Agenda Item 4.3 — Special Species Sessions

Beaked Whales

Document 4.3 — **Overcoming Challenges to Protect Beaked Whales in the Northeast Atlantic-ASCOBANS Intersessional Working Group Report, September 2021**

Action Requested

- Review the report
- Endorse the recommendations

Submitted by — Intersessional Working Group on Beaked Whales

Overcoming Challenges to Protect Beaked Whales in the Northeast Atlantic

ASCOBANS Intersessional Working Group Report, September 2021

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Abstract

The topic of beaked whales was raised at the 9th Meeting of the Parties to ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas) in September 2020, because of the apparent increase in strandings that had occurred in the UK, Ireland, Iceland, the Faroes and elsewhere in the region. Many of the species involved are categorised as Data Deficient under the IUCN. The level of monitoring at sea was inadequate, so it is difficult to specify at-sea causal factors driving the strandings. An intersessional working group (IWG) of ASCOBANS was established to bring together experts to summarise information about recent strandings, population abundance and distribution, to discuss potential reasons for the strandings, and to report back to the 26th Meeting of the ASCOBANS Advisory Committee (8-12 November 2021).

Strandings data from the NE Atlantic region (1990-2020) presented here shows a high and potentially growing incidence of strandings of beaked whales, with several Unusual Mortality Events (UMEs) recorded over this period. The Northeast Atlantic has become a global hotspot for beaked whale UMEs, with the largest ever beaked whale stranding occurring in 2018, and such UME's appear to be increasing in both magnitude and frequency. Given the vulnerability of beaked whales to underwater noise, supported by significant advances in our understanding of the impacts of military sonar on these animals, it seems likely that powerful sonars deployed in or close to important beaked whale habitat may at least be in part responsible. Knowledge of beaked whale biology in the region, including distribution and habitat needs, remains poor, making the significance of these events difficult to fully evaluate. We review latest information on distribution, seasonal occurrence, abundance estimates and status in the annex. We also review the latest strandings information here and provide some recommendations for further research and other actions to address this issue. Action to prevent further lethal and sublethal impacts should not be delayed.

Recommendations

Monitoring

- A standardised biological long-term baseline monitoring protocol would enable better understanding of beaked whale populations at the appropriate national/regional scale, with a focus on identification to species level, collection of winter-time data, and a deep-water offshore survey strategy, including visual and static, fixed, drifting and towed passive acoustic monitoring.
- A programme of long-term acoustic monitoring and analysis is required to provide information on anthropogenic noise events. Such an array of long-term acoustic recorders required for this could also provide information on cetacean densities.
- Co-ordination and communication among sound producers, stranding responders and researchers is needed to facilitate planning and preparation prior to sound exposure events, to monitor animal behaviour opportunistically, and to allow sound producers and researchers to conduct retrospective analysis.
- Better understanding of pressures in the European context is required to inform management decisions, particularly regarding military active sonar.
- Improvement in regional stranding responses is required (e.g. use of key diagnostic features), including an ability to obtain an international overview on beaked whale strandings.
- Beaked whales stranded in very good condition should be prioritised for full post-mortem examination whenever possible, and include attempts to establish cause of death.
- Collaborative efforts between researchers to better understand the factors that may be leading to an increase in strandings.
- Noise registry data (the range of noise sources included) and availability (both accessibility and in closer to real-time) should be improved.

- Advances should be made to develop a multi-disciplinary approach, for example, better integration of noise effects to strandings and further implementation of methods to detect cases of noise exposure.

Mitigation

- Increased effort should be made to identify important beaked whale habitat in the Northeast Atlantic region and this information should be used to inform mitigation strategies.
- Where data allows assessment, there should be avoidance of military sonar activity in beaked whale habitat.
- Governments, militaries and other sound producers should collaborate with beaked whale experts to develop and implement effective and precautionary mitigation strategies where data are not adequate.

General

- Parties to ASCOBANS and the IWC should raise the profile of the issue, both through engagement with and conveying recommendations to national navies and to NATO; and distribute findings widely, both nationally and internationally.

Following presentation at the International Whaling Commission Scientific Committee meeting in May 2021, the following recommendations were added:

• The Committee **recommends** the development of harmonised response protocols for beaked whale strandings to ensure that the necessary datasets (e.g. pathology, meteorology prior to the stranding, oceanography, acoustic monitoring, and any information on use of high intensity sound sources) can be rapidly assembled to assist with the identification of the time, location and cause of the mortality event. Identifying which data are required for such an investigation will also highlight data collection gaps which could be prioritised to ensure such data are available when needed.

• The Committee further **recommends** improved data sharing between countries to better identify and investigate mortality events.

1. Background

The association between the development of military active sonar in the 1960s and unusual mortality events of beaked whales, particularly Cuvier's beaked whales (*Ziphius cavirostris*), is well documented (e.g. Evans & Miller, 2004; Cox et al., 2006), although the true extent globally remains unclear. Early events that occurred in European waters include those in the Spanish Canary Islands (Simmonds & Lopez-Jurado, 1991; Fernandez et al., 2005) and in Greece (Frantzis, 1998). The European Cetacean Society has held a number of beaked whale workshops, including on active sonar (Evans & Miller, 2004, Dolman et al., 2010) and on research (Dolman et al., 2009). NATO has also held meetings on the issue of military sonar (e.g. Haelters & Noirot, 2005), whilst a series of international workshops on the impacts of sound in the ocean on marine mammals (ESOMM) have focused attention upon impacts of sonar (see, for example, Lam & Bröker, 2019).

Most cases of beaked whale unusual mortality events (UMEs) have been in tropical to warm temperate regions (D'Amico et al., 2009). However, in 1994, 2008, 2018 and again in 2020, UMEs of beaked whales occurred in northern European seas leading to ASCOBANS forming a working group on beaked whales to address the need for further research within the Agreement Area.

1.1. *Lethal and sub-lethal impacts*

Jepson et al. (2003) and Fernández et al. (2005) first evidenced decompression sickness associated with active sonar in cetaceans and leading to the mortality of individuals that live stranded. Initially, attention focused on mass strandings and subsequent deaths of beaked whales. However, Simonis et al. (2020) identified several single beaked whale strandings that were associated with major multinational Anti-Submarine Warfare training events, indicating that strandings of individual animals should be considered as potentially sonar-associated.

In the last decade or so, exposure experiments have been conducted, using simulated and active sonar, advancing our understanding of the diving and foraging behaviours and the behavioural responses to active sonars, such as avoidance at low received sound levels, displacement for tens of kilometres, changing and termination of foraging patterns (Tyack et al., 2011; DeRuiter et al., 2013; Stimpert et al., 2014; Miller et al., 2015; Falcone et al., 2017) of Cuvier's beaked whales, Blainville's beaked whales (*Mesoplodon densirostris*), Baird's beaked whales (*Berardius bairdii*) and northern bottlenose whales (*Hyperoodon ampullatus*). The behavioural responses described and the live strandings of beaked whales associated with active sonar together suggest that these animals are most likely to have responded with a 'flight or fight' response to escape the sonar (Bernaldo de Quiros et al., 2019). Wensveen et al. (2019) found that northern bottlenose whales off Norway responded strongly to both close and distant navy sonar signals. The typically strong reactions of beaked whales observed in exposure experiments support the likely causal link that extreme behavioural changes cause beaked whales to suffer physiological effects, such as decompression sickness (Cox et al., 2006). Any effects of decompression sickness, stress or habitat displacement may have clear impacts on the welfare of individual beaked whales.

Cryptic mortality is thought to occur in beaked whales, following military sonar activity (Faerber & Baird, 2010), with only a small proportion of dead animals ending up stranded. Blainville's beaked whales on the Atlantic Undersea Test and Evaluation Centre (AUTEC) range have lower reproductive rates than nearby residents (Claridge, 2013). High site fidelity, low reproductive rates, and disruption of social structure may combine to impact local populations. The removal of dozens of individuals from local populations that tend to be small is likely to be detrimental (Bernaldo de Quiros et al., 2019). Resident populations of beaked whales are most likely to have suffered population level impacts where active sonar operations routinely occur.

1.2. *Policies to protect beaked whales*

The NATO Undersea Research Centre (NURC), which conducts maritime research in support of NATO's operational and transformation requirements, has produced rules and procedures to protect marine mammals (NURC, 2008). The Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area (ACCOBAMS) has produced maps to overlay beaked whale habitat and noise hotspots, yet effective efforts to prevent sonar impacts are currently restricted to the Canary Islands, where no mass strandings have been recorded since the Spanish government imposed a moratorium on naval exercises in these waters in 2004 (Fernández, 2013). This clearly shows that such bans can be effective. The US Navy uses a 'step function' to predict behavioural disturbance in beaked whales, for environmental compliance. Wensveen et al. (2020) reported that a 140 dB re 1 mPa step function still underestimates behavioural disturbance to northern bottlenose whales.

1.3. *Some previous key recommendations*

Cox et al. (2006) made a number of recommendations, including for improved co-ordination and communication among sound producers, stranding responders and researchers to facilitate planning and preparation prior to sound exposure events and to monitor animal behaviour opportunistically, and sound producers and researchers to conduct retrospective analysis. These recommendations have not been actioned sufficiently to inform events in a timely way. In addition, improved baseline data on distribution, abundance and habitat preferences of beaked whales are needed (Cox et al., 2006).

Bernaldo de Quirós et al. (2019) reviewed advances in research on the impacts of anti-submarine sonar on beaked whales and made recommendations for future research regarding anatomy, physiology, pathology, ecology, behaviour and technology development for monitoring of free-ranging whales. Recommendations included: (1) a moratorium on mid frequency active sonar (MFAS) in those regions where atypical mass stranding events (MSEs) continue (e.g. regions of the Mediterranean Sea), (2) continued research in areas with MFAS to determine if sub-lethal impacts on individuals result in population-level impacts, (3) comparative studies on populations of beaked whales in the absence of MFAS, (4) determination of species life-history parameters, (5) studies in anatomy, physiology, and pathophysiology to better understand the development of decompression-like sickness in whales, and (6) continued development of technologies to measure physiological responses of free-swimming beaked whales. Continued interdisciplinary studies and exchanges will facilitate better understanding of this complex problem.

The 25th Meeting of the ASCOBANS Advisory Committee recommended that applying the precautionary principle is of greater importance with beaked whales, as compared with other small cetaceans, given the likelihood of small population sizes in beaked whales and the overwhelming evidence that military activities can have severe impacts on these taxa, and acknowledging the difficulties encountered in gaining reliable information (ASCOBANS 2019).

2. Collection of beaked whale data from recent strandings

2.1. Trends in beaked whale strandings

Detailed data on beaked whale strandings were collected from stranding networks within the ASCOBANS Agreement Area alongside an overview of all cetacean strandings reports. A summary of these data is given in Figure 1 and 2 below. Overall, beaked whales represent <1% of all stranding reports for each country (Belgium, France, Germany, Ireland, Netherlands, UK). However, there are notable patterns in the incidence of beaked whale strandings compared to other species.

