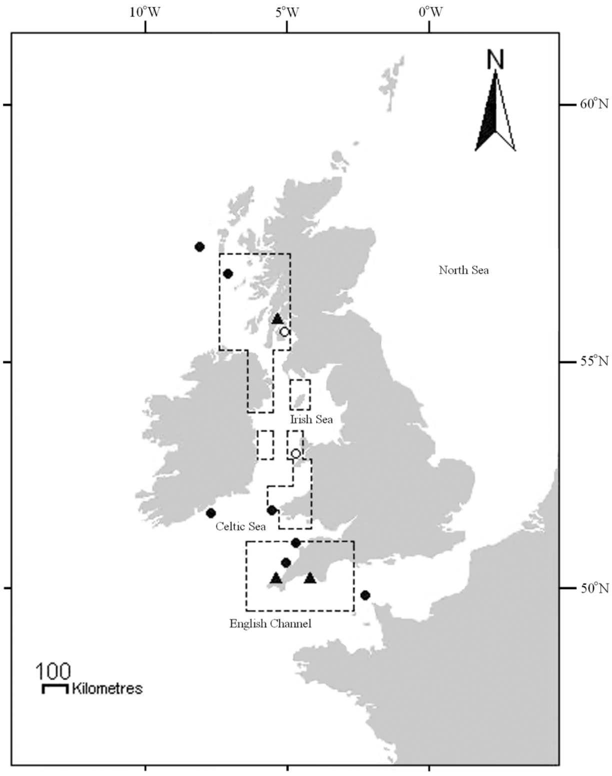

Figure 1. Tagging locations (filled triangle), pop-off locations (filled circle), tag recovery positions (open circle), sea areas covered by boat surveys, between 54°–57°N and 4°–7.5°W, 51.4°–53.5°N and 4°–6.1°W, 49.5°–51.2°N and 1.8°–6.6°W (broken line).

MATERIALS AND METHODS

Satellite tracking

Geolocations of the movements of eight free-ranging basking sharks (total body length, range, 3.0–7.0 m) on the European continental shelf between May 2001 and December 2002 were obtained from satellite-linked archival telemetry undertaken by the Marine Biological Association (MBA) laboratory. Full descriptions of electronic tags, tagging and track reconstruction methodologies are given in Sims et al. (2003, 2005a). Basking shark tagging and pop-off locations are shown in Figure 1.

Effort-corrected surveys

Basking shark occurrence was recorded by visual surveys from research vessels operated by four organizations: the MBA (1994–2004), the UK Wildlife Trusts (1994–2004), the Hebridean Whale and Dolphin Trust (2003), and the International Fund for Animal Welfare (2002–2003). The surveys were conducted in and between areas of the British Isles that were historically important for basking shark fishing and thus, surfacing behaviour (Figure 1).

Surveys were conducted on board 8.5 to 18-m long vessels during daylight hours, between April and September in each year. Line transects were used to structure the search pattern, and at least two observers scanned the sea surface either side of the vessel for basking shark dorsal fins. Surveys were conducted only on relatively calm days when the sea was classed as slight, with wind speed <30 km h^{-1} (Beaufort scale, wind force 4 or less), and sea state 3 or less. Search effort was classed as the time spent actively searching for surface-occurring basking sharks along each leg of the line transect. Surface sightings per unit effort (SPUE) was calculated from the number of basking sharks observed each day divided by the amount of time spent searching (in minutes).

Public sightings

Basking shark sightings reported by the UK public and organizations to the Marine Conservation Society's Basking Shark Watch scheme have been collated since 1987. Over 6000 records had been collected up to May 2004, detailing 19,421 sightings dating back to 1934. Of these data, 4919 records of 17,226 sharks with information on geographical location were included in the analysis. Differences in the seasonal variation of basking shark public sightings were assessed by calculating total monthly frequencies of the total number of reports received and the total number of basking sharks sighted.

Data treatment

The data collected using the three different methods were compared on a standardized grid comprising $0.5\times0.5°$ (latitude/longitude) cells encompassing the geographical extent of all basking shark locations. Basking shark geolocations, public sightings, survey observations and the survey effort for all years were assigned to each respective $0.5\times0.5°$ grid cell (spatial unit). Where parts of more than one spatial unit were surveyed during the course of a single line transect the proportion of time spent searching in each unit was allocated to each respective cell.

