Marine Pollution Bulletin 187 (2023) 114565

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Baseline

An investigation into the effects of climate change on baleen whale distribution in the British Isles

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ARTICLE INFO

Keywords:
Climate change
Distribution
Baleen whales
British Isles

ABSTRACT

Climate change is predicted to impact the distribution of many marine species. In the North-East Atlantic and elsewhere in the world, studies indicate that climate change is leading to poleward shifts in cetacean distribution.

Here, strandings data collected in the British Isles from 1990 to 2020 were used to assess whether there is evidence of a shift in baleen whale distribution. Linear regression models were used to compare the number of strandings over time between six regions of the British Isles and, whilst the results indicate no significant change in the number of strandings in the most southerly region of the British Isles, there have been significant increases in more northern regions. Data related to stranded minke whales is the primary driver of these increases, with a number of potential variables affecting this trend, including observer effort. These variables are discussed and further research to explore this potential association is suggested.

1. Introduction

The effects of anthropogenic climate change on the marine environment include ocean warming, acidification, deoxygenation and altered ocean currents (Doney et al., 2012; Gattuso et al., 2015; Hoegh-Guldberg and Bruno, 2010). These changes are predicted to impact the distribution of many marine species (Doney et al., 2012). For example, poleward shifts have been predicted in numerous taxa (Cheung et al., 2009; Molinos et al., 2015; Morley et al., 2018). Effects of such distribution shifts may include local extinctions (Jones and Cheung, 2015) and the production of novel species assemblages (Hoegh-Guldberg and Bruno, 2010).

The distribution of cetaceans may be affected by climate change directly, through the physiological effects of higher water temperature, or indirectly, through changes in the distribution of prey or ecologically similar competitive species (Learmonth et al., 2006). In general, it is predicted that increasing ocean temperature will lead to an expansion in the distribution of cetaceans adapted to warmer water, and a poleward contraction in the distribution of those adapted to a cooler environment (MacLeod, 2009). Changes in distribution of whale species as a result of climate change have been predictively modelled in some studies (e.g. Peters et al., 2022) and some changes in cetacean population distribution linked to changing climate are reported in the literature. Van Weelden et al. (2021) recently systematically reviewed the relevant literature which includes reports of changes in beluga whale (*Delphinapterus leucas*) distributions in the Arctic; a significant increase in the sightings of humpback whales (*Megaptera novaeangliae*), fin whales (*Balaenoptera physalus*) and common minke whales (*Balaenoptera acutorostrata*) in the sub-Arctic – with all three species displaying a northward shift between 2002 and 2014; and, in addition, sperm whales (*Physeter macrocephalus*) and killer whales (*Orcinus orca*) becoming more prevalent in Arctic waters. Outside of the Arctic, there is also published evidence of distributional shifts in Bryde's whales (*Balaenoptera edeni*) and fin whales.

In the North-East Atlantic, several studies indicate that there have been northward shifts in the distribution of various cetacean species concurrent with increasing sea surface temperature (SST) and/or shifting prey distribution, such as fin whales in Norway (Løviknes et al.,

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https://doi.org/10.1016/j.marpolbul.2022.114565
Received 30 September 2022; Received in revised form 28 December 2022; Accepted 30 December 2022
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2021), blue whales (*Balaenoptera musculus*) in Iceland (Víkingsson et al., 2015) and also potentially minke whales in Iceland (Albrecht et al., 2022). Around the British Isles, changes in stranding frequency of warm water-adapted and cold water-adapted delphinid species have been suggested to potentially reflect shifting distributions (MacLeod et al., 2005; Williamson et al., 2021). However, it is yet to be determined whether the distribution of baleen whales in this region has shifted.