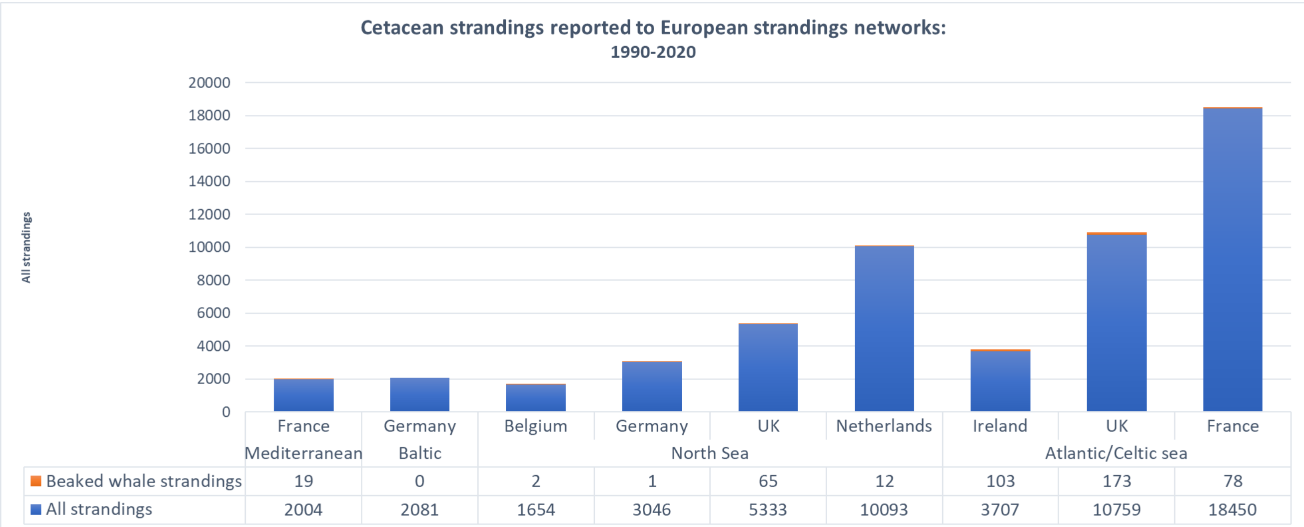
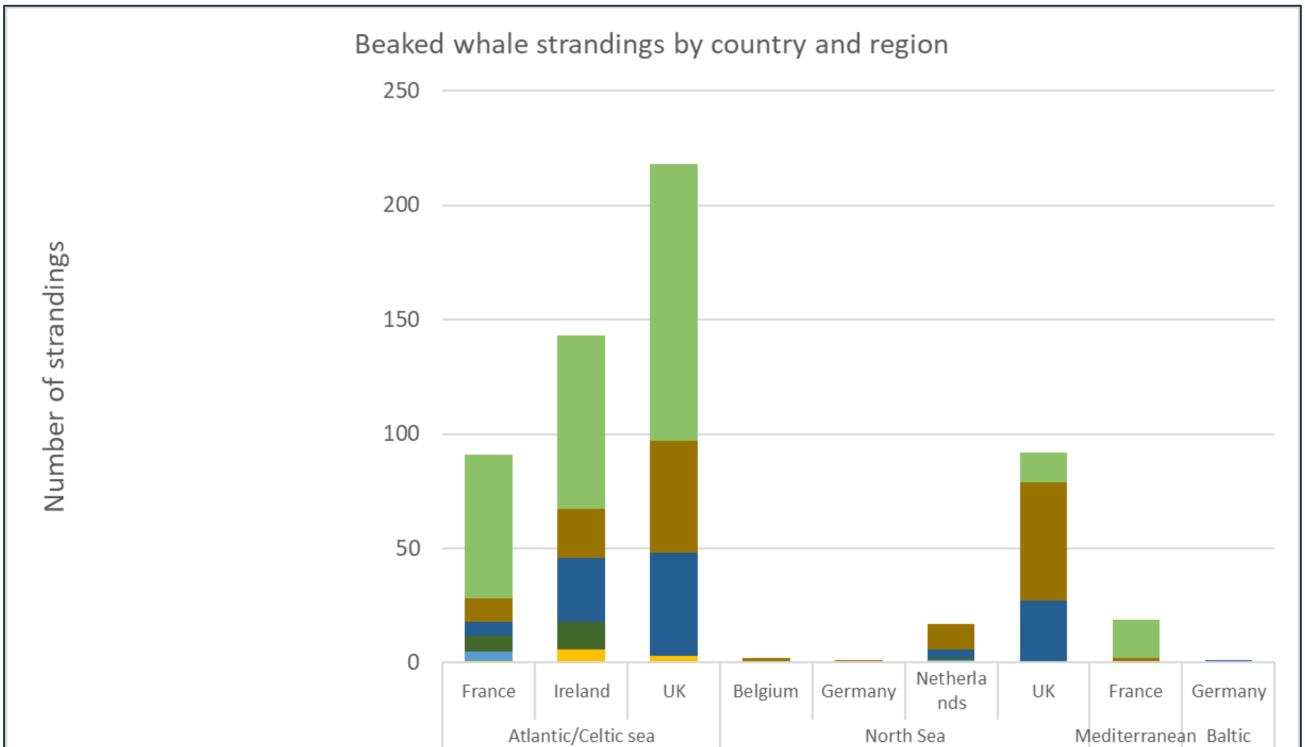


Figure 1. *Strandings reported 1990-2020, by country*

Figure 3 and Figure *4* show the annual incidence of all cetacean and beaked whale strandings for the North Sea region (comprising data from Belgium, Germany, the Netherlands and the eastern UK) and the Atlantic/Celtic region (comprising the western seaboard of the UK and France and Ireland) between 1990 and 2020. In both areas, there is a general increasing trend for cetacean strandings over the three decades represented in this analysis. Beaked whale (BW) strandings also increase but at a slower rate. However, there are clear clusters in the incidence, with likely significant overdispersion (greater variability in counts per year). Some years, notably 1994, 2008, 2018 and 2020 show significant clusters which would be classed as unusual mortality events (UME's). Such UME's appear to be increasing in both magnitude and frequency. As an example, over a third (34%) of beaked whale strandings reported during the past 30 years have occurred in the previous five-year period (since January 2016) and, in the Atlantic region, more Cuvier's beaked whales stranded in 2018 alone than over the previous decade years summed together. Figure 5 shows the cumulative number of strandings since 1990. Over the past decade, the year-on-year increase in BW strandings has lagged behind overall stranding reports, suggesting this pattern of overdispersion in incidence of BW strandings is not reflected in the wider strandings record. More detailed statistical analysis on these trends is required. However, at initial inspection it suggests the observed 'peaks' in beaked whale strandings are not echoed in other cetacean species. Consequently, it is unlikely that the increase in BW strandings simply represent a wider increase in cetacean strandings attributable to increasing reporting effort or oceanographic factors. It is plausible therefore that these peaks of BW reports represent increased mortality and hence are of potential concern.



	France	Ireland	UK	Belgium	Germany	Netherlands	UK	France	Germany
	Atlantic/Celtic sea			North Sea				Mediterranean	Baltic
Sum of Cuvier's beaked whale	63	76	121	0	0	0	13	17	0
Sum of Sowerby's beaked whale	10	21	49	2	1	11	52	2	0
Sum of Northern bottlenose whale	6	28	45	0	0	4	27	0	1
Sum of Beaked whale (indeterminate species)	7	12	0	0	0	1	0	0	0
Sum of True's beaked whale	0	6	3	0	0	0	0	0	0
Sum of Blainville's beaked whale	4	0	0	0	0	1	0	0	0
Sum of Gervais's beaked whale	1	0	0	0	0	0	0	0	0

Figure 2. *Beaked whale strandings by country, ocean basin and species 1990-2020 in the ASCOBANS region*

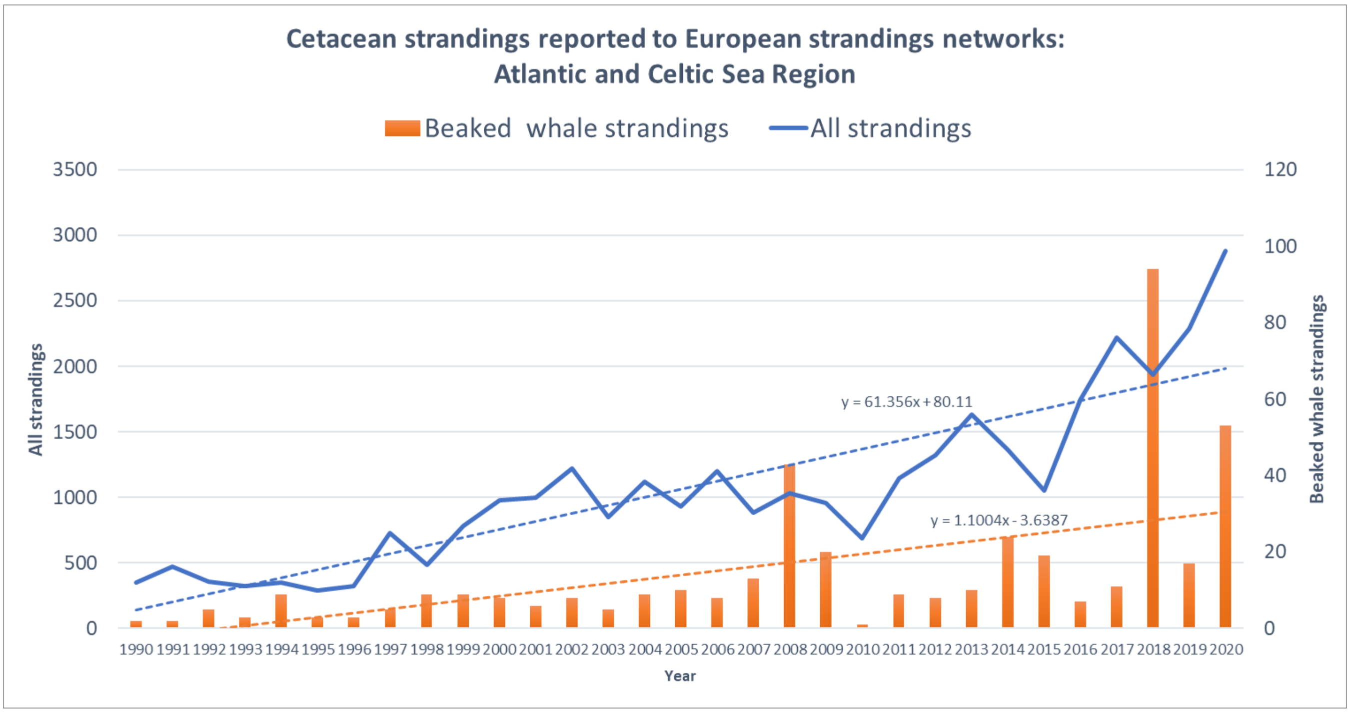


Figure 3. *Incidence of beaked whale strandings versus all cetacean strandings reports in the Atlantic and Celtic Sea regions*

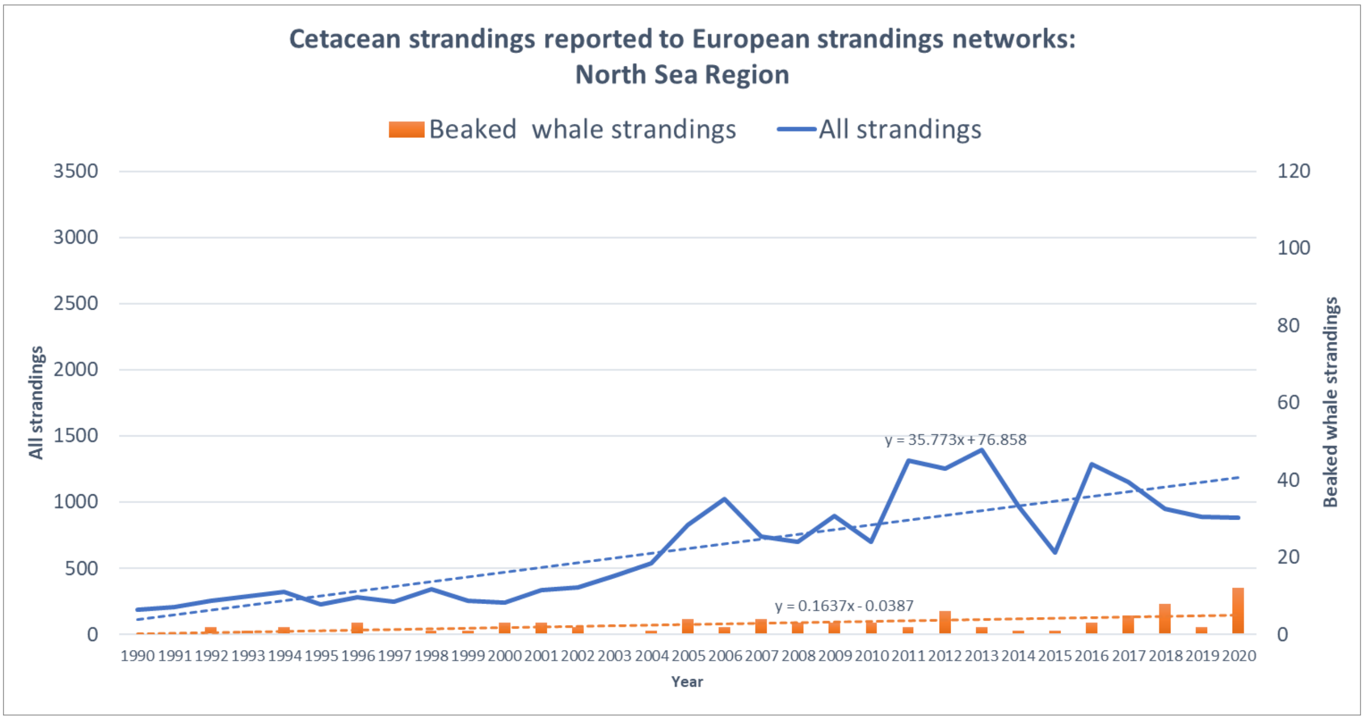


Figure 4. *Incidence of beaked whale strandings versus all cetacean strandings reports in the North Sea region*