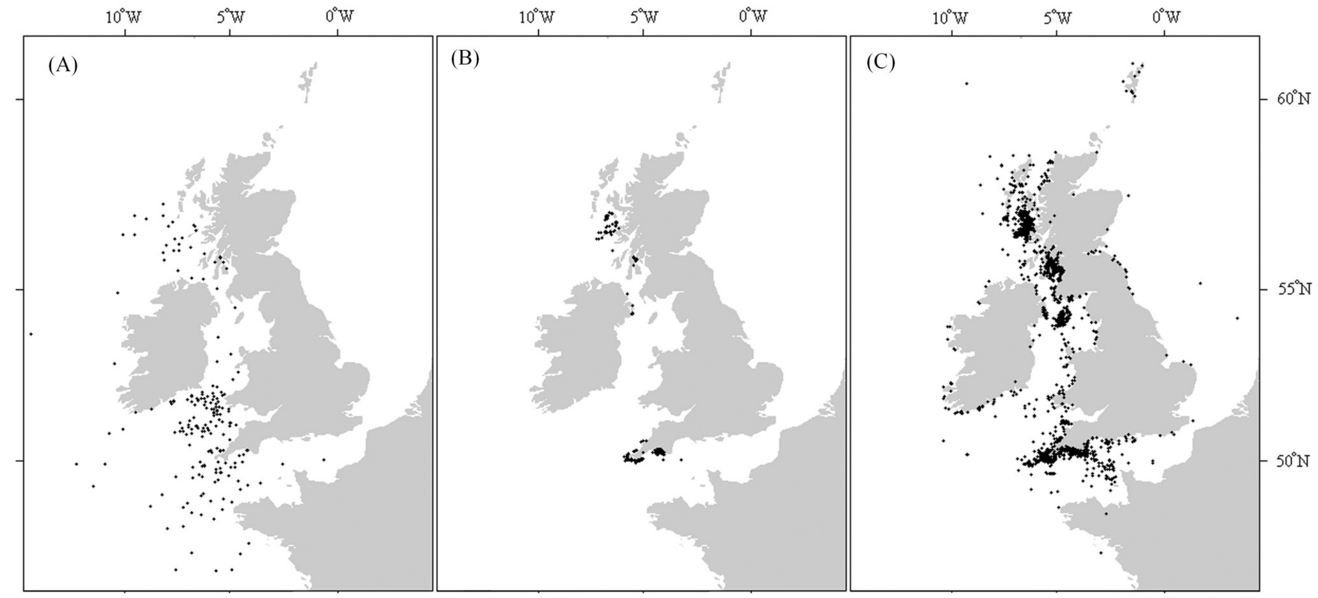

Figure 2. Distributions of basking sharks determined using the three methods of (A) 191 tag geolocations collected from eight satellite tagged basking sharks between 2001–2003; (B) survey sightings of basking sharks (1994–2003), 814 basking sharks were sighted in 3576 hours of search time; and (C) 4919 public sightings collected between 1987 and May 2004.

The frequency of occurrence of shark 'hotspots' between each of the methods was investigated using chi-squared analysis. Each cell of the standardized grid, which in total area was 1512 km (46°–60°N) by 936 km (001.5°–014.5°W), was assigned a number from 1 to 957. The occurrence data contained in each cell were ranked according to the highest occurrence of sharks per cell in each of the three grids representing the three different survey methods. Therefore, the grid cells containing the highest occurrence of sharks were defined as spatial density 'hotspots'. The consistency of hotspots was examined by determining the frequencies with which the top five hotspots for each method used to assess distribution occurred in each of the other methods top 25 hotspots. Thus, similarity in distribution pattern of shark-density hotspots between methods would be evident if there was

