INTRODUCTION

Gaining knowledge on the ecology of large marine vertebrates is complex due to the logistically challenging nature of gathering observations in the habitats they occupy. These species often spend only small amounts of time at or near the surface, decreasing the periods during which they can be observed and recorded using visual surveying methods. Evolving biotelemetry techniques (Wilson et al. 2008), where electronic tags gather information on an individual’s location and sometimes behaviour, have advanced our knowledge of marine vertebrates, their physiology, behaviour and ecology (Cooke 2008). While the number and diversity of species instrumented with biotelemetry technology is increasing...
standardised rates of detection, which facilitates
the degree of observer effort necessary to determine
considerable care, as they lack information on the
cryptic. Public sightings data must be analysed with
data, which can provide wide spatial scale 'snap-shots' of
such datasets that can be multi-annual in nature and can
allow some facets of ecology to be explored and offer
short durations when compared to the multi-decadal
lifespan of long-lived vertebrates. Furthermore,
these studies can be limited in their ability to allow
inference of patterns through space and time, par-
ticularly with respect to environmental change that
operates over decades and beyond, e.g. anthropo-
genic driven climate change (see Robinson et al.
2009 for review) or oscillations in climate such as
the North Atlantic Oscillation (NAO; Hurrell 1995),
which is of particular interest in northern Europe.
The NAO is associated with westward wind stress
blowing from the North Atlantic Ocean onto the
European landmass (Hurrell 1995). These winds
influence the level of nutrient mixing in the water
column, the degree of thermal stratification and
subsequent growth conditions for plankton (From-
mentin & Planque 1996). As such, they exert a
strong influence on marine ecosystems, including
plankton (Fromentin & Planque 1996, Lynam et al.
2004), fish and top predators (Thompson & Ollason
2001) (reviewed by Ottersen et al. 2001).

Data collected by public sightings programmes
may help in gathering useful information on marine
vertebrates (López et al. 2002), producing substantial
datasets that can be multi-annual in nature and can
have wide spatial coverage. These features may
allow some facets of ecology to be explored and offer
population-level insights that may otherwise remain
cryptic. Public sightings data must be analysed with
considerable care, as they lack information on the
degree of observer effort necessary to determine
standardised rates of detection, which facilitates
comparisons across space and time. Even when con-
sidering this important caveat, vast datasets on pub-
lic sightings may hold information that is otherwise
lacking for many large vertebrate species, demon-
strating the utility of 'citizen-science' (Cohn 2008)
monitoring programmes.

The long-lived basking shark *Cetorhinus maximus*
is the world’s second largest fish species (Compagno
2001), has a circumglobal distribution (Kenney et al.
1985, Valeiras et al. 2001, Francis & Duffy 2002, Wil-
son 2004, Sandoval-Castillo et al. 2008) and can
undertake extensive trans-ocean basin migrations
(Gore et al. 2008, Skomal et al. 2009), although the
relative frequency and importance of these migra-
tions are unknown. The species is an obligate ram-
feeding zooplanktivore (Compagno 2001) with an
apparent preference for calanoid copepod zoo-
plankton, such as *Calanus helgolandicus* (Sims &
Merrett 1997) and *C. finmarchicus*. The basking
shark is slow to mature and has low fecundity
(Matthews & Parker 1950), which makes the species
slow to recover from exploitation (Kunzlik 1988).
Seasonally abundant aggregations of basking
sharks form in continental shelf habitats for feeding
and presumed reproduction (Kenney et al. 1985,
shark size (body length) at first reproduction is
thought to be between 5 and 7 m (Compagno 2001
and reviewed by Sims 2008), at approximately 12
and 16 yr of age, although individuals can attain
maximum lengths of approximately 10 m (circa
50 yr of age; Compagno 2001, but see Natanson
et al. 2008 for discussion on the complexities of infer-
rings age from body size).