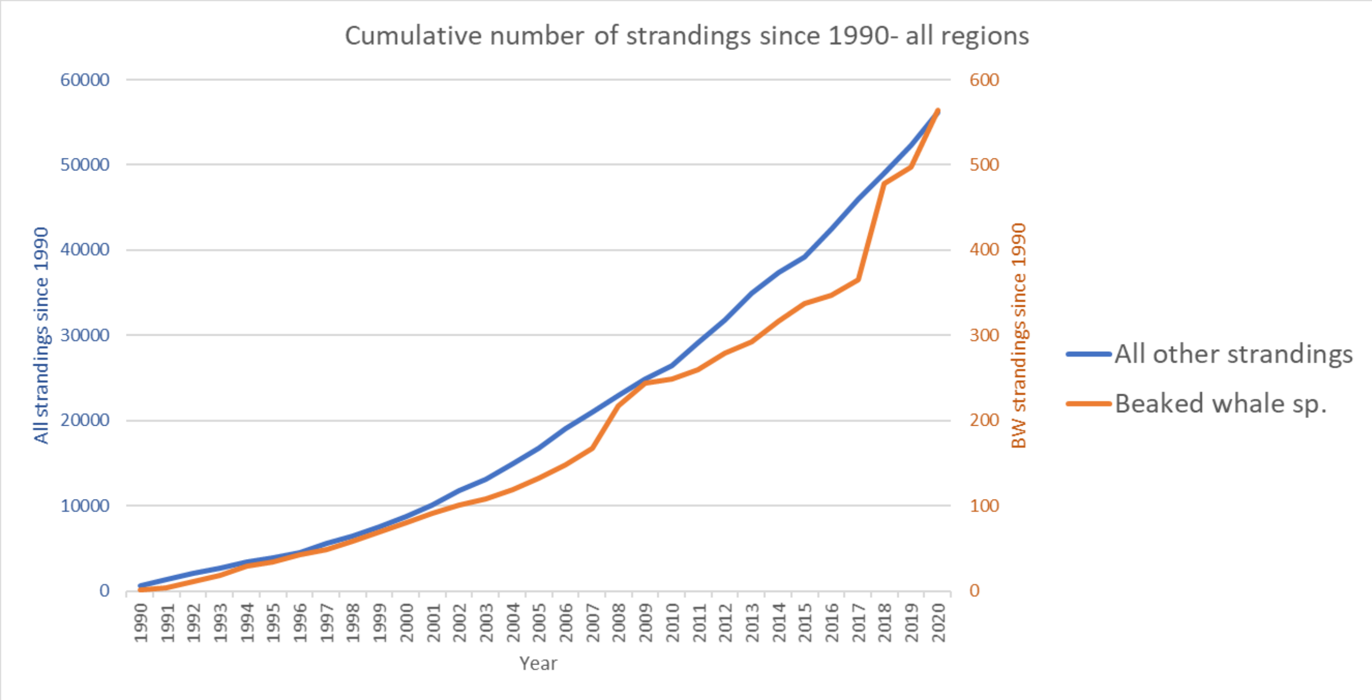


Figure 5. *Cumulative stranding reports since January 1990, all countries*

Figure 6 shows the seasonality in strandings by species. Cuvier's beaked whales and Sowerby's beaked whales are the two most frequently reported beaked whales stranded, comprising 50% and 25% respectively of all beaked whale strandings, with peaks in August and Jan-March. This pattern, and also the seasonality by country (Figure 7) of strandings are likely influenced by UMEs, for example the 2018 UME in the NE Atlantic. Nonetheless, further investigation into seasonal trends would be justified as this may indicate times of year with higher strandings incidence and therefore offer targets for potential mitigation of known hazards, e.g. impulsive noise.

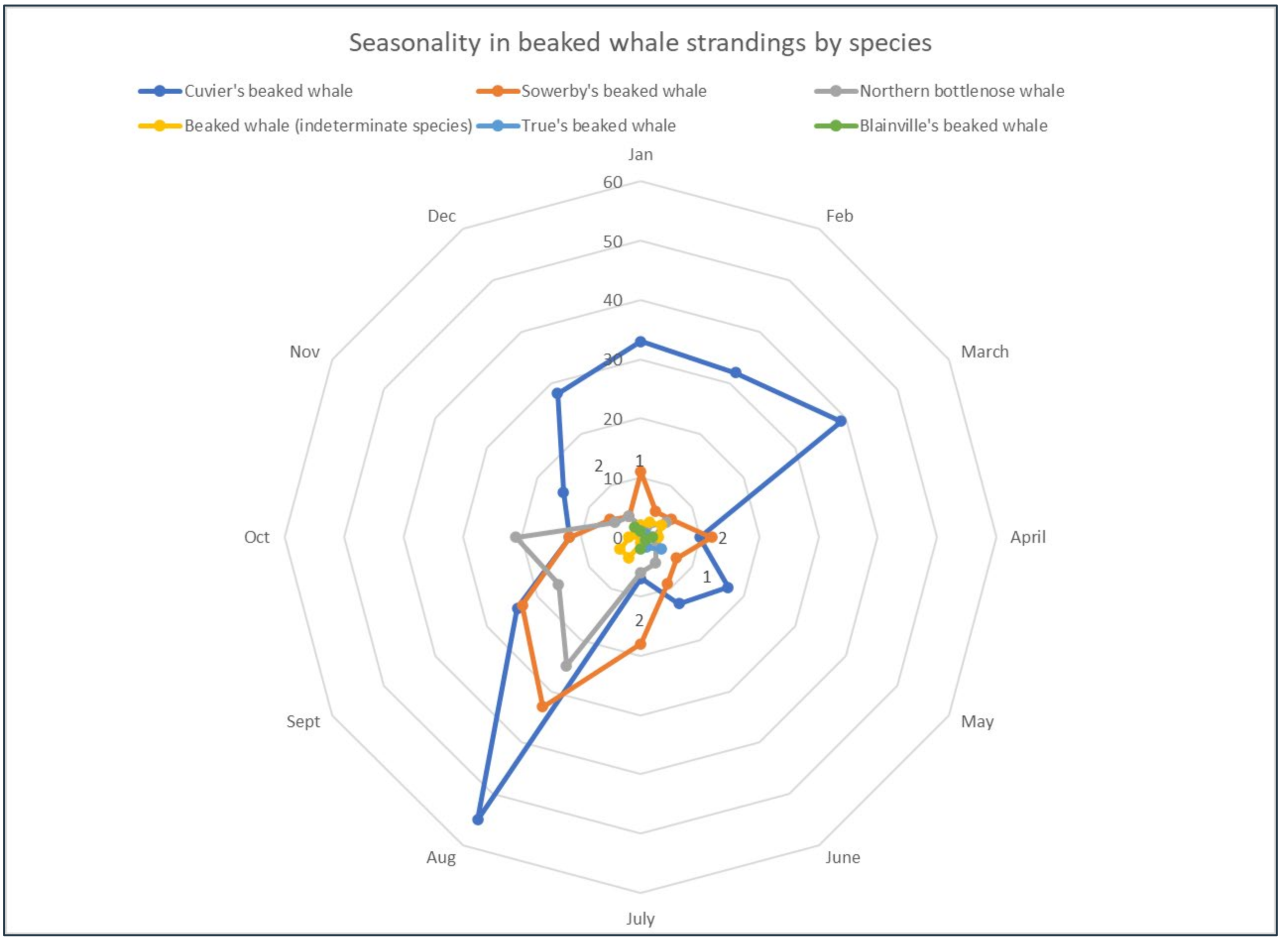


Figure 6. *Seasonality in beaked whale strandings by species in the ASCOBANS region*

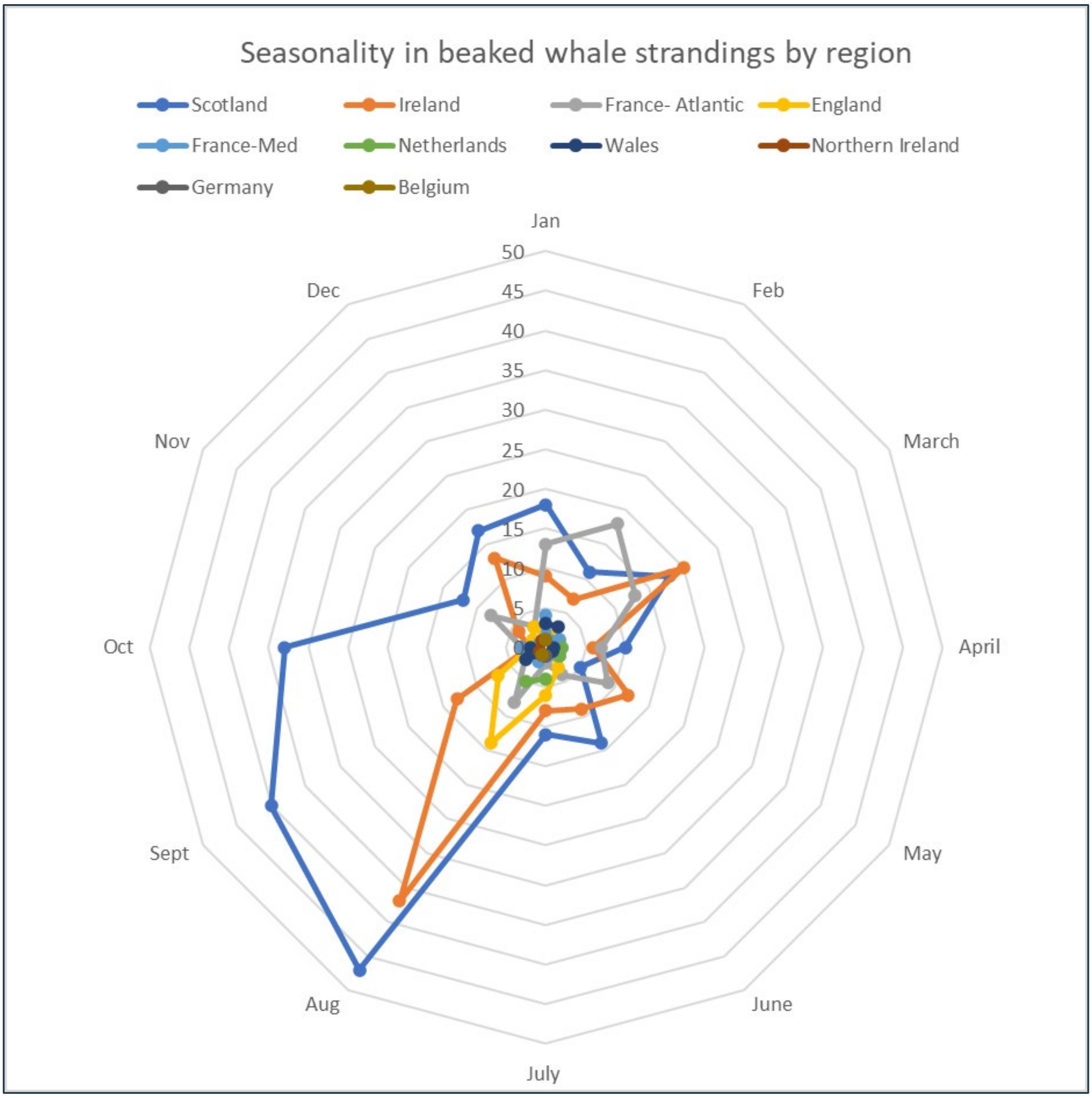


Figure 7. *Seasonality in beaked whale strandings by country*

Figure 8 shows the level of investigation possible for stranded carcasses, split by decomposition condition and examination level. Decomposition status was taken from the carcass decomposition scale used by each strandings network transposed into the standardised best practice for post-mortem examination of stranded cetaceans (IJsseldijk et al., 2019). Carcasses coded as good necropsy candidates (DCC code 1&2) were fresh and intact and a complete diagnostic investigation would have been possible. Carcasses coded as limited diagnostic value (DCC3) would be viscera decomposed and hence non-informative on several potential causes of death. Carcasses with significant decomposition (DCC code 4&5) are only suitable for limited tissue sampling, as even significant pathology can be masked by autolysed or incomplete carcasses. Figure 8 partitions the proportion of beaked whale strandings by decomposition status and level of investigation. Of note, of the 561 reported strandings, only 15% (n=82) were both in good enough condition for necropsy and subsequently underwent examination. An additional 10% (n=55 of cases) would have been suitable for necropsy based on carcass condition, but were not investigated. Logistics, funding, and availability of experienced personnel all influence whether a carcass can be examined, even if in a suitable state. Post-mortem investigation of stranded animals is the best, and in many cases only, way to attempt to attribute causation for mortality, identify emerging threats and gain insights into the life history and disease ecology of these species. However, reliable diagnosis is contingent on a thorough investigation of a fresh and largely intact carcass. The strandings networks contributing to this dataset represent some of the most longstanding, experienced, and well-resourced networks globally, and yet their diagnostic capability will have been curtailed due to the majority of beaked whale carcasses stranding in remote locations and/or in a significant decomposed state.