Since 1990, the collaborative UK Cetacean Strandings Investigation Programme (CSIP) and the Irish Whale and Dolphin Group (IWDG) have been monitoring cetacean strandings in the British Isles. The term 'strandings' throughout this report refers to those strandings that have been reported and are recorded in the respective strandings databases. Some stranded animals may have been missed in more remote regions, although the animals being considered here are large and are perhaps more likely to have been seen than smaller cetaceans. The distribution of cetacean strandings has been shown to be a good indicator of species occurrence (Jung et al., 2009; Maldini et al., 2005; Pyenson, 2011). Therefore, strandings records can potentially be used to investigate broadscale changes in cetacean distribution in the British Isles over time, although other factors such as increased reporting effort may also affect recorded stranding numbers.

Here, strandings records from the British Isles were used to assess whether there is evidence of a climate-related distribution shift occurring in baleen whales.

2. Materials and methods

2.1. Strandings data

Data collected by CSIP and IWDG between 1990 and 2020 were analysed. The raw datasets contained records of strandings with accompanying metadata such as species identification, temporal and spatial data and nutritional status. The date, species, latitude and longitude were extracted from each dataset and combined into a new spreadsheet. In the UK, strandings data were reported from a wide number of potential sources, including but not limited to local authorities, statutory agencies, local volunteer networks, social media reports and directly by members of public. During the study period surveillance increased in Cornwall and in Scotland, due to increased effort by regional volunteer networks, but this change in effort is difficult to quantify (Deaville, 2019). Supplementary Fig. 1 shows the location of each stranding event by species.

2.2. Data analysis

All data analysis was carried out using SPSS version 27 (IBM, 2021). Preliminary analyses were performed to ensure there was no violation of the assumptions of normality and linearity.

We considered a number of different divisions that might allow latitudinal differences in strandings over time to be explored before settling on dividing the British Isles into six regions of 2° of latitude (Supplementary Fig. 2):

- 49–51° N
- 51–53° N
- 53–55° N
- 55–57° N
- 57–59° N
- 59–61° N

To understand how the total number of baleen whale strandings changed over time, linear regression analyses were performed for each region of the study area (Table 1). Year was the independent variable and total number of strandings the dependent variable. To investigate species differences in the number of strandings over time, this was repeated with the number of strandings of each species as the dependent variable. Arrangements for reporting stranded cetaceans have remained largely unchanged over thirty years across much of the UK with some increase in volunteer effort in both Cornwall and Scotland (Deaville, 2019).

Table 1
The results of the linear regression analyses for all species combined, showing the F statistic, degrees of freedom, p value and R^2 value. Significant p values are highlighted in bold.

Region	F	df	Sig.	R^2
49–51° latitude	0.683	1, 29	$p = 0.415$	0.023
51–53° latitude	8.585	1, 29	$\boldsymbol{p = 0.007}$	0.228
53–55° latitude	25.207	1, 29	$\boldsymbol{p < 0.001}$	0.465
55–57° latitude	15.045	1, 29	$\boldsymbol{p = 0.001}$	0.342
57–59° latitude	16.957	1, 29	$\boldsymbol{p < 0.001}$	0.369
59–61° latitude	10.023	1, 29	$\boldsymbol{p = 0.04}$	0.257

To provide a comparison between the number of strandings over time in each region, a general linear model was constructed with region, year and the interaction between region and year as the independent variables, and total number of strandings as the dependent variable. This was used to compare the slopes of the linear regressions for regions between 51 and 61° N relative to the slope of the region of 49–51° N, which was designated as the reference region once the first part of the analysis revealed no significant change in the number of strandings here.

3. Results

The final dataset contained 740 strandings; 610 minke whales, 87 fin whales, 34 humpback whales and 9 sei whales.

The total number of strandings increased significantly over time in all regions except 49–51° N (Fig. 1). Supplementary Table 1 shows the total number of strandings per year for each region of the study area.

The trend in strandings for each species is shown in Fig. 2. The number of minke whale strandings increased significantly over time in all regions except 49–51° N (Supplementary Table 2). There was a significant increase in fin whale strandings over time in the regions of 53–55° N and 55–57° N (Supplementary Table 3), and a significant increase in humpback whale strandings over time in the regions of 55–57° N and 57–59° (Supplementary Table 4). The number of sei whale strandings did not increase significantly over time in any region (Supplementary Table 5).