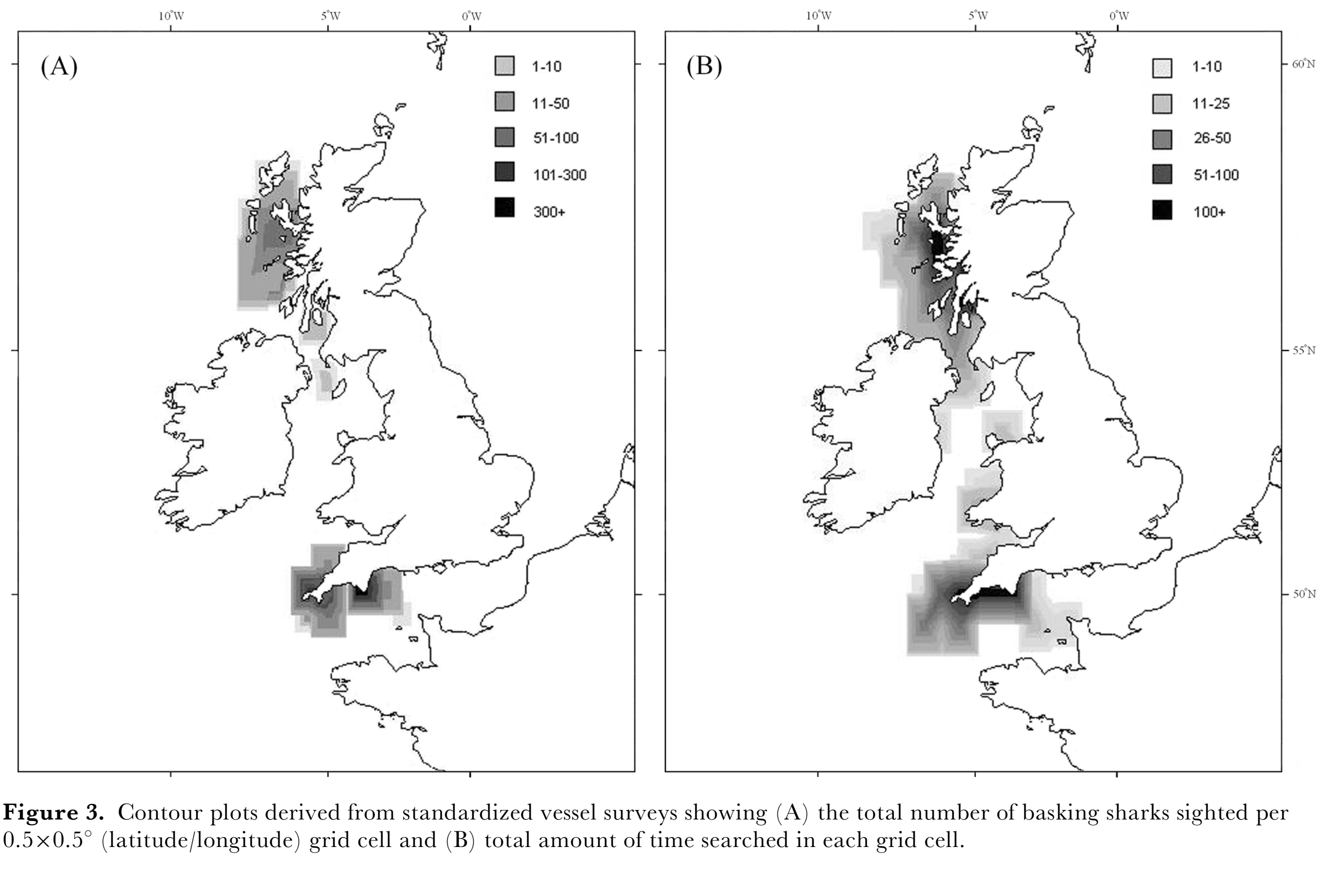

Figure 3. Contour plots derived from standardized vessel surveys showing (A) the total number of basking sharks sighted per 0.5×0.5° (latitude/longitude) grid cell and (B) total amount of time searched in each grid cell.