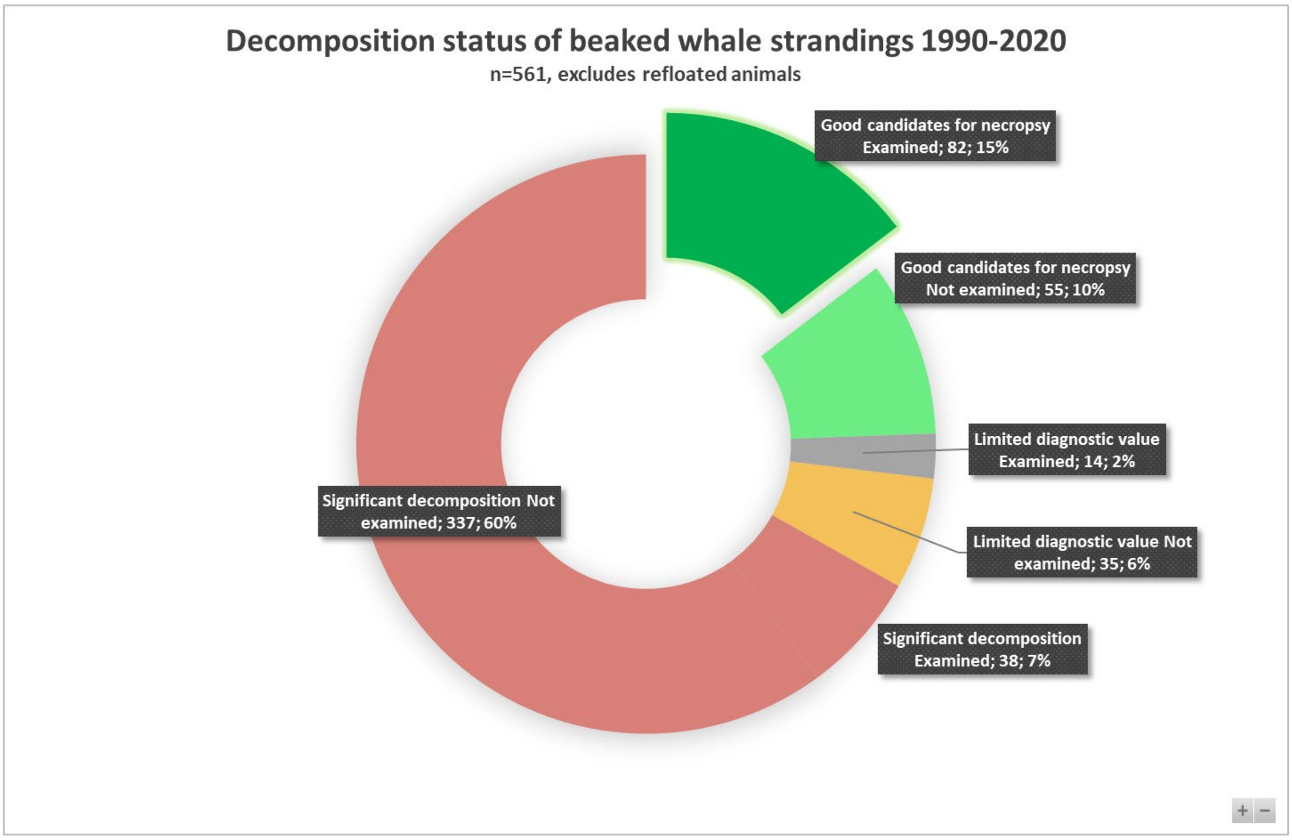


Figure 8. *Decomposition status and examination level for beaked whale strandings 1990-2020*

Figure 9 shows the findings recorded by all networks for the 561 beaked whale strandings. As highlighted above, 72% of cases were not necropsied, likely mainly because the carcasses were too decomposed. Of those which were necropsied and for which a cause of death was diagnosed (Figure 10, n=106), 'Live stranding' was diagnosed as the main cause of death in 73% of cases. Live stranding is the diagnosis given to cases which were either known or determined to be alive at the point they stranded on land, where no other underlying reason for the stranding (e.g. injury or disease) can be found. 'Trauma', either through bycatch, entanglement or ship strike comprised 12% of cases, and 'Infectious disease' comprised 7%. It is of note that gas embolism, potentially one sequalae to overexposure to underwater noise and, as evidenced by gross pathology, was only present in 2% of examined cases.

It is important to recognise, however, that this highlights the difficulties in identifying the pathological legacy of underwater noise exposure, and the true incidence may be significantly higher. For example, live stranding can be the result of a behavioural response to a number of external stimuli, either directly through herding animals out of normal habitat into shallow waters/areas of complex bathymetry or indirectly through animals becoming disoriented, lost or separated from social groups. Exposure to underwater noise may invoke these behavioural responses, which may be further exacerbated by a wide range of environmental factors such as weather or oceanographic conditions. As a behavioural response to acoustic triggers cannot be detected through necropsy, quantifying the anthropogenic impact of underwater noise exposure on beaked whales solely through necropsy and pathology of stranded animals can be limited, and a wider, interdisciplinary approach is required.

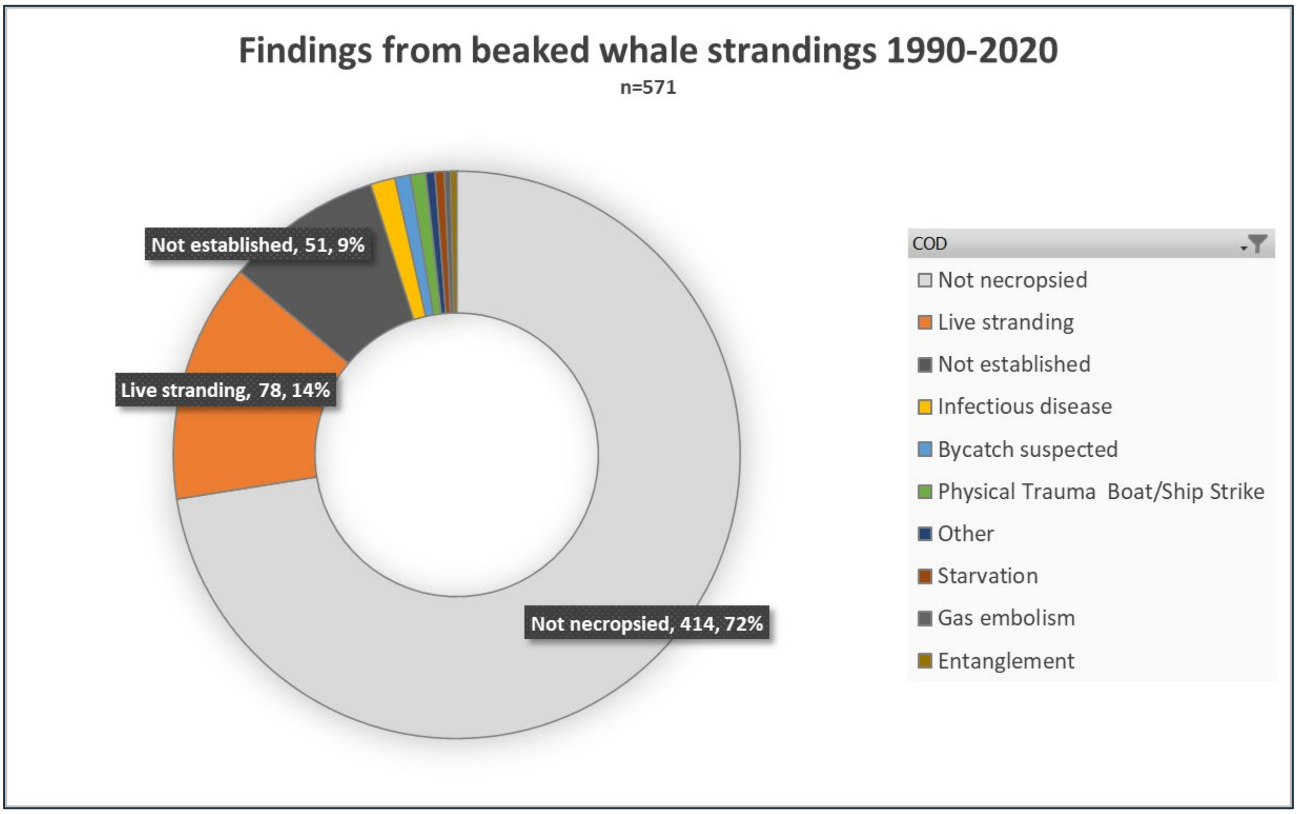


Figure 9. *Pathological findings and likely cause of death from beaked whales examined 1990-2020*

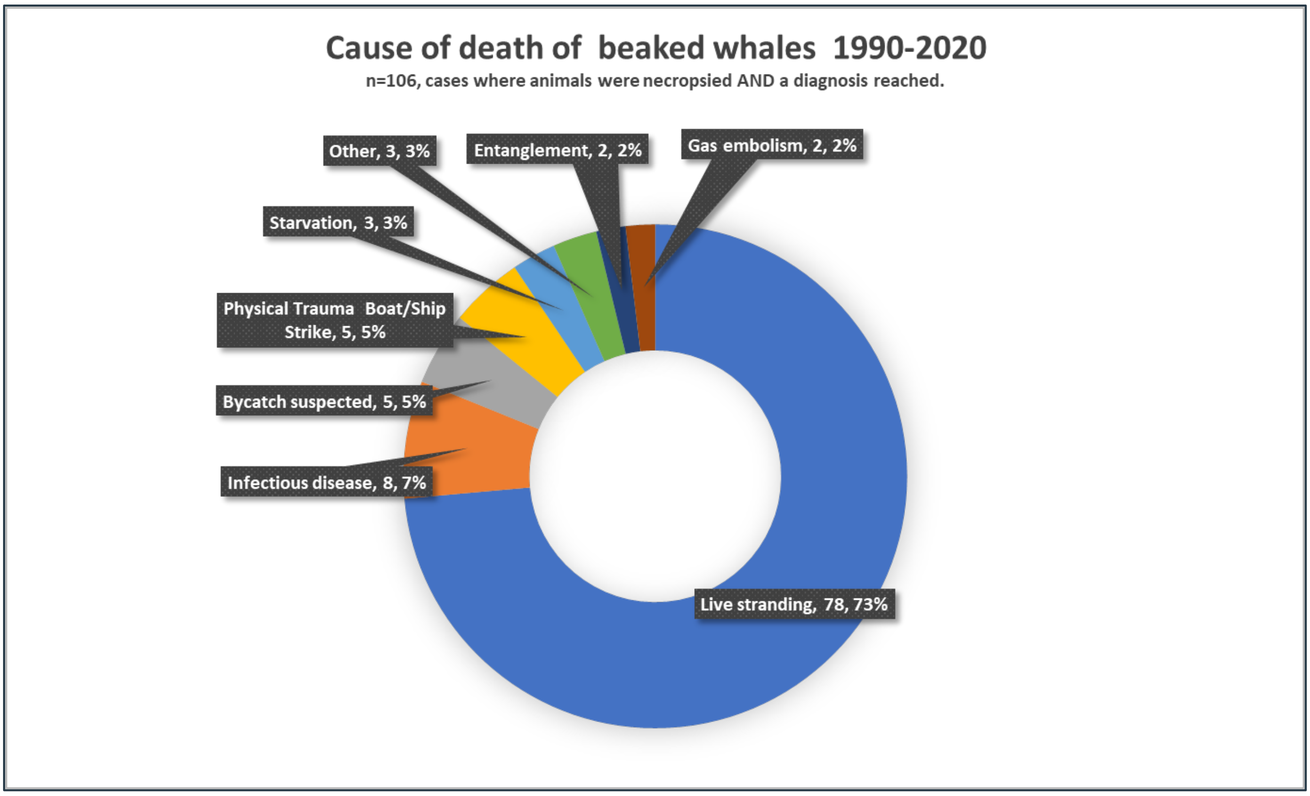


Figure 10. *Cause of death diagnosed for cases sent for necropsy*

The overall trend in beaked whale strandings by country between 1990 and 2020 is shown in Figure A1 of Appendix 1, with plots of individual strandings shown in Figure A2. Table A1 lists the number of individuals stranding by country and decade over the 50-year period 1970-2019, for each beaked whale species.

3. Pressures

3.1. Noise

High intensity active sonar, and other loud noise sources, such as for example those from gas exploration, seismic surveys, pile driving and explosions, have the potential to cause impacts ranging from masking, through altering behaviour and potentially leading to physiological impacts in beaked whales, causing hearing impairment and lesions to exposed animals as well as lethal impacts (Hildebrand, 2005; Simmonds et al., 2014). Siebert et al. (2020) reported several cases of blast injury in harbour porpoises (*Phocoena phocoena*) after explosions of unexploded munition (33% of the individuals), which was judged to be the cause of death. Pathological findings included dislocation and fracture of the middle ear ossicles, and bleeding in the acoustic fat of the lower jaw, ears and melon. In addition, lesions in the inner ear that are compatible with noise-induced hearing loss were found in another cetacean species, a long-finned pilot whale (*Globicephala melas*) involved in a mass stranding (Morell et al., 2017). Although these lesions were described for other cetacean species, it is likely that similar pathological findings can also be found in beaked whales. Interestingly, however, when Kowarski et al. (2018) used static acoustic monitoring (SAM) to explore the spatio-temporal occurrence of Cuvier's and Sowerby's beaked whales off western Ireland, and detected seismic airgun shots, with daily sound exposure levels as high as 175 dB re 1 μPa^2·s, these nevertheless did not appear to affect the mean daily number of Cuvier's or Sowerby's beaked whale click detections, suggesting a lack of avoidance of sounds that are potentially damaging.