The general linear model confirmed that the slopes of the linear regressions for regions between 51 and 61° N were significantly different from the slope of 49–51° N ($p = 0.002$).

4. Discussion

Whilst the number of baleen whale strandings in the most southerly region of the study area did not change significantly between 1990 and 2020, all other regions displayed significant increases in the number of strandings. The results show that minke whales, the most numerous species in the dataset, are driving these trends.

There are several factors that may be causing the results observed here. Firstly, it is possible that these trends are a result of an increase in minke whale population size combined with a northward shift in their distribution. Although minke whales are a migratory species, their seasonal distribution and migratory patterns are generally poorly understood (Risch et al., 2019a). Common minke whales are mainly present around the British Isles from June to November (Macleod et al., 2004; Risch et al., 2019b; Tetley et al., 2008), but at least some have been recorded every month of the year (Evans, 2019). As would be expected with a northward shift in distribution, the number of strandings in the more northern regions increased over time. However, whilst the number of strandings in the most southerly region might be expected to decrease as animals move out of the area, the number of strandings remained constant. This might be affected by an overall increase in

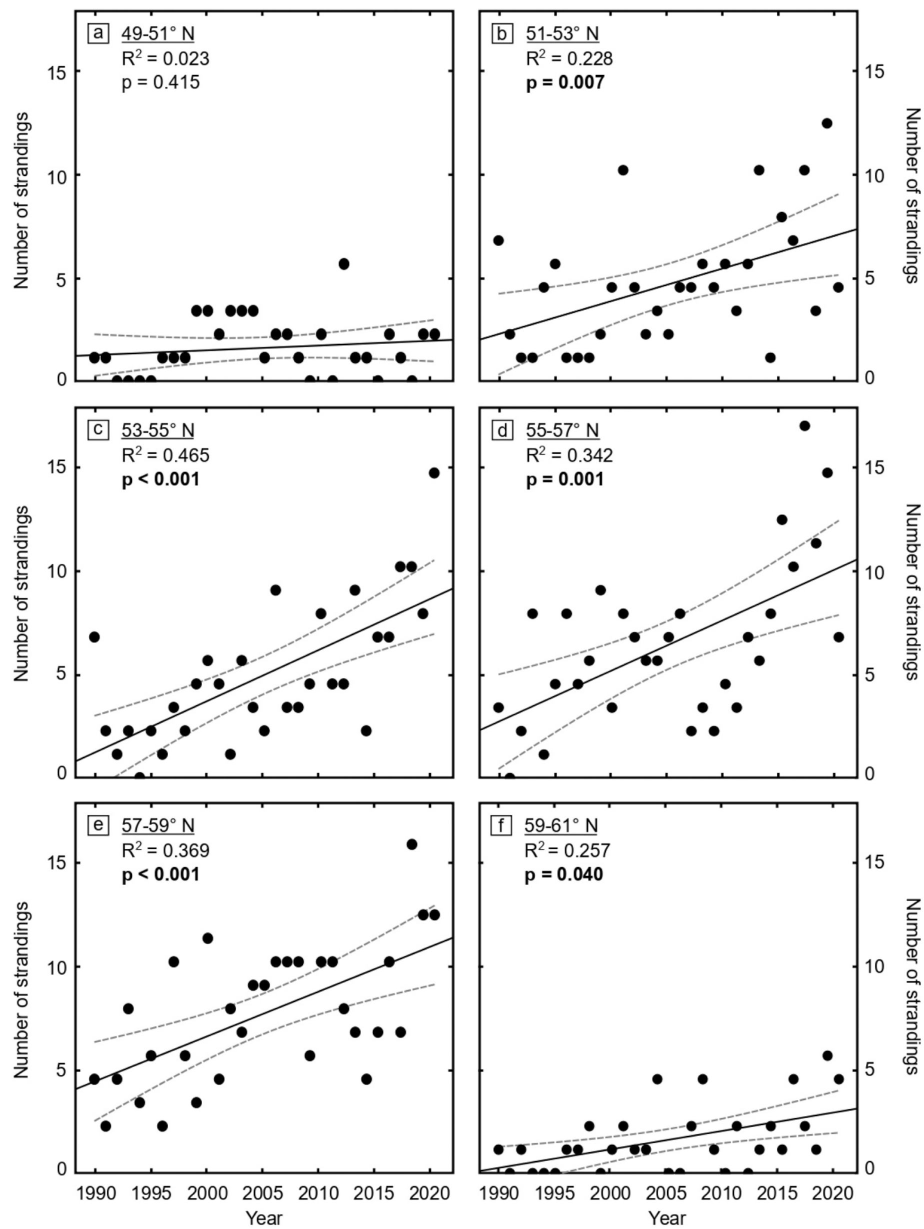

Fig. 1. The number of baleen whale strandings over time in each region of the British Isles. Trend lines (solid line) with 95 % error (dashed line) and p values are presented for each region. Significant *p* values are presented in bold.

abundance masking the movement of individuals out of this region. There is some evidence of this, with it being estimated that the North-East Atlantic common minke whale population increased from 65,000 to 90,000 between 1989 and 2013 (IWC, 2021). However, in the North Sea, the estimated overall abundance of minke whales has