Basking sharks have been subject to historic
exploitation throughout their range (Kunzlik 1988)
and are protected under Appendix II (2002 onwards)
of the Convention on International Trade of Endan-
gered Species (CITES 2010), and Appendices I and II
(2005 onwards) of the Convention on Migratory Spe-
cies (CMS 2009). The International Union for Conser-
vation of Nature (IUCN) Red List of Threatened Spe-
cies assessed the global status of the basking shark
as ‘Vulnerable’ (1996 onwards), with the north
Pacific and northeast Atlantic stocks, which have
been subject to targeted historic fisheries, assessed
as ‘Endangered’ (Fowler 2005) from 2000. These
assessments are based primarily on past records of
rapidly declining local populations as a result of fish-
eries exploitation and slow population recovery rates
(Fowler 2005). In the UK, the basking shark is pro-
tected under the Wildlife & Countryside Act (1981)
(1998 onwards) and more recently in Scotland by the
Population size estimates for the basking shark in the northeast Atlantic are lacking, and tracking efforts to date (Sims et al. 2003) demonstrate short-term (months) movements on the northeast Atlantic continental shelf but as yet have been unable to robustly describe the scale of movement exhibited by individuals on repeat annual cycles. The capacity exists, however, for extensive movement (to many thousands of kilometres; Gore et al. 2008). Limited genetic studies have been unable to confidently describe the structuring of the northeast Atlantic population (Noble et al. 2006), although genetic diversity is thought to be globally low for the species (Hoelzel et al. 2006).

With cumulative anthropogenic activity in the northeast Atlantic becoming increasingly well described (Halpern et al. 2008), including fisheries (Witt & Godley 2007, Lee et al. 2010), large vessel traffic and marine renewable energy installations (Witt et al. 2012), there is a growing need to better understand the spatial and temporal dynamics of basking shark distribution, abundance and behaviour to inform marine spatial planning activities. We therefore undertook a comprehensive assessment of basking shark surface sightings from 2 public recording programmes operating in the UK. We set out to: (1) describe spatio-temporal patterns of basking shark sightings (including seasonal and inter-annual trends) to expand upon existing knowledge (e.g. Cotton et al. 2005, Southall et al. 2005), (2) investigate the annual patterns of sightings with respect to environmental forcing, as represented by the NAO, and (3) investigate patterns in basking shark demography through analysis of reported basking shark body lengths to ascertain whether there are any signals of recovery post-exploitation. We further contextualise patterns of basking shark sightings from public records with information gathered from dedicated in situ boat-transect surveys. These surveys enable a formal quantification of basking shark sighting abundance in regions with relatively high levels of public sightings.

MATERIALS AND METHODS

Public sightings

Public records of surface sightings of basking sharks were obtained from 2 databases, viz. Basking Shark Watch (BSW; www.mcsuk.org/sightings/baskingshark.php) managed by the Marine Conservation Society (MCS; UK) and Seaquest Southwest (SSW; www.cornwallwildlifetrust.org.uk/conservation/living_seas/send_us_your_marine_sighting) hosted by Cornwall Wildlife Trust.

Basking Shark Watch

The MCS basking shark sightings database (n = 12,872 records, 1988 to 2008) was initiated in 1987 to provide a general indication of the distribution and seasonality of basking shark surface sightings in UK coastal waters (R. Earll & J. Turner unpubl.). MCS has promoted public participation in BSW through media releases and the distribution of promotional materials at public forums. The degree of promotional effort undertaken each year was categorised using the ordinal scale (1 to 3), where 1 represented general operation of the scheme and 3 represented significant promotional effort. This metric of effort was used to contextualise the number of records received in each year. MCS encouraged the public to submit their sightings by telephone or post using dedicated sightings cards that assist detailed recording. An internet-based recording facility was introduced in 2001, and the recording cards were eventually discontinued in 2007.

Seaquest Southwest

The Cornwall and Devon Wildlife Trusts in conjunction with the Environmental Records Centre for Cornwall and the Isles of Scilly operate the SSW public sightings database. SSW was initiated in 1997 to gather records of all large marine vertebrates, including basking sharks, within the waters of the region (n = 3,494 records of basking sharks, 1988 to 2008). Members of the public are encouraged to submit their sightings of basking sharks by the use of telephone and via the internet.