The Spanish government imposed a moratorium on naval exercises in Canary Islands waters in 2004, following several beaked whale mass stranding events linked to military activities (Fernández et al., 2013).

In 2013, the Irish National Parks and Wildlife Service and the Department of Communications, Climate and Energy implemented and enforced a mitigation zone along the Irish shelf slopes and canyons from which seismic survey effort was excluded. This mitigation zone covered habitats of importance to deep diving species, especially beaked whales, and was implemented during three seismic surveys in 2013 and 2014 (Figure 11), but was then dropped without explanation. The zone's initial designation appeared to be linked to some of the recommendations of the Irish Offshore Strategic Offshore Assessment, which highlighted the importance of the Irish Self slopes for beaked whales.

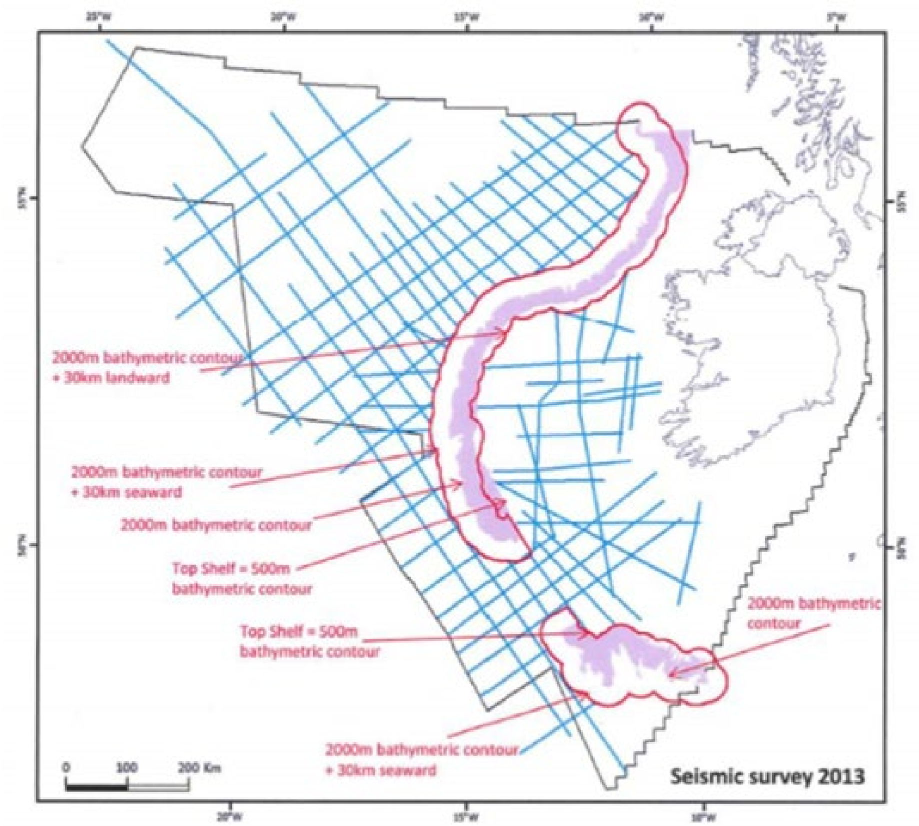


Figure 11. Map of seismic surveys carried out in 2013 in the Irish EEZ and the Irish Shelf Slopes Mitigation Zone (DCCE, 2013)

3.2. Other Pressures

Although underwater noise is probably the greatest pressure currently facing beaked whales, there are other potential pressures, such as collisions with vessels (Aguilar de Soto et al., 2006), ingestion of marine debris (Lusher et al., 2015), and entanglement in fishing gear (Gowans et al., 2000; Garrison, 2007). Beaked whales may also under certain circumstances be vulnerable to other contaminants (Hooker et al., 2008). Finally, climate change is likely to lead to range shifts, and species such as Cuvier's beaked whale and Blainville's beaked whale may be expected to extend their range northwards in the North Atlantic (Evans & Waggitt, 2020b), with possible increased frequency of incursions into shelf waters as some cephalopod prey species extend their own range into areas such as the North Sea (Van der Kooij et al., 2016). In those regions, beaked whales are likely to become exposed to a wider variety of anthropogenic pressures. Some evidence of a northwards range extension for Cuvier's beaked whale is already observed with more frequent sightings of the species north of the Bay of Biscay, and first records from as far north as Norway and Iceland.

4. Discussion and future conservation efforts

It is twenty years since the link between beaked whales and military sonar was established with evidence of decompression sickness and subsequent mortality. More than a decade of focused exposure experiments has demonstrated a range of sub-lethal behavioural and physiological responses to military sonar.

The Northeast Atlantic has become a global hotspot for beaked whale UMEs, with the largest ever beaked whale stranding occurring in 2018, and UMEs likely increasing in magnitude and frequency.

Despite significant advances in our understanding of the sub-lethal behavioural and physiological impacts of sonar on beaked whales, monitoring and management measures remain largely unchanged, and inadequate. There is no coordinated regional research to understand beaked whale health, distribution, abundance and trends, and inadequate policy to protect them. Enough is known not to delay action to prevent further lethal and sub-lethal impacts resulting from military sonar.

5. Knowledge gaps and challenges

Spatial overlap of beaked whale distribution with noise sources is a significant data gap.

Obtaining timely access to data from potential noise producers. Historically, issues have been encountered with collation of such data, to help inform investigations of atypical stranding and/or mortality events (e.g. Jepson et al., 2013; Southall et al., 2013).

Some European countries maintain noise registers, which are databases of summaries of some noise producing activities reported by noise producers at quite broad spatial and temporal scales (OSPAR, 2017). These may be useful to tracking gross trends, but they are not adequate for understanding the contexts and causes of standings. Many significant events, such as military sonar use outside publicised training exercises, are unlikely to ever be registered. Filling this important data gap requires a programme of broad band acoustic monitoring covering locations which are significant for sensitives species (e.g. hot spots) and in areas where significant anthropogenic sounds are likely to occur (e.g. exercise areas, exploration and construction locations). This can be achieved using arrays of static acoustic recorders and these should also provide useful data on cetacean density patterns and behaviour. Fortunately, the hardware and software required for this is becoming increasingly capable and affordable.

Performing full post-mortem investigations of stranded beaked whales is logistically challenging. In addition, sampling and analysis of target structures that can give information on potential exposure of the individual to noise, such as the analysis of gas bubbles (Bernaldo de Quirós et al, 2012) and ears (Morell & André, 2009; Ketten et al., 2007; Morell et al., 2017, 2020a; Wohlsein et al., 2019) is time sensitive. However, priority should be given to recovering stranded beaked whales in very good condition for full post-mortem examination to attempt to establish cause of death.

Long-term research has already been conducted in finding optimised analysis methods of inner ears of cetaceans using electron microscopy (Morell et al., 2015, 2017), markers to distinguish between recent lesions from old ones (Morell et al., 2020a) and combinations between auditory evoked potentials and cochlear findings in individuals with and without hearing loss (Morell et al., 2020b). However, there is still a large knowledge gap on inner ear anatomy and hearing capabilities in the majority of species of beaked whales.

Predictions of the frequency map of the cochlea based on morphological features will give information on the hearing frequency range of the species, but they have not yet been presented for beaked whale species.

In order to focus future attention, the following recommendations are made.

6. General Recommendations

Monitoring

- A standardised biological long-term baseline monitoring protocol would enable better understanding of beaked whale populations at the appropriate national/regional scale, with a focus on identification to species level and collection of winter-time data, and a deep-water offshore survey strategy, including visual and static, fixed, drifting and towed passive acoustic monitoring.
- A programme of long-term acoustic monitoring and analysis is required to provide information on anthropogenic noise events. Such an array of long-term acoustic recorders required for this could also provide information on cetacean densities.
- Co-ordination and communication among sound producers, stranding responders and researchers is needed to facilitate planning and preparation prior to sound exposure events, to monitor animal behaviour opportunistically, and to allow sound producers and researchers to conduct retrospective analysis (as in Cox et al., 2006).
- Better understanding of pressures in the European context is required to inform management decisions, particularly regarding military active sonar.
- Improvement in regional stranding responses is required (e.g. use of key diagnostic features, see Bernaldos de Quiros et al., 2019; Morell et al., 2017, 2020a; and best practices by IJsseldijk et al., 2019), including an ability to obtain an international overview on BW strandings.
- Beaked whales stranded in very good condition should be prioritised for full post-mortem examination whenever possible, and include attempts to establish cause of death.
- Collaborative efforts between researchers to better understand the factors that may be leading to an increase in strandings.
- Noise registry data (the range of noise sources included) and availability (both accessibility and in closer to real-time) should be improved.
- Advances should be made to develop a multi-disciplinary approach, for example, better integration of noise effects to strandings and further implementation of methods to detect cases of noise exposure.

Mitigation

- Increased effort should be made to identify important beaked whale habitat in the NE Atlantic region and this information should be used to inform mitigation strategies
- Where data allow assessment, there should be avoidance of military sonar activity in beaked whale habitat.
- Governments, militaries and other sound producers should collaborate with beaked whale experts to develop and implement effective and precautionary mitigation strategies where data are not adequate.

General

- Parties to ASCOBANS and the IWC should raise the profile of the issue, both through engagement with and conveying recommendations to national navies and to NATO; and distribute findings widely, both nationally and internationally.

7. Acknowledgements

We are indebted to all members of the French Stranding Network RNE for their indefatigable and continuous help in collecting stranding data. Irish stranding data were provided by the Irish Whale and Dolphin Group Cetacean Stranding Scheme, and Ireland's ObSERVE Programme by the Department of Communications, Climate Action and Environment (DCCAE) in partnership with the Department of Culture, Heritage and the Gaeltacht. UK stranding data are provided by the Cetacean Strandings Investigation Programme and the Scottish Marine Animal Strandings Scheme which are funded by Defra and the devolved governments of Scotland and Wales. We are grateful to the many observers who participated in the surveys and collected all the data but also the ships' captains, crews and pilots. We thank the *Direction Générale de l'Armement* (DGA) for funding Auriane Virgili's research grant.

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ANNEX

Beaked whale species, their status and distribution in the region

With the exception of the extra-limital record of Gray's beaked whale (*Mesoplodon grayi)*, that stranded in the Netherlands in Dec 1927 (Smeenk & Camphuysen, 2016), there are six species of beaked whale considered native to the North Atlantic. These are northern bottlenose whale (*Hyperoodon ampullatus)*, Cuvier's beaked whale (*Ziphius cavirostris)*, and four *Mesoplodon* species – Sowerby's beaked whale (*M. bidens)*, True's beaked whale (*M. mirus)*, Blainville's beaked whale (*M. densirostrisi)*, and Gervais' beaked whale (*M. europaeus).* Our knowledge of their overall status and distribution remains limited.

Within the Central and Northeast Atlantic, the following represents a summary of our knowledge of the status and distribution of beaked whale populations.

Northern Bottlenose Whale

Northern bottlenose whale is confined to the North Atlantic from temperate to arctic seas. Its main range extends from Baffin Island and West Greenland south to New England in the west, and from Svalbard to the southern tip of the Iberian Peninsula in the east, including around the oceanic archipelago of the Azores, although it occurs occasionally further south to c. 15ºN. The main regions of concentration, identified from former whaling activities, appear to be off western (Møre) and northern (Andenes) Norway, west of Svalbard, north-east of Iceland, between Iceland and the Faroes, in the Davis Strait off Labrador, and in The Gully off eastern Canada (Benjaminsen, 1972; Benjaminsen & Christensen, 1979; Reeves et al., 1993; Whitehead & Hooker, 2011).

In NW Europe, the species is seen primarily in waters exceeding 1,000m, such as the Faroe-Shetland Channel, Rockall Trough, and southern Bay of Biscay (Bloch et al., 1996; Williams et al., 1999; Reid et al., 2003; Compton, 2005; Hooker et al., 2008), Occasionally, the species ventures onto the shelf, for example in west Scotland (Fig. A12), mainly between June and September (Evans et al., 2003; Evans & Waggitt, 2020a; see Fig. A15). Acoustic monitoring west of Ireland has also confirmed its occurrence in small numbers in late summer and autumn, particularly on the southern edge of the Rockall Trough (Kowarski et al., 2018), and in the Faroes, catches of the species were highest in August and September (Bloch et al., 1996). It has been suggested that they undergo latitudinal migrations, occurring most commonly between Iceland and Jan Mayen in late April to early June, and then moving southwards during June-July (Thompson, 1928; Bloch et al., 1996).

Figure A12 shows the distribution of northern bottlenose whale sightings between southern Scandinavia and northern France (animals close inshore generally later live-stranded), whilst Figure A10 shows sightings from dedicated surveys (as part of the large-scale collation of aerial and vessel surveys between 1985 and 2018 – see Figure A8, and Waggitt et al., 2020, for details). Most northern bottlenose whale strandings in Europe come from the UK and Ireland (Table A1).