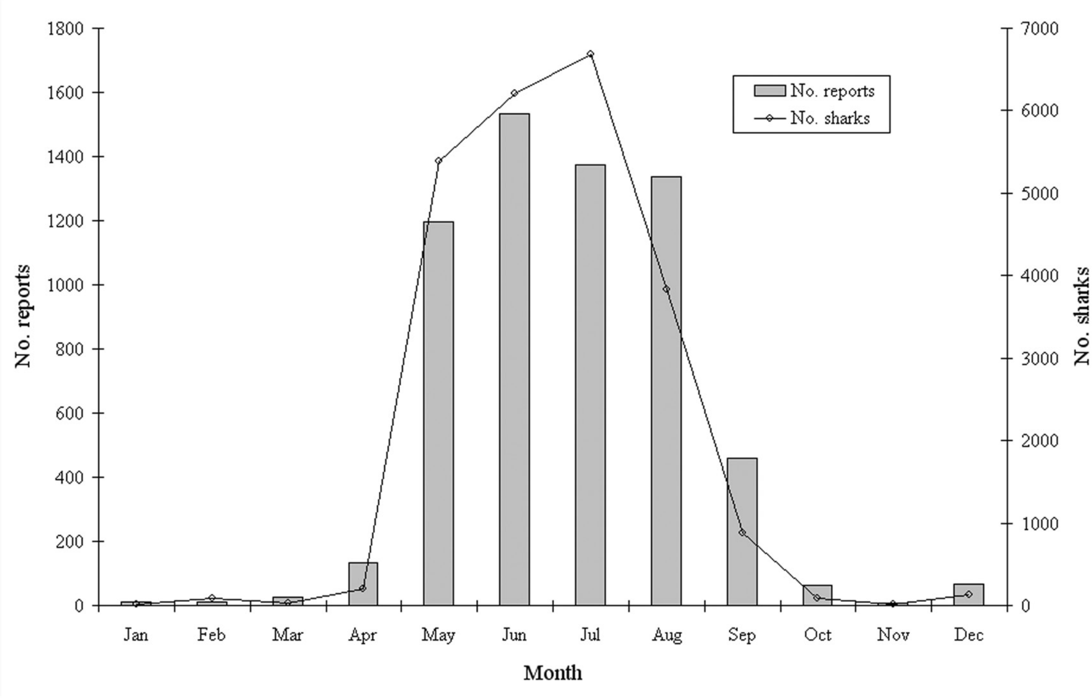

Figure 4. Total monthly frequencies of public sighting reports and the total number of basking sharks sighted between 1987 and 2004.

symmetry between two methods in the frequency of occurrence of the top five hotspots within the other method's top 25 and vice versa.

RESULTS

Satellite-tag geolocations of eight basking sharks (Sims et al., 2003, 2005a) showed these individuals used areas of the European continental shelf principally to the west of the UK, extending from western Scotland in the north, to the Bay of Biscay off France in the south (Figure 2A). The highest density distributions of geolocations occurred in the Celtic Sea and Western Approaches of the English Channel, with fewer geolocations occurring off western Scotland, the Irish Sea, and to the west of Ireland. Both the distributions derived from survey and sightings data showed high densities close inshore off south-west England and between the Inner and Outer Hebrides off western Scotland (Figure 2B,C). The high densities observed in these areas during surveys reflected the concentration of survey effort in these locations, though it was also apparent that there were no sightings in the offshore Celtic and Irish Sea areas despite some survey effort, albeit at a lower level than off south-west England and western Scotland (Figure 3A,B). Whilst numbers of public sightings were high around the Isle of Man in the Irish Sea and in the Firth of Clyde, Scotland (Figure 2C), the survey and tag geolocations both indicated relatively lower density distributions in these areas. Public sightings data indicates a low occurrence of basking sharks to the east of Britain in the North Sea (Figure 2C).

Comparison of the highest spatial-density hotspots between each of the methods indicates that hotspot locations derived from tag geolocations were significantly different to those identified by the public sightings scheme (chi-squared analysis: $\chi^2=8.1$, $P<0.005$). In contrast, the hotspot locations identified by the survey method were similar to those observed by the public ($\chi^2=2.5$, $P>0.05$).

The number of basking sharks sighted by the public in each month was closely matched by the number of reports received (Figure 4). The highest numbers of sharks seen were in the summer months, with >1100 reports submitted and 4500 sharks sighted per month between May and August, whereas <100 reports, and fewer than 750 sharks were sighted, in each month between October and March.

DISCUSSION

The tendency of basking sharks to feed or cruise at the sea surface during summer months has encouraged surveys to be conducted with the aim to determine numbers of animals using particular areas (Kenney et al., 1986; Sims et al., 1997; MCS, 2003). This type of monitoring provides useful information on where basking sharks occur at the surface, and clearly raises the profile of basking sharks in the public's consciousness, but it is now apparent from this study that sightings (even corrected for efficiency of surveillance effort) do not reliably indicate the full extent of habitat use and distribution of basking sharks in and around UK and Irish waters.

The distributions obtained by all three methods suggest a restricted range for basking sharks around Britain, with the majority of positions falling between the Hebrides and the north coast of Brittany and relatively few occurrences on the west coast of Ireland and the east coast of the UK. This suggests the western region of the European shelf is a particularly important habitat for basking sharks within the north-east Atlantic. However, this study shows that, whilst the broad distribution patterns revealed by these different methods are similar, there are considerable differences in density distributions. There is a strong emphasis in the surface sightings data of higher densities in the Hebridean Sea, Clyde Sea, Irish Sea and close inshore around Devon and Cornwall, areas that clearly represent important habitat for basking sharks, most probably in relation to feeding opportunities (Sims & Quayle, 1998; Sims et al., 2003). Tag geolocations, in contrast, identified two areas where individuals spent considerable time outside these areas: in the Celtic Sea and Western Approaches of the English Channel. In particular, tag geolocations show sharks undertaking persistent ranging movements near the Celtic Sea front, whereas surface sightings (from both public and structured surveys) would indicate relatively few sharks in this area.