Database preparation

Each record of a basking shark sighting contained a varying degree of information, from approximate numbers of sharks sighted with date, time and nearest town (at its simplest form), to more detailed accounts that included geographic coordinates of location, shark sizes (body length) and site description (at its most detailed). We first interrogated data within each database (BSW and SSW) to remove obvious duplicate records. We then eliminated po-
Potential repeat sightings of basking sharks occurring across the 2 databases, particularly for southwest England where the 2 reporting schemes operated simultaneously. This was achieved by intersecting sightings records by their date; subsequently, any SSW record that occurred on the same date as a BSW record in southwest England was removed if its reported location was within 25 km from the BSW sighting record. Individual basking shark site fidelity is unknown, and to date tracking studies (Sims et al. 2003) have only utilised light-based geolocation, which has coarse spatial resolution (~50 km radius of real location). As such, little is known of the daily rates of movement, and we therefore arbitrarily chose the separation distance of 25 km. The 2 databases were then merged and subjected to further interrogation, which led to the removal of 4108 records. Records were removed for the following reasons: sighting not of a basking shark, sighting prior to 1998, sighting off the northeast Atlantic continental shelf, absence of location data and/or date of sighting, number of basking sharks sighted not reported, record collected using more formal survey methods and sighting of a dead individual (see Table S1 in the supplement at www.int-res.com/articles/suppl/m459p121_supp.pdf). We then determined the day of year of occurrence for each record. The cleansed dataset formed from the merging of BSW and SSW data (years 1988 to 2008) represented 11 781 records of basking shark surface sightings (BSW: n = 9161 records; SSW: n = 2620).

Spatial patterns of occurrence

We constructed a hexagonal grid that encompassed the UK marine region (coastline to 200 nautical miles [n miles] offshore). Using this grid, we ascertainment on a 10 d interval for each year, e.g. Days 1 to 10, Days 11 to 20, whether grid cells (~500 km², pixel height 25 km or 13.5 n miles) contained one or more records of basking shark surface sightings. Since the temporal and spatial scales of individual basking shark site fidelity are unknown, we arbitrarily chose 10 d intervals and a 500 km² area over which to summarise the public sightings data. We then determined the mean annual number of 10 d periods in which each hexagonal grid cell received one or more sighting records. Data were temporally partitioned in this manner to limit the opportunity for repeat sightings of basking sharks that may show fidelity to quasi-persistent oceanographic features, such as tidal mixing fronts that may occur over short periods of time. The procedure highlighted 3 regions of high relative basking shark surface sightings, which we term aggregations or ‘hotspots’ that informed further regional-based analysis; these regions were western Scotland, Isle of Man and southwest England.

To ascertain the spatial distribution of public sighting records occurring within each regional aggregation (hotspot), we calculated relative estimates of density using a kernel smoothing approach (Worton 1989; see Laver & Kelly 2008 for review). This method statistically estimates the probability of occurrence of a spatial phenomenon, e.g. observations of basking sharks, over a grid using a definable smoothing parameter. This results in an utilisation distribution (UD) that describes the likelihood of the density of observations across the grid. From the UD, areas of constant density can be extracted and displayed as polygons or lines. For each region, we compiled all sightings data by the hexagonal grid cell in which they occurred. We then took the first record to occur in each grid cell in successive 10 d periods (irrespective of the year of occurrence) and aggregated these data to a single dataset, from which we then derived a spatial estimate of relative density. Kernelling enabled spatial patterns to be determined without concern for the varying number of records among regions. To limit the influence of large aggregations of basking sharks, particularly given the difficulties in adequately enumerating group size, the kernelling procedure only used records of sightings and not the number of sharks associated with each record. Two parameters were used in the kernel density estimation procedure: grid resolution and a smoothing parameter. The grid resolution was set at 1 km; this parameter value was used to achieve a balance between the computationally demanding kernelling process and the minimum realistic spatial resolution and positional accuracy of the sightings data. Sightings records were smoothed using a parameter of 30 km for western Scotland, 5 km for Isle of Man and 10 km for southwest England. Selection of the kernel smoothing parameter was predominantly driven by the spatial scale of each region and the complexity of coastline morphology, e.g. embayments, peninsulas and deep intrusions into land (sea lochs), which ultimately physically constrains the spatial pattern of basking shark distribution.