North Atlantic Sightings Surveys (NASS) in 1987 and 1989 yielded a population estimate of about 40,000 animals across the central northern North Atlantic (Vikingsson, 1993; NAMMCO, 1993). From these surveys, Gunnlaugsson & Sigurjónsson (1990) estimated a population size of 4,925 (CV 0.16) off Iceland, and 902 (CV 0.45) off the Faroe Islands. However, these did not use conventional distance sampling methods or correct for potential biases. Subsequently, Pike *et al.* (2003) estimated 27,879 (CV 0.67; 95% CI: 12,396-62,700) for a survey in 1995, and 24,561 (CV 0.23; 95% CI: 15,261-39,528) in 2001, although neither was corrected for availability bias.

Collating data from the Faroese sector of the Trans-North Atlantic Sightings Surveys (TNASS), and the SCANS II and CODA surveys spanning from SW Scandinavia to NW Spain, Rogan et al. (2017) obtained a design-based abundance estimate of 19,539 (CV 0.36, 95% CI: 9921–38,482], based upon 15 sightings mainly south-west of the Faroes.

A further North Atlantic Sightings Survey (NASS) was conducted in June/July 2015 and covered a large area of the central northern North Atlantic (see Fig. A3). The Icelandic and Faroese ship survey component of the NASS covered the area between the Faroe Islands and East Greenland from latitude 52° to 72° N. Northern bottlenose whales were sighted across the survey area mainly between latitudes 60° and 65° N, particularly around the Faroes. None were sighted close to Iceland, although the species does occur there in late spring and early summer, whilst few were seen in the northern part of the area during the time of the survey. Aerial surveys around Iceland between 1987 and 2016 have also yielded few sightings in coastal waters, most occurring south and east of Iceland. (Pike et al., 2020b; see Fig. A4).

A total corrected (for both perception and availability bias) estimated abundance of 19,975 (CV 0.60, 95% CI: 5,562–71,737) individuals (based upon 36 sightings, largely of groups of 1-5 individuals) was obtained from this survey (Pike et al., 2019). None were seen during the capelin survey covering waters between west Iceland and East Greenland in the autumn, consistent with the hypothesis of a southward directed migration.

A ship-based mosaic survey of the north-eastern sector of the northern North Atlantic (see Fig. A5) was conducted by Norway over a 5-year period from 2014-18. The area surveyed extended from the North Sea in the south (southern boundary at 53° N), to the ice edge of the Barents Sea and the Greenland Sea. By combining data across years, sufficient sightings were obtained to estimate the abundance of northern bottlenose whales. The estimated abundance in the area was 7,800 (CV 0.28, 95% CI: 4,373-13,913) (Leonard & Øien, 2020b).

When the overlap in one of the survey blocks between the Icelandic/Faroese survey in 2015 and the Norwegian survey in 2016 is removed, a combined estimate for northern bottlenose whales in the total area is 23,528 (CV 0.56; 95% CI: 8,453-65,487). It should, however, be noted that this combined estimate is based on surveys conducted in different years (2015, 2016) and therefore does not account for possible distributional/seasonal changes.

There is a long history of hunting of this species, dating back at least to the 16th century, although largest numbers were taken between the middle of the 19th century and first half of the 20th century, with an estimated 65,000 killed between about 1872 and 1972, which was believed to have significantly depleted the populations (Mitchell, 1977, Reeves et al., 1993). Despite intense survey coverage over the past 30 years (Øien & Hartvedt, 2011), northern bottlenose whales are rarely sighted, with most occurring in the vicinity of Svalbard and Jan Mayen, but still in small numbers. It is possible that the population using this area may have been severely reduced (Pike et al., 2019).

Consistent with the results summarised above, during the acoustic monitoring as part of the Irish ObSERVE project, much lower numbers of northern bottlenose whale were recorded than both Sowerby’s and Cuvier’s beaked whale, and with detections recorded in deeper waters (Berrow et al., 2018a; Kowarski, 2018).

Cuvier’s beaked whale

Cuvier’s beaked whale has the most widespread distribution of the family Ziphiidae, occurring probably worldwide in tropical to warm temperate seas. The species favours deep, warm waters of 500-3,000m depth and is the most common beaked whale in the Bay of Biscay particularly the Santander Channel (Kiszka et al., 2007; Smith, 2010), around the Iberian Peninsula and in the Mediterranean (Notarbartolo di Sciara & Birkun, 2010; Santos et al., 2012; Podestà et al., 2016; Laran et al., 2017), and is a regular inhabitant of the waters around the Azores, Madeira and Canaries, where it is seen year-round (Aguilar de Soto, 2006; Freitas et al., 2012; Silva et al., 2014). Its presence has been recorded acoustically year-round offshore west of Ireland, with a seasonal increase in late autumn off north-west Porcupine Bank, a region of relatively high detections (Kowarski *et al*., 2018).

Further north, it is relatively rare, with a small number of sightings from around the British Isles and Ireland (Evans et al., 2003; Berrow et al., 2010; Evans & Waggitt. 2020a; Figures A10 & A13). There are isolated stranding records from Iceland, Denmark, Sweden and The Netherlands (Van Waerebeek et al., 1997; Evans et al., 2008b; Kinze et al., 2011; C. Kinze *pers. comm*.), most occurring in the British Isles and Ireland (Berrow & Rogan, 1997; McGovern et al., 2016). As noted earlier in the report, in Feb-May 2008 and Aug-Sep 2018, there was a surge in strandings mainly in the western UK and Ireland, in 2018 also extending to northern Norway and Iceland (Dolman et al., 2010; Brownlow et al., 2018; Deaville et al., 2019).

Using data from the Faroese sector of the Trans-North Atlantic Sightings Surveys (TNASS), SCANS II and CODA surveys spanning from SW Scandinavia to NW Spain (see Fig. A6), Rogan et al. (2017) obtained a design-based abundance estimate of 2,286 (CV 0.48; 95% CI: 942–5,552) individuals, based upon 17 sightings, mainly in the Bay of Biscay.

Cuvier's beaked whales were the most frequently sighted beaked whale during the ObSERVE aerial surveys of the Irish EEZ in the summer and winter of 2015 and 2016 (Rogan et al., 2018). Although most sightings could not be assigned to species, an abundance estimate was made for Cuvier's beaked whale of 237 (CV 0.71; 95% CI: 67-847) in summer 2016, and 765 (CV 0.77; 95% CI: 200-3,000) in winter 2016-17 (Rogan et al., 2018). As part of the Irish ObSERVE project, acoustic surveys using towed hydrophones during the same period detected Cuvier's beaked whales mainly during summer (Berrow et al. 2018a). Kowarski et al. (2018), using static acoustic data from eight sites west of Ireland, showed a significant effect of month and latitude on detections of both Cuvier's and Sowerby's beaked whales. They found Cuvier's beaked whales to be most frequently detected at lower latitudes during summer, whereas Sowerby's beaked whales were more frequently detected at higher latitudes, particularly in spring. This is consistent with the known preferred ranges of the two species.

Sowerby's beaked whale

Sowerby's beaked whale inhabits the waters of the temperate North Atlantic, occurring more commonly in European seas than in eastern North America, with a distribution centred upon deep waters of 500-3,000m depth in the mid- and eastern North Atlantic somewhat north of other *Mesoplodon* species, and generally north of Cuvier's beaked whale. In northern European waters, there have been confirmed sightings south of Iceland, in the Norwegian Sea, west of Norway, around the Faroe Islands, north and west of the British Isles and Ireland, in the Channel Approaches, and in the Bay of Biscay (Macleod 2000, Pollock et al., 2000; Weir, 2001; Evans et al., 2003; Macleod, 2005; Rogan et al., 2017; Berrow et al., 2018b; Evans & Waggitt 2020a; see Figures A10 & A14). Further south and west, they have been observed regularly around the Azores and Madeira (Freitas et al., 2012; Silva et al., 2014), and even as far south as the Canary Islands (Martin, 2011), occasionally also entering the western Mediterranean (Bittau et al., 2018).

Most strandings in Europe come from the British Isles (Table A1 in Appendix I). These have occurred mainly in the Northern Isles of Scotland and along the coast of eastern Britain although there are a number of records also from the English Channel, western coasts of Britain and Ireland, and those European countries bordering the North Sea (Camphuysen & Peet 2006, Smeenk & Camphuysen 2016, Deaville, 2018). Strandings within the relatively shallow North Sea, however, may reflect passive drift from further north. Live sightings in shelf seas are very few, most being off the edge of the continental shelf north and west of Scotland and west of Ireland (Fig. A14). Sightings in Britain and Ireland have occurred in most months of the year but with the great majority in July (Evans & Waggitt, 2020a). Static acoustic monitoring west of Ireland indicated Sowerby's beaked whales to be by far the most frequently detected beaked whale species off western Ireland, showing a widespread distribution but with the highest occurrence off northwest Ireland, and particularly in the month of May (Kowarski et al., 2018). Towed hydrophone surveys showed that densities were highest in an area along the shelf-break with steep bathymetric slopes (Berrow et al., 2018a; see also Fig. A16).

Rogan et al. (2017) made a design-based abundance estimate for the species of 3,518 (CV: 0.43; 95% CI: 1570-7883) from the Faroese sector of the Trans-North Atlantic Sightings Surveys (TNASS), and the SCANS II and CODA surveys, spanning from SW Scandinavia to NW Spain, based upon six sightings, five of which were west of Scotland or between Scotland and Iceland.

Acoustic monitoring of Cuvier's and Sowerby's beaked whales

The largest SAM study of beaked whales in the NE Atlantic was carried out between March 2015 and November 2016 along the Irish continental shelf edge (Berrow et al., 2018a). A total of 1,657 days of data were collected at eight from 55°N south to 49°N using Autonomous Multichannel Acoustic Recorders (AMAR). Cuvier's and Sowerby's beaked whale clicks occurred at all stations throughout the monitoring period. There was a significant effect of month and station (latitude) on the mean daily number of click detections for both species. Cuvier's beaked whale clicks were more abundant at lower latitudes, while Sowerby's were greater at higher latitudes, particularly in the spring, suggesting a spatial segregation between species, possibly driven by prey preference (Kowarski et al., 2018).

Six dedicated Passive Acoustic Monitoring (PAM) surveys were also carried out between May 2015 and October 2016, resulting in 3,784 nautical miles of survey effort. Despite few sightings (six Sowerby's; one Cuvier's; eight unidentified) a total of 38 acoustic detections of Sowerby's and nine Cuvier's detections were made. The detections and predicted relative densities for Sowerby's beaked whales were highest in areas of high maximum slope along the shelf edge, and most abundant in the upper and mid bathyal biological zones. Latitude was strongly influential in the model, with densities increasing to the north of the study area (Berrow et al., 2018a; see Fig. A16). One sighting of a group of five individual Sowerby's beaked whales was the first confirmed group with calves in the northeast Atlantic (Berrow et al. 2018b).

A number of recent studies in Ireland have suggested the Rockall Trough margin of the NW coast as sensitive habitats for Sowerby's and Cuvier's beaked whales as well as other deep-diving species (Rogan et al., 2017; Berrow et al., 2018a; Rogan et al., 2018; Breen et al., 2020).

Acoustic moorings have been deployed on the Rockall Bank and on the west side of the Outer Hebrides, as part of the Collaborative Oceanography and Monitoring for Protected Areas and Species (COMPASS) and Static Acoustic Monitoring of Scottish Atlantic Seas (SAMOSAS) projects, and will be analysed for beaked whale vocalisations (D. Risch, *pers. comm*).

True's beaked whale

The status of True's beaked whale is very poorly known, due in part to the difficulty of species identification at sea (Aguilar de Soto et al. 2017). They appear to be widespread, occurring in deep waters (500-2,500m depth) of the temperate Atlantic although they are also recorded in the southern Indian and South Atlantic Oceans, with records from eastern North America, NW Europe, Macaronesia, Brazil, South Africa, Mozambique, Madagascar, southern Australia and the Tasman coast of New Zealand (Constantine et al., 2014; Jefferson et al., 2015; Bachara & Gullan, 2016). There have been 15 stranding records from Europe since 1899, thirteen of those from western Ireland (Berrow & Rogan, 1997; Berrow et al., 2010; McGovern et al., 2016). The other European records are from France (Barriety, 1962) and the UK (Kitchener et al., 2020), although the species has been reported also from the Canaries and Azores, confirmed by genetics (Vonk & Martin, 1988;

Aguilar de Soto et al., 2017). Sightings have also been made in the Canaries, the Azores, and the Bay of Biscay (Steiner et al., 1998; Weir et al., 2004; Aguilar de Soto et al., 2017; see also Fig. A10). These suggest a distribution possibly influenced by a southern branch of the North Atlantic Current.

Blainville's beaked whale

Blainville's beaked whale is one of the most widely distributed species of the genus *Mesoplodon*, recorded from tropical and warm temperate seas of all oceans (Jefferson et al., 2015). They are more commonly seen at sea than other North Atlantic *Mesoplodon* species, suggesting that they may be quite common in some areas, although it is also easier to identify. It has been recorded in waters of 500-5,000m depth (Evans & Waggitt, 2020a).