It is unlikely that this discrepancy in distribution is due to the potential effect of different temporal-sampling 'windows' between the different methods used. Although sea surveys for basking sharks were conducted only between April and September, satellite-tag geolocations were determined for the majority of the year, between May and February (61% of geolocations occurred between May and September), while public sightings were made year-round and followed the predicted seasonal pattern. This indicates there was significant temporal overlap in sampling effort between the three methods, particularly in summer months, which limits the potential bias of different sampling periods affecting interpretations of shark distribution between the methods. On balance, the most likely reason for this discrepancy is that 'basking' behaviour in the Celtic Sea and Western Approaches of the English Channel area is reduced, resulting in few surface sightings (Sims et al., 2005b).

One explanation for the differences identified here is that the behaviour of basking sharks occupying waters that are well-stratified differs from that in tidal front regions (Sims et al., 2005b). This results in very different surfacing frequencies in different ocean habitats. It suggests sightings per unit effort do not reflect real differences in geographic (horizontal) abundance between areas, because the probability of sighting a basking shark may be 60-fold higher in frontal areas than in well-stratified zones (Sims et al., 2005b). This behavioural difference in surfacing frequency between different habitats is broadly consistent with the density distributions found in this study. Well-stratified water columns are persistent features of the Celtic Sea and Western Approaches from March to October (Pingree & Griffiths, 1978), which may account for the few sightings in this area despite apparently high shark density distributions in these areas. Similarly, the high number of sightings of basking sharks from sightings data in coastal regions of Devon and Cornwall and in western Scotland are predicted by the fact that tidal fronts are present seasonally in these areas (Le Fèvre, 1986; Sims & Quayle, 1998; Sims et al., 2000) and results in the high incidence of daytime 'basking' behaviour.

This has profound implications for the use of sighting data both in defining population distribution and estimating abundance trends. These results, taken in the light of the spatial differences identified in this study, suggest bias-reduction according to habitat type should be incorporated into analyses of survey data when attempting to estimate abundance. Accurate estimates of basking shark abundance are needed because of the concerns about possibly low population levels in the north-east Atlantic. Thus, future tagging studies should be designed to enhance and verify the existing information on basking shark movement: seasonally, horizontally and vertically, and in relation to oceanic conditions, particularly fronts. These data should provide the means to calculate weightings to sightings data in order to determine changes in local abundance and stock trends. In this way, satellite tracking of basking sharks should be used in parallel with sightings surveys, which not only raise the profile of the basking shark with the public, but serve as a viable long-term monitoring tool for this species.

The data sharing and integration phase of this work was funded by the Esmée Fairbairn Foundation through a grant to the Marine Biological Association. The satellite tagging programme was led by D.W.S. and J.D.M. and was supported by the UK Department for Environment, Food and Rural Affairs, the UK Natural Environment Research Council (NERC), US National Geographic Society, The Royal Society, and The Fisheries Society of the British Isles. The Wildlife Trusts Basking Shark Project was supported by the Heritage Lottery Fund, National Express group, The Born Free Foundation, WWF-UK, Earthwatch Institute (Europe), English Nature, Environment and Heritage Service, Swiss Shark Foundation and Project AWARE (UK). M.C.S. would like to thank the Countryside Council for Wales, D'Oyly Carte Trust, Environment and Heritage Service Northern Ireland, and Project AWARE for Basking Shark Watch project support during 2001–2004. The Irish Whale and Dolphin Group, Millport Marine Laboratory, Devon Local Record Centre, Seawatch Southwest, Shetland Local Record Centre, Silver Dolphin Diving, the Shark Trust, Solway Shark and Sea Mammal Survey, Manx Wildlife Trust, Scottish Wildlife Trust, Sea Mammal Research Unit, Biscay Dolphin Research Group, Ulster Wildlife Trust, Environment Agency, SeaTrust Foundation, Royal National Lifeboat Institute, Centre for Environmental Data and Recording, Northern Ireland and the Royal Society for the Protection of Birds (RSPB) also provided input. We are grateful to M. Pawson, A. Moscrop, T. Lewis and R. Leaper for discussions and comments on the manuscript. D.W.S. is supported by an NERC-funded MBA Research Fellowship.

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Submitted 8 March 2005. Accepted 19 August 2005.