shown no change between 1994 and 2016 (Hammond et al., 2021). More recent abundance estimates are required to assess whether the increasing trend in population size for the whole North-East Atlantic area has continued, whether the overall population in the North Sea has remained constant and how relative abundance may vary across the region. Other factors that might affect the more southerly region include the relatively small number of records from there relative to the more northerly zones, and an increase in observer effort.

A potential driver behind a northward shift in minke whale distribution may be increased SST. Williamson et al. (2021) found that annual mean SST increased significantly around the UK between 1990 and 2018, and this has been linked to an increase in stranding frequency of common dolphins (*Delphinus delphis*) and striped dolphins (*Stenella coeruleoalba*), both warm water species (Williamson et al., 2021). Increasing SST has also been linked to an increase in stranding frequency of common dolphins in North-West Scotland in the period 1992–2003, concurrent with a decline in stranding frequency of white-beaked dolphins (*Lagenorhynchus albirostris*), a cold water species (MacLeod et al., 2005). These changes in stranding frequency are suggested to represent shifting distributions.

Another factor that may be affecting the distribution of minke whales is changes in the abundance and distribution of their prey. It has already been demonstrated that increasing SST is leading to changes in the composition of fish assemblages in the North Sea; between the 1960s and 1980s, assemblages were typically characterised by cold water species such as Atlantic herring (*Clupea harengus*), whereas since the 1990s the assemblages have been comprised of warmer water species such as European anchovy (*Engraulis encrasicolus*) (Montero-Serra et al., 2015). Northward shifts have also been reported in other species, such as Atlantic cod (*Gadus morhua*) (Perry et al., 2005). As minke whales feed upon small schooling fishes such as herring (Macleod et al., 2004; Olsen