In the Atlantic, they are mostly recorded from south-eastern United States, the Gulf of Mexico, and the Caribbean, but with records in the west ranging from Nova Scotia to southern Brazil. In the eastern North Atlantic, the species has been recorded from Spain, Portugal, Madeira, and the Canaries, most records coming from the Canaries where sightings of the species frequently occur (Aguilar de Soto, 2006; Evans et al., 2008a; Evans, 2020). There are also single extra-limital stranding records from Wales (July 1993; Herman et al. 1994), Cornwall, SW England (Dec 2013; Deaville 2018), the Netherlands (April 2005; Smeenk & Camphuysen, 2016), and Iceland (1910; Petersen & Olafsson, 1986), and three strandings in France (1998, 2002, 2008), including a live stranding of two individuals on the south Biscay coast (Van Canneyt et al., 2009). There are no confirmed live sightings from northern Europe.

Gervais' beaked whale

Gervais' beaked whale is known only from the Atlantic. Although the type specimen was found floating in the English Channel in 1848, most records come from the Western Atlantic, from Long Island, New York in the north to the eastern Caribbean in the south (mainly south of North Carolina). It is the most common species of *Mesoplodon* recorded from eastern United States and the Gulf of Mexico (Mead, 1989; Jefferson & Schiro,1997).

In recent years, several strandings of the species have been recorded in the eastern North Atlantic. These include from Western Ireland (Berrow & Rogan, 1997), France, Portugal, southern Spain, the Azores (Steiner et al., 1998), Mauritania and Guinea-Bissau (Reiner, 1980; Evans et al., 2008c), although most records have come from the Canaries (Carrillo & Martin, 1999; Ritter & Brederlau, 1999; Aguilar de Soto, 2017). Extra-limital records from the Mediterranean Sea include a dead animal stranded in Italy, and a live stranding thought to be of this species from Turkey (Notarbartolo di Sciara & Birkun, 2010).

Beaked whales

In many cases, *Mesoplodon* species are not identified specifically, particularly from aerial surveys. Figure A11 shows the distribution of unidentified animals from the MERP collation of dedicated surveys, amounting to 2.68 million kilometres of aerial and vessel survey effort spanning the region from southern Scandinavia to north Spain, over the period 1985-2018 (Fig. A8).

Combining data from the Faroese sector of the NASS survey in summer 12007 with the SCANS II and CODA surveys, Rogan et al. (2017) obtained a total beaked whale abundance estimate of 29,154 (CV 0.23; 95% CI: 17,478-48,629). However, Rogan et al. (2017) used a common detection function for all beaked whales, combined with species specific encounter rates, so estimates should be treated with some caution.

Dedicated aerial and acoustic surveys of the Irish EEZ were carried out under the ObSERVE_Aerial project during summer and winter 2015 and 2016 (see Fig. A7). Design based abundance estimates for Cuvier's beaked whales, *Mesoplodon* species and all beaked whales combined were presented by Rogan et al. (2018). An abundance estimate for all beaked whales in summer 2016 was 3,142 (CV 0.505; 95% CI: 1,200-8,100) and in winter 2016-17 of 4,948 (CV 0.54; 95% CI: 1,800-13,500), in both seasons in deep offshore waters west of Ireland (Rogan et al., 2018).

Most recently, combining estimates from SCANS-III and ObSERVE in summer 2016, spanning from southern Scandinavia to Portugal but excludes Faroese waters (Hammond et al., 2017; Rogan et al., 2018) yields an overall estimate for all beaked whale species of 14,536 (CV 0.41; 95% CI: 6,700-31,400).

Table A2 summarises the best available abundance estimates by beaked whale species.

Predicted beaked whale densities

Virgili et al. (2019) have assembled effort and sighting data in the North East Atlantic from seven organisations using aerial and vessel-based platforms between 1998 and 2016 (Figure A9), in order to model beaked whale distribution. Effort data represented 430,250 km (only effort performed in good conditions was used in the analysis), and resulted in 161 sightings of beaked whales (including *Ziphius cavirostris*, *Hyperoodon ampullatus* and *Mesoplodon* spp.; note that species generally cannot be identified at a species level by plane).

Effective strip width (Buckland et al., 2015) was estimated for each combination of platform, class of Beaufort sea state and class of observation height by building a hierarchical model (Virgili et al., 2019) and included as offset in Generalised Additive Models (GAMs; Hastie & Tibshirani, 1986). GAMs were fitted to effort and sighting data by using environmental variables (depth, slope, roughness, sea surface temperature, gradients of sea surface temperature, current speed, chlorophyll a concentration, net primary production). A selection procedure was implemented (combinations of variables with Pearson correlation coefficients higher than |0.5| were removed and all models with combinations of one to four variables to avoid excessive complexity (Mannocci et al., 2014) were tested) to select the best model. The model was finally used to predict relative densities of beaked whales over the entire study area at a 10km resolution (Figure A17).

The highest densities of beaked whales were predicted near the continental slope and the Mid-Atlantic Ridge, but also in the abyssal plains (Figure A17). From the predicted relative densities, abundance of beaked whale in the area was estimated at 18,750 individuals (95% CI: 10,430- 27,060).

Studies have demonstrated that at least some beaked whale species typically reside in a small, defined core use area (Gowans et al., 2000; Rogan et al., 2017), and Cuvier's beaked whale populations in particular are known to exhibit high degrees of site fidelity (McSweeney et al., 2007; Schorr et al., 2014; Falcone et al., 2017; Reyes, 2017; Baird, 2019; Foley et al., 2021). Fixed bathymetric features may be driving the consistent occurrence of beaked whales (Kowarski et al., 2018; Gowans et al., 2000; Foley et al., 2021). Individual beaked whale species may also occupy distinct ecological niches and exhibit fine-scale habitat partitioning with other beaked whales and deep-diving odontocetes (MacLeod, 2005). Northern bottlenose whales, on the other hand, might perform long migrations from north to south, but this is not yet well documented (Miller et al., 2015).

Future monitoring requirements

Avoidance of beaked whale habitat requires accurate predictions of population densities, which requires adequate surveys and monitoring. Beaked whales are often not the target species of surveillance surveys and so population estimates are subject to availability bias that cannot easily be adjusted for, and key habitats may lack coverage.

Rogan et al. (2017) suggest a combined visual and acoustic approach may help refine abundance estimations and better elucidate habitat use for deep diving species, including beaked whales. Given the elusive nature of beaked whales, and the recent success of static acoustic monitoring (Berrow et al., 2018a; Kowarski et al., 2018), this monitoring technique is recommended to assess the geographical and temporal occurrence of beaked whales in suitable habitats. Mobile surveys, visual, towed PAM are required investigate spatial distribution. Drifting PAM is also showing considerable promise for beaked whales (Barlow et al., 2021). More work to understand the click characteristics of beaked whales is still required to train algorithms to use in automatic click detectors. Long term PAM is also essential for monitoring for the occurrence of anthropogenic noise.

Whereas Table A2 identifies the IUCN red list status of beaked whales globally, regional assessments in the NE Atlantic have yet to be made. Concern remains that the appropriate status is not available at the smaller, and most relevant level for sub-populations.

Appendix I: Strandings maps and charts

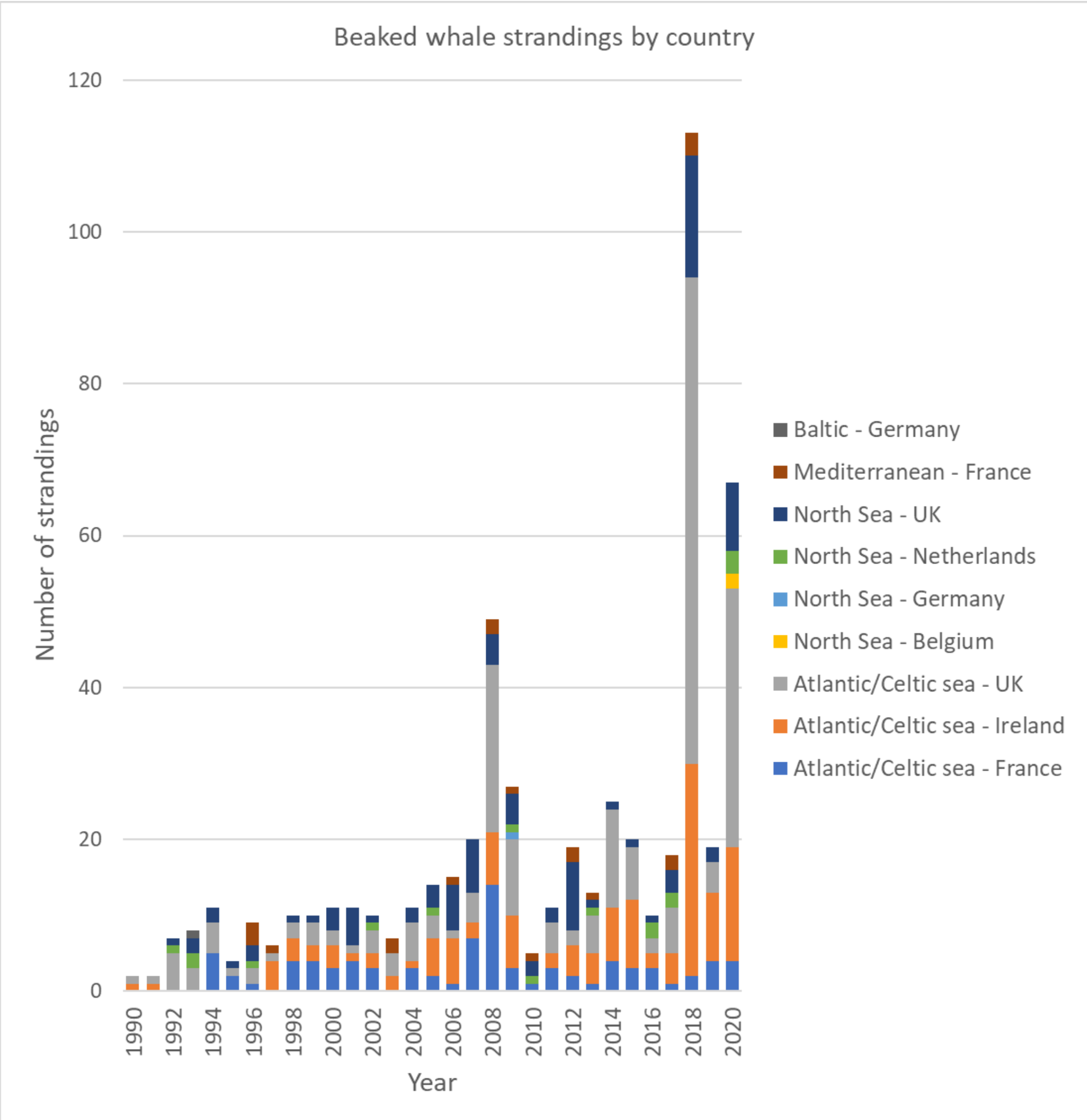
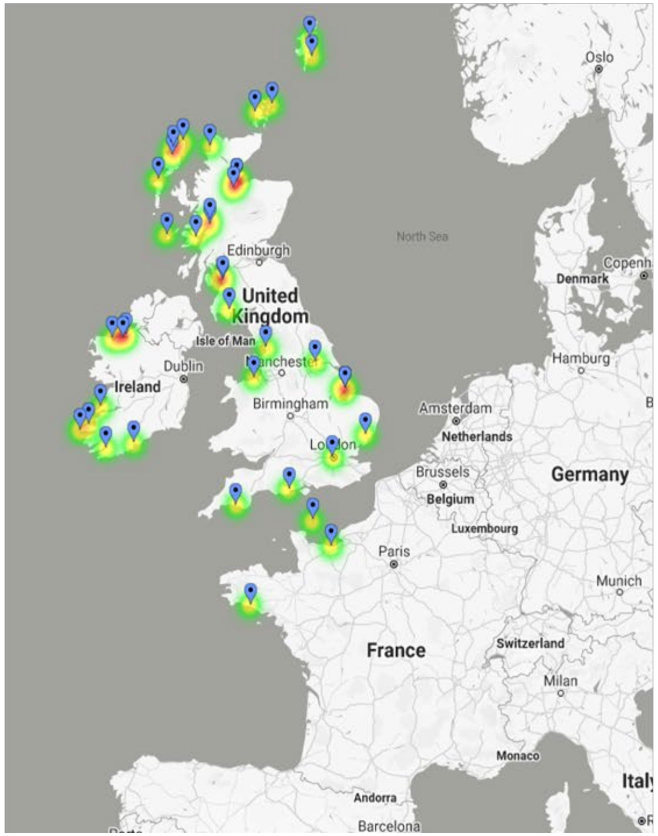