Effort-corrected boat-based surveying

To contextualise public sighting records, we used previously published data collected by in situ boat-based line transect surveys conducted as part of
The Wildlife Trusts’ Basking Shark Survey (sailing boat; 11.7 m length) in western Scotland (Speedie et al. 2009) and southwest England (Speedie & Johnson 2008). This method of surveying enabled abundance estimates to be obtained, which were expressed with respect to the number of hours surveyed (sharks h\(^{-1}\)) at a 25 km\(^2\) resolution. Transect routes were weather dependent, and routes were structured to cover broad geographical regions reported as being productive for surface sightings of basking sharks (i.e. western Scotland and southwest England). Boat-based surveys were intended to cover each transect route at least twice during each survey season (Fig. S1 in the supplement). Body lengths (in m) of basking sharks encountered near to the survey route were assessed by careful comparison to the known length of the survey vessel (at distances of less than 10 m during calm conditions). Boat-based surveys in western Scotland occurred between 2002 and 2006, providing 146 ± 84 surveys yr\(^{-1}\) (range 65 to 288). Mean ± SD survey duration was 1.3 ± 1.0 h (range 0.13 to 5.9), and surveys were conducted predominantly in the months of July, August and September. Boat-based transect surveying in southwest England occurred between 2002 and 2005, providing 112 ± 29 surveys yr\(^{-1}\) (range 73 to 137). Mean survey duration was 1.3 ± 1.3 h (range 0.12 to 8.3), and surveys were conducted predominantly in the months of April, May and June. Data from these transect surveys were used to derive sightings per unit effort (sharks h\(^{-1}\)) only when sea states (World Meteorological Organisation scale) were 3 or less (Speedie et al. 2009).

Environmental context

We obtained data on the NAO winter-time index (from https://climatedataguide.ucar.edu/sites/default/files/cas_data_files/asphilli/nao_station_djfm.txt; accessed 26 March 2012) to examine the relationship between this large ocean basin scale climatic forcing event and the duration of the basking shark sightings season in each year (1998–2008). The NAO winter-time index represents the normalised mean atmospheric pressure difference between the persistent pressure systems localised to Iceland and the Azores, and is generally expressed as the average of monthly normalised pressure differentials for December to March. The duration of the sightings season, for each year, was taken to be the number of days between the first and last sighting in each year derived from a subset of data representing 90% of each year’s sightings records centred upon the median sighting.

Body size from public sightings

We summarised records of basking shark sightings with estimates of body length (only using records with 5 or fewer sharks sighted; n = 5019 records) into 3 categories: <4 m, 4–6 m and >6 m. Given the difficulties of following individual sharks in large aggregations, we arbitrarily chose to limit the number of body length estimates from groups of sharks to 5 individuals. We felt this was appropriate given that coastal behaviour of sharks when in aggregations is commonly described as nose-to-tail following (Harvey-Clark et al. 1999, Sims et al. 2000a, Francis & Duffy 2002), which makes discriminating individuals and their body length more difficult for lay observers.

Size class categories arose as a best fit from the structure of the differing public recording schemes, i.e. BSW provided body size according to 5 categories, <2 m, 2–4 m, 4–6 m, 6–8 m and >8 m, whereas SSW provided uncategorised estimates of body length. We therefore re-categorised all data into 3 categories <4 m, 4–6 m and >6 m. These classes were chosen to best reflect small (proxy for young), medium-sized (proxy for juvenile) and large sharks (proxy for adult) based on available syntheses regarding size at first sexual maturity for male and female basking sharks (Sims 2008).

The proportion of surface-sighted sharks with body sizes in each of these categories was determined for each year (1988 to 2008), and patterns of change through time were investigated using linear modelling within the R statistical framework (R Development Core Team 2008) using the package lm with year as the independent term.

RESULTS

Spatio-temporal distribution patterns from public sightings

Public records of basking shark surface sightings within the BSW and SSW databases (Fig. 1; n = 11 781; 1988 to 2008) occurred in waters of the UK (including Northern Ireland and Isle of Man; n = 11 318), Channel Islands (n = 46), Republic of Ireland (n = 376) and France (n = 41). Of the total database, 11 625 records (98.7% of all records) occurred within 12 n miles of land, highlighting the coastal nature of the dataset. Highest densities of public sightings records occurred along western facing shores (Fig. 1). Spatio-temporal filtering of sightings records, used to minimise the bias of re-
sighting sharks, highlighted 3 regions where the density of basking shark surface sightings was highest in the dataset (Fig. 2a): western Scotland, Isle of Man and southwest England, which builds upon the knowledge from Southall et al. (2005). Once data were subject to kernelling (Fig. 2b-d; records occurring within 12 n miles of land), several coastal features appeared important for sightings: (1) straits between islands, e.g. in western Scotland, (2) headlands, e.g. in Isle of Man, and (3) near-shore regions with deep water access, e.g. in southwest England, with apparent consistency through time (see Fig. S2).