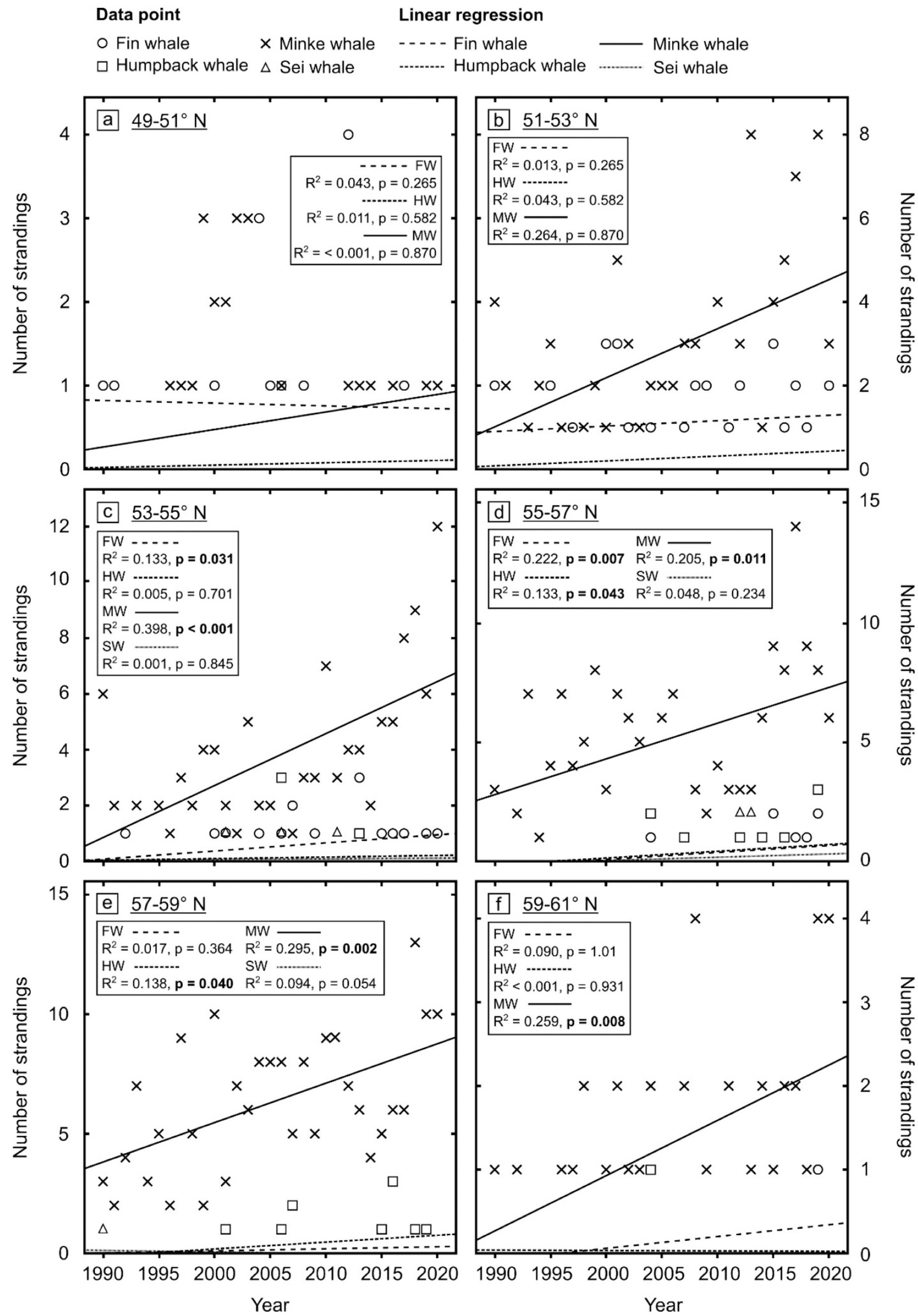

Fig. 2. The number of strandings per year for fin whales (FW), humpback whales (HW), minke whales (MW) and sei whales (SW) in each region of the British Isles. For clarity purposes, if a symbol does not appear above the 0 line, there were no strandings that year. Trend lines with R^2 and *p* values are presented for each species. Significant p values are highlighted in bold. 95 % confidence intervals were left out for clarity purposes.

and Holst, 2001; Pierce et al., 2004), it is possible that the whales are shifting northwards in accordance with their prey. Further research is required to investigate whether the distribution of prey species around the British Isles is shifting and, if so, whether this could be affecting minke whale distribution.

Changing prey abundance and distribution has been linked to shifts in baleen whale distribution in other regions of the North-East Atlantic. For example, a decrease in minke whale abundance on the Icelandic continental shelf has been attributed to the movement of individuals from this area to the east coast of Greenland in pursuit of capelin (*Mallotus villosus*) (Víkingsson et al., 2015). Furthermore, a northward shift in blue whale distribution has been attributed to a decrease in euphausiid abundance in southern waters (Víkingsson et al., 2015). In the Norwegian Sea, a northward shift in fin and humpback whales has also been attributed to changing prey availability (Løviknes et al., 2021). In the Svalbard archipelago, northward shifts in minke whales, fin whales, blue whales and humpback whales have coincided with increased ocean temperature and increased abundance of prey species such as krill and mackerel (Storrie et al., 2018).

The possible northward shift in minke whale distribution observed here aligns with the predictions of Lambert et al. (2014). It has been predicted that there will be a substantial reduction in the availability of suitable habitat for minke whales in the British Isles by the 2080s, particularly in the southern end of their range. This may have serious implications for minke whale conservation, as the shelf waters around the British Isles are an important summer feeding ground for the North-East Atlantic population (Born et al., 2003).

However, it is possible that the observed increase in minke whale strandings between 51° N and 61° N is affected by increased reporting effort. Quantifying effort in terms of reactive strandings networks is difficult, and therefore one of the primary caveats of this study is that variation in effort could not be readily accounted for. However, it is known that there was an increase in effort in Cornwall from the late 1990s onwards, coinciding with the creation of the Cornwall Wildlife Trust Marine Strandings Network (CWTMSN) volunteer network, and an increase in Scotland from the middle of the last decade, coinciding with the establishment of the Scottish Marine Animal Stranding Scheme (SMASS) volunteer network (R Deaville 2021, pers. obs.). Despite the increase in effort in Cornwall, this region did not present a significant trend in the number of baleen whale strandings. However, it is possible that the significant increase in baleen whale strandings seen in Scotland is, at least in part, a result of increased reporting effort.

Despite this, the greatest increase in strandings, in the region of 53–55° N, does not coincide with the regions of increased effort through use of observer schemes. Other than the two regions of known increases, it is thought that effort in other parts of the UK has remained relatively constant.

Another possible explanation for the increase in strandings between 51° N and 61° N is increased mortality of minke whales. Factors that may cause mortality and lead to strandings include, but are not limited to, ship strikes (Laist et al., 2001), entanglement (Leeney et al., 2008), pollution and plastic contamination (Eisfeld-Pierantonio et al., 2022), disease events and starvation (Leeney et al., 2008). If the incidence of threats to whales is increasing, such as increased shipping traffic, this may lead to increased mortality. An example of this in other species is the likely association between military sonar and the high and potentially increasing incidence of beaked whale strandings in the North-East Atlantic (Dolman et al., 2021). As there was not a significant increase in strandings in the region of 49–51° N, further research might usefully investigate whether environmental or anthropogenic pressure on minke whales may be increasing in regions of 51–61° N but not in the region of 49–51° N.

The numbers of stranded whales of other species is relatively low and, therefore, conclusions on any trends are far more speculative. However, the number of humpback whale strandings showed a significant increase in the regions of 55–57° N and 57–59° N. One explanation for this may be the reported increase in the North Atlantic humpback whale population (Stevick et al., 2003). Humpback whales migrate between feeding grounds in Iceland, Greenland and Norway and breeding grounds in Cape Verde and the West Indies (Evans, 2019), and it has been suggested that Scotland may be a migratory stopover for this species (O'Neil et al., 2019). Therefore, the increase in strandings between 55 and 59° N may be a result of increased numbers of individuals passing through this area as their population recovers after the cessation of commercial whaling. Another factor that could explain the increased number of humpback whale strandings in this region is the increase in reporting effort in Scotland. The significant increase in humpback whale strandings between 55 and 59° N may also be a result of increased mortality of whales in this region due to a pressure that varies spatially. For example, entanglement in fishing gear, particularly creel gear, is thought to be an increasing threat to humpback whales in Scottish waters (Ryan et al., 2016) and is also significant for humpbacks in Iceland, noting that some humpback whales in this part of the world may be part of the endangered Cape Verde population (Basran et al., 2019). Such pressure may also be acting in concert with one another.