While the pattern over the 21 yr study period was generally of increasing public records of basking sharks (Fig. 3a; quadratic regression in R; $F_{2,18} = 18.9$, $R^2 = 0.68; p < 0.01$), some apparent peaks and troughs in the annual number of sightings occurred. In all 3 regions, comparatively smaller numbers of public-derived records were obtained during the late 1980s and early 1990s. Most noticeable was the generally greater number of public records since 2004 in western Scotland (Fig. 3b) and the Isle of Man (Fig. 3c), whereas the numbers of public records in southwest England appeared more variable (Fig. 3d). There was no significant relationship between the level of promotion effort in each year and the number of basking shark sightings reported to MCS (Spearman rank correlation; rho = 0.4, p = 0.07).

The annual sightings season for basking sharks appeared to start earliest in southwest England (April; Fig. 4c), followed by Isle of Man and western Scotland (May; Fig. 4a,b). The month of peak sightings progressed northwards, in general starting in southwest England (June; Fig. 4c), then Isle of Man (June–July; Fig. 4b) and finally Scotland (August; Fig. 4a).

The temporal distribution of the dates of sightings within each year was variable (Fig. 5a) with the median day of the sightings year slowly increasing during the late 1980s and early 1990s, followed by a gradual decrease and subsequent increase (although see Fig. S3 for regional variations). There was no significant linear relationship between year and the median day of the sightings season (Spearman rank correlation; rho = −0.19, p = 0.42). During the 2000s, the intra-annual temporal distribution of records became less synchronous at the regional level with the median day of the sightings season becoming progressively earlier for Scotland and Isle of Man and later in southwest England (Fig. S3).

**Spatial distribution patterns from boat-based transects**

Estimates of basking shark relative density derived by boat-based transect surveys (sharks h$^{-1}$ cell$^{-1}$ on a 0.25 km$^2$ grid; mean ± SD), for regions spatially coin-
cident to areas containing 50% or more of all public sightings records (as identified by kernelling), were 3.1 ± 8.5 sharks h\(^{-1}\) for western Scotland (Fig. 2e; range 0.1 to 50 sharks h\(^{-1}\); 2002 to 2006) and 3.1 ± 3.0 sharks h\(^{-1}\) for southwest England (Fig. 2f; range 0.1 to 8.3 sharks h\(^{-1}\); 2002 to 2005; see Fig. S1 for survey effort).

**Environmental context**

There was a statistically significant positive correlation between the duration of the sightings season (days) and the NAO winter-time index (Fig. 5b; Spearman’s rank correlation; rho = 0.45; p = 0.03). This pattern was evident following the censoring of 2 outlier data points; first in 1991, when the total number of records for the year was low (n = 254) and basking shark sightings during December in the Isle of Man extended the duration of the sightings season; and a second in 1996, a year in which the NAO is known to have undergone a large single year reversal in phase and intensity, and the NAO index was −3.78 (see Greene & Pershing 2003 for a discussion on these anomalous events). Without censoring of these data points there was no significant correlation (Spearman’s rank correlation; rho = 0.264; p = 0.25).
Body size from public sightings

The annealed (BSW and SSW) basking shark public sightings database contained 5019 records with estimated basking shark body lengths (n = 7959 sharks in total). The proportion of sharks reported in each of 3 body size classes was 0.32 for sharks <4 m (n = 2518 sharks), 0.61 for sharks 4–6 m (n = 4856) and 0.07 for sharks >6 m (n = 585).

We investigated possible changes in the annual proportions of basking shark sightings reported in each of these body length size classes. Two statistically significant patterns were identified: the annual proportion of basking sharks <4 m in length declined through time (Fig. 6a; linear regression, $F_{1,19} = 11.39, R^2 = 0.37, p < 0.01$), whereas the annual proportion of basking sharks 4–6 m increased through time (Fig. 6b; linear regression, $F_{1,19} = 10.94; R^2 = 0.37; p < 0.01$). There was no relationship between year and the proportion of large sharks sighted (Fig. 6c; linear regression, $F = 0.658_{1,19}, R^2 = 0.03, p = 0.42$). However, patterns of body size through time occurring in each of the regions were, for the majority, non-linear as highlighted by local order polynomial regressions (Cleveland 1979) (Fig. S4).

Body size from boat-based transects

Information on basking shark body lengths was also collected during dedicated in situ boat-based transects in western Scotland (2002 to 2006, n = 332 sharks) and southwest England (2002 to 2005, n = 78 sharks). These data were summarised to the same size classes as used for the public sightings data. The proportion of sharks observed in each of 3 body size classes was 0.14 for sharks <4 m (n = 63 sharks), 0.22 for sharks 4–6 m (n = 95) and 0.64 for sharks >6 m (n = 252 sharks). We did not analyse these body length data for trends through time, as the respective time series for western Scotland and southwest England were of a limited duration (5 and 4 yr, respectively). It is clear, however, that in general the size distribution is markedly further skewed to large size classes than the public sightings data.

DISCUSSION

Data from public sightings programmes, once adequately quality controlled, can provide insights into large marine vertebrate ecology (particularly for species that use coastal habitats), including phenology of seasonal appearance in coastal waters and potential habitat preference and thus the putative risks faced. Despite basking sharks being an important species of conservation concern, and in the absence of ongoing dedicated effort-corrected surveys, the available data are all that exist from which to generate insights to direct conservation activities at large spatial and temporal scales. We discuss the utility of this dataset in the context of 3 overarching questions.
1. Spatio-temporal patterns of public sightings: Are basking shark hotspots consistent through space and time?

Spatial analysis of basking shark surface sightings from the general public (1988 to 2010) highlighted 3 regional hotspots: western Scotland, Isle of Man and southwest England, areas which had been previously identified by Southall et al. (2005) but using a shorter time series of records from the BSW database (1987 to 2004) alone. A defined seasonality in basking shark sightings (occurring late spring to early autumn across UK waters, with regional variation) was evident, which similarly supports existing knowledge.

Corroboration of the seasonal patterns observed in the sightings data, for at least southwest England, is provided by monthly aerial surveying for large marine vertebrates in coastal waters (coastline to 6 n miles offshore) of Cornwall (Leeney et al. 2012).
These surveys suggest that basking sharks are either not present during winter months or are at depth (Shepard et al. 2006) and hence not amenable to sighting, perhaps influenced by the distribution of zooplankton prey, which are typically deeper and more offshore during winter months (Colebrook 1985, Greene & Pershing 2000, Beaugrand et al. 2001). Furthermore, basking shark depth utilisation data extending into autumn and winter (n = 2; November to January), collected by Sims et al. (2003), show that little time spent is spent by these planktivores near the surface during this period.

The pattern of basking shark sightings records occurring within each year showed a marked seasonality, peaking earlier in southwest England and later in the Isle of Man and western Scotland. This observed pattern could be due to northward movement or seasonal expansion of a putative northeast Atlantic population of basking sharks to higher latitudes to feed as the ‘bloom’ of copepod prey extends northwards with the season (Sims et al. 2006). Light-based geolocation tracking of basking sharks (Sims et al. 2003) has shown that some individuals move between the hotspot regions identified in this study. Sightings data cannot, however, provide further insights into the extent of this movement at the individual level, and the possibility remains that different individuals may be sighted later in the year in Scotland than those observed earlier in the year in southwest England.

2. What impact does environment have on basking shark sightings?

Concordance of the seasonal patterns of basking shark surface sightings with sea surface temperature and copepod prey has undergone prior analysis (for southwest England using MCS BSW data, 1988 to 2001; Cotton et al. 2005), including an investigation into the potential relationship of the abundance of basking sharks sighted with climatic phenomena, such as the NAO. These authors identified a significant association between sea surface temperature and shark sighting abundance for southwest England, where warmer mean annual temperatures were associated with greater abundance of sharks. Similar to Cotton et al. (2005), but using an updated time series, we detected a significant correlation between the length (duration in days) of the sightings season in any one year and the state of the NAO. We used sightings season duration, in place of shark abundance, given the lack of robust effort correction (bias reduction) that could be applied to the public sightings data. The effects of NAO are thought to differ somewhat on the dominant prey types for basking sharks; for example, during the NAO positive phase, Calanus finmarchicus abundance increases, while C. helgolandicus decreases and vice versa during the NAO negative phase (Fromentin & Planque 1996). Whether the correlation between westward wind stress (described by the NAO index) and the duration of the basking shark sighting season is due to temperature or prey, an interaction of both or sightings probability due to weather conditions, has yet to be
determined. Elucidating the potential influencing mechanisms of NAO would, however, require considerable effort using formal abundance survey methods over many seasons on a large spatial scale. These requirements are important given the challenges faced in ecological studies where large-scale phenomena that have the potential to influence patterns are rarely matched in the datasets used to investigate their potential influence, ultimately complicating or potentially invalidating predictions (Levin 1992). Importantly, our finding highlights that population estimates based on visual detection techniques should potentially be undertaken in years when a larger proportion of the putative northeast Atlantic population is available for enumeration, i.e. when the NAO is positive.