The number of fin whale strandings only increased significantly in the regions of 53–55° N and 55–57° N. Although many fin whales undergo a seasonal migration to polar seas in spring and summer, those around the British Isles seem to be present all year round (Evans, 2019). Therefore, the increase in strandings in the regions of 53–57° N but not others may represent shifting prey distribution. Another explanation may be increased mortality of whales in these regions, including from ship-strikes, and such events may affect strandings when bodies are transported by the vessels that have struck them wrapped around the prow.

5. Conclusion

The results of this study show that, during the period 1990–2020, baleen whale strandings in the British Isles increased significantly between 51° N and 61° N. However, there was no change in the number of strandings in the region of 49–51° N. Minke whales, the most numerous species in the dataset, are the main driver of the observed trends. The increase in strandings in the more northerly regions but not in the south deserves more investigation and this preliminary investigation should be followed up by further research. If this trend is real, it might at least in part be explained by a combination of population growth and a northward distribution shift. The overall abundance increase might be disguising the movement of individuals out of the most southerly region, although this may be being affected by other factors including an increase in observer effort here. The numbers stranded in this southernmost sector are also relatively small.

The notion of population growth is supported by the reported increase in the North-East Atlantic minke whale population between 1989 and 2013, although more updated abundance estimates are required. A potential driver behind a northward distribution shift may be increasing SST, which is known to have increased significantly around the British Isles throughout the study period and which has been linked to changes in the distributions of other cetaceans both in this region and elsewhere. Shifting prey distribution, which has been shown to affect the distribution of baleen whales in other regions of the North-East Atlantic, may also be an explanatory factor. Other factors that might be affecting the results observed here potentially include increased minke whale mortality, which itself could be caused by a variety of potential factors including impacts from fisheries and disease.

This study suggests a potential distribution shift in at least the minke whale population of the North-East Atlantic and this is in-line with what has been reported for other cetacean species in this region, where distribution shifts have been linked to climate change impacts. It is in the nature of strandings data that it is affected by many variables which may make interpretation difficult. Therefore, some further lines of research are recommended in order to further consider the potential relationship between climate change and cetaceans strandings data. This should include the relationship of strandings data to the changing patterns of SST around the British Isles. SST is widely accepted as a main predictor variable of cetacean habitat suitability (Peters et al., 2022). Secondly, further analyses might be conducted via a Generalised Additive Modelling approach (GAM), which could incorporate a whole range of factors including latitude and SST (see for example, Benjamins et al., 2017).

CRediT authorship contribution statement

Maria Snell: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft. **Andrew Baillie:** Resources, Data curation. **Simon Berrow:** Resources, Data curation. **Robert Deaville:** Resources, Data curation, Writing – review & editing. **Rod Penrose:** Resources, Data curation. **Matthew Perkins:** Resources, Data curation. **Ruth Williams:** Resources, Data curation. **Mark Simmonds:** Conceptualization, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

Strandings data was provided by the UK Cetacean Strandings Investigation Programme and the Scottish Marine Animal Strandings Scheme, which are co-funded by Defra and Welsh Government; and by Scottish Government respectively. The Irish Cetacean Stranding Scheme is part funded by the Irish National Parks and Wildlife Service of the Department of Housing, Local Government and Heritage. The authors would also like to thank Dr. Paul Jepson for his role in leading the research directions and outputs of the UK Cetacean Strandings Investigation Programme over this period.

The authors also thank their anonymous referees for helping to improve the manuscript. Maria thanks her course supervisor and the statistical support unit and everyone associated with the MSc in Global Wildlife Health and Conservation at the University of Bristol.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2022.114565.

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