3. Are basking sharks recovering from past exploitation?

Basking sharks under exploitation are likely to be particularly prone to rapid population declines since fecundity is low, growth is generally slow, and sexual maturity comes late; these life history characteristics may also result in populations taking many years to recover from exploitation. The northeast Atlantic saw historic targeted hunting of this species principally in Norway, Ireland and Scotland, where at least 81 639 basking sharks were killed between 1952 and 2004 (ICES 2006); the recovery status of the species is currently unknown (Sims 2008). Significant exploitation ended in the UK in 1953 and in Ireland in 1975 (Kunzlik 1988), although a largely opportunistic fishery operated from the Firth of Clyde, Scotland, from 1982 to 1994. Harvesting continued in Norway until the turn of the millennium (CITES 2005). Incidental mortality in fisheries continues to be reported within the public sighting databases (for the UK), although the numbers are comparatively small (130 individuals over 21 yr; Table S1). There have been many more sightings of basking sharks in recent years. However, it is difficult to separate changes in abundance of records (and potentially sharks) from increases in awareness and the influence of environment.

When public sightings data are examined more closely for reported body size, there is evidence of changing patterns through time, with a decreasing trend in the proportion of small sharks (<4 m) and an increasing trend for medium-sized sharks (4–6 m). Given that our data may carry effort-related bias, interpretation of trends should be made cautiously; however, this may signify a population that is slowly recovering with the maturation of the younger sharks that remained following the period of exploitation in the later part of the 20th century. There is some lack of agreement in the size structure of sharks reported in the 2 datasets, i.e. the public sightings database and the boat-based transects database, with the boat-based surveys identifying a considerably greater proportion of large sharks (>6 m). This lack of concordance could exist for several reasons, including that boat-based transects might be accessing regions that support larger individuals (potentially engaged in courtship and reproduction) that are not accessible to lay observers in coastal areas, limiting the opportunity to be sighted by the public. Further, the number of sharks observed during boat-based surveys represents only 7% of those reported by public sightings. Whatever the underlying reason for this difference, its existence highlights the need for cautious interpretation of both datasets—one which lacks effort correction (public sightings) and the other which was focused on regions previously identified as supporting considerable numbers of sharks.

What future monitoring efforts are required?

Data from basking shark public sighting schemes provide a spatio-temporal overview of the whereabouts of basking sharks in UK waters, and can provide a key focus for efforts seeking to estimate population size. For example, these data may help to focus aerial surveying or boat-based survey activities. Public-derived data also complement studies investigating the geo-political extents of basking shark distribution, particularly for those individuals that move large distances (Southall et al. 2006). Further efforts towards genetics studies (Hoelzel et al. 2006), photo-identification (Sims et al. 2000b), effort-related surveying (Speedie et al. 2009), understanding depth utilisation (Shepard et al. 2006), particularly for coastal waters, and tracking (Sims et al. 2003, Gore et al. 2008) will further help to elucidate the ecology of basking sharks and will lend additional support to the interpretation of public sightings data. Photo-identification work (Sims et al. 2000b) and high-resolution GPS-based satellite-tracking (see Sims et al. 2009, Witt et al. 2010) would provide essential information on the degree of site residency shown by basking sharks, thereby building an understanding of the likelihood of re-sighting. When combined, data from these diverse survey methods will help yield a greater understanding of how this species might be
better conserved and protected in UK waters and provide necessary insights into the population status of this species in the northeast Atlantic. This is exemplified by the relationship gained from the public sightings data on the association between sightings season duration and the intensity and phase of NAO, which provides context for more optimal timing of monitoring efforts and population estimates.

CONCLUSION

Given our increasing anthropogenic footprint in marine ecosystems (Halpern et al. 2008) and the challenges of conducting large-scale long-term wildlife monitoring programmes (financial and logistical), all available data on species of conservation concern need to be analysed in a concerted way so that future conservation activities might be appropriately directed. Here we show how sightings data gathered from across large spatial and temporal scales can provide key information on the whereabouts of a large marine vertebrate recovering from past exploitation into an ever changing marine environment with newly emerging risks. Public sightings data, when amalgamated with other information, such as focused aerial surveying efforts (Leeney et al. 2012) at key sightings hotspots and beyond, can ultimately aid efforts for spatial planning seeking to ensure the long-term recovery of the species.

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