Figure A1. Beaked whale strandings by year and country

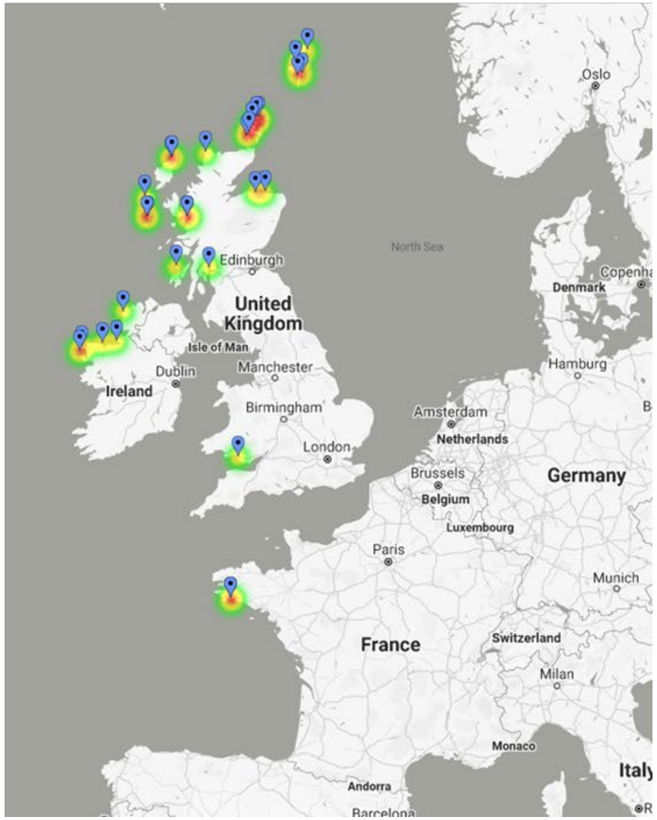
Northern bottlenose whale (*Hyperoodon ampullatus*)

1990-1999 n=18

2000-2009 n=39



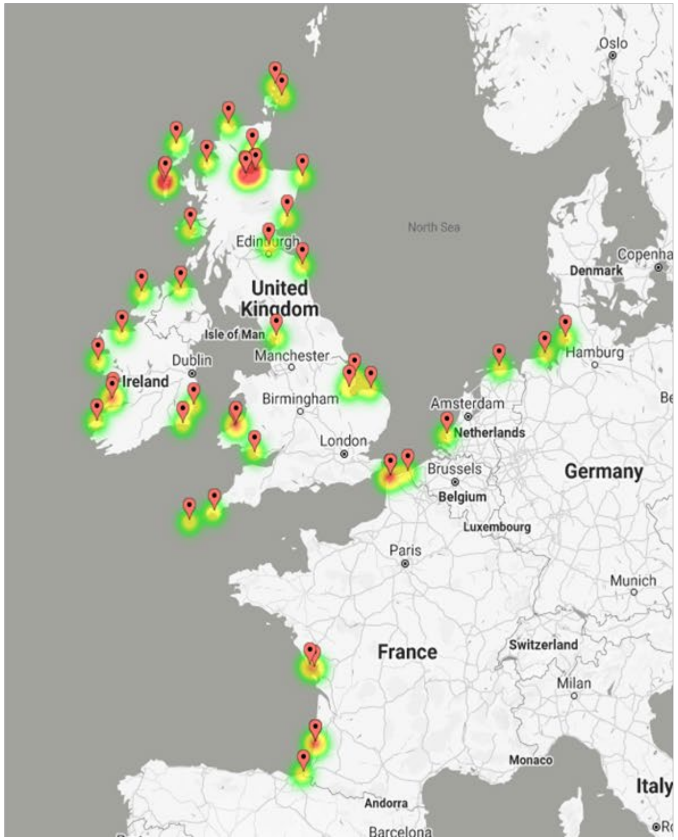
2010-2019 n=29



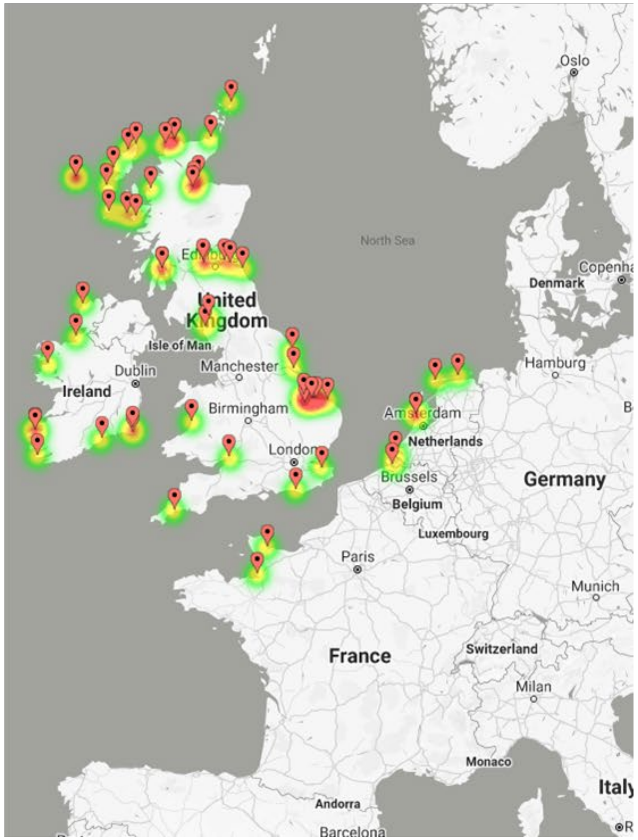
Sowerby's beaked whale (*Mesoplodon bidens*)

1990-1999 n=22

2000-2009 n=49



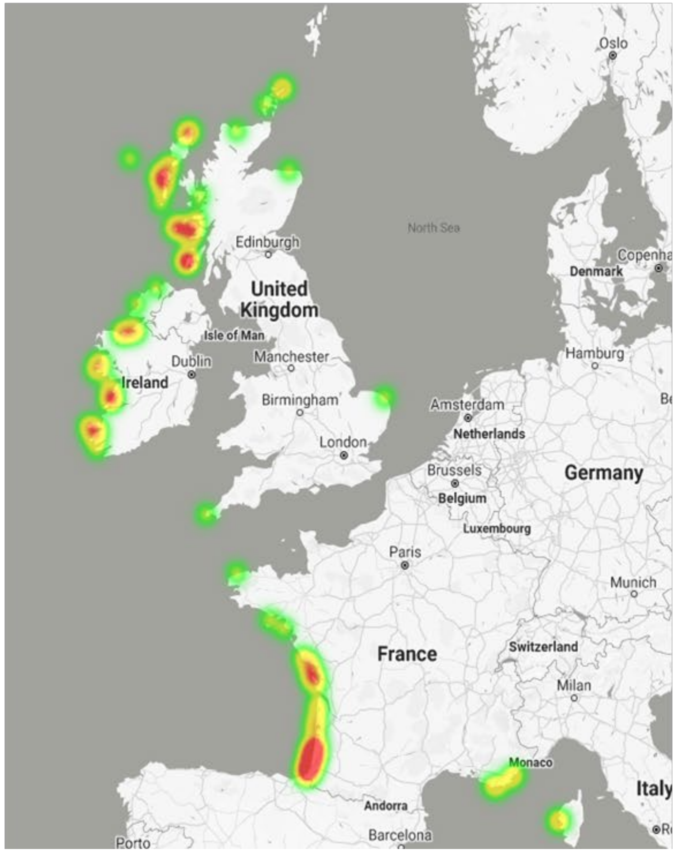
2010-2019 n=58



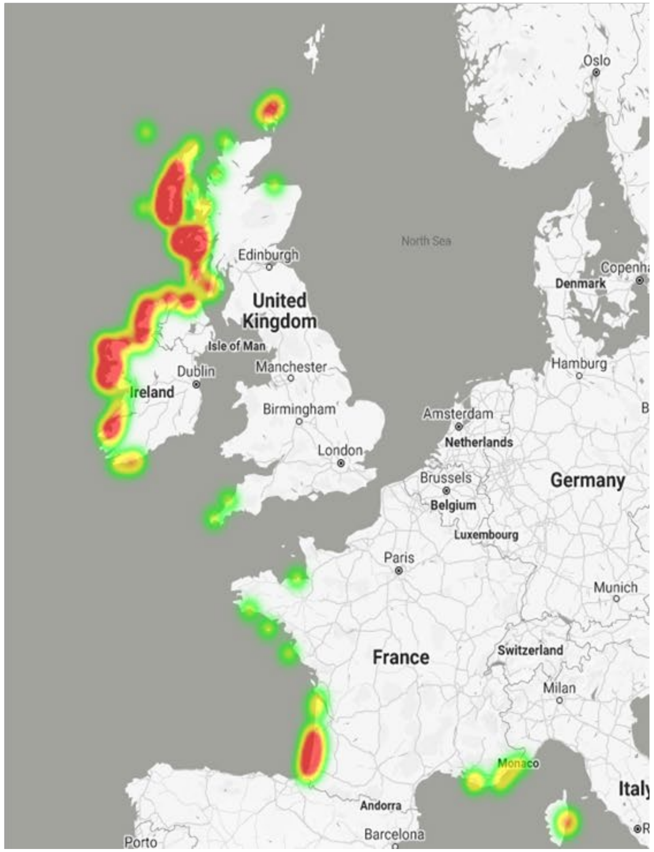
Cuvier's beaked whale (*Ziphius cavirostris*)

1990-1999 n=23

2000-2009 n=81

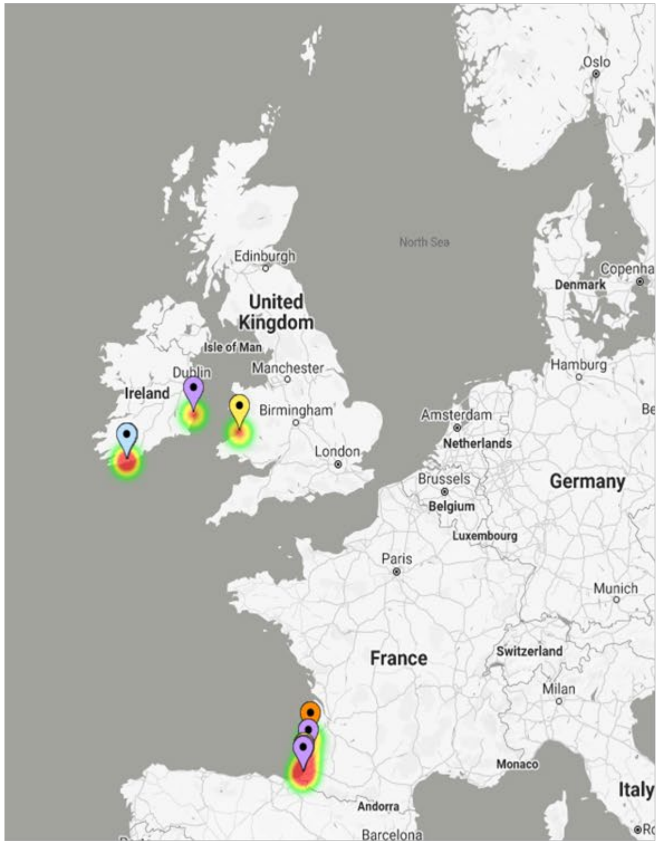


2010-2019 n=163

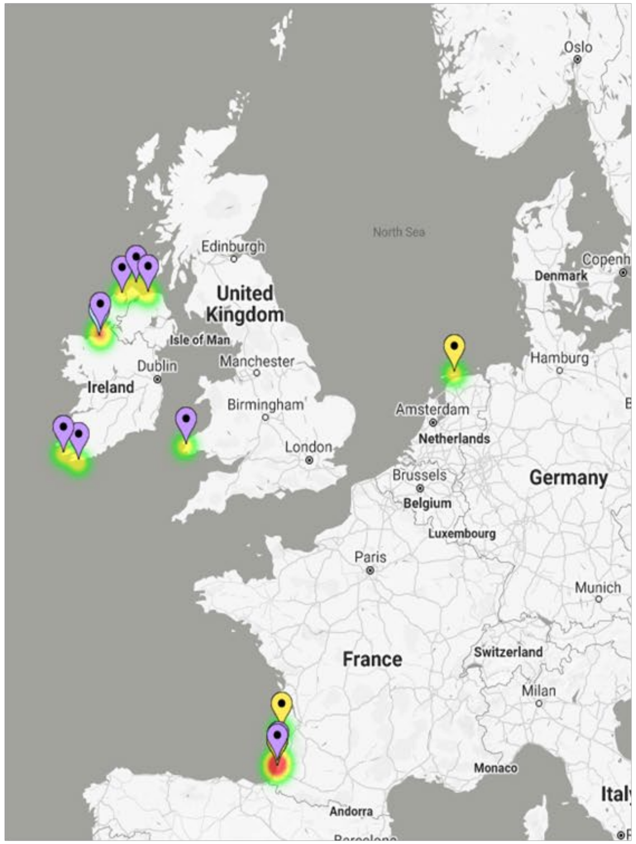


Other beaked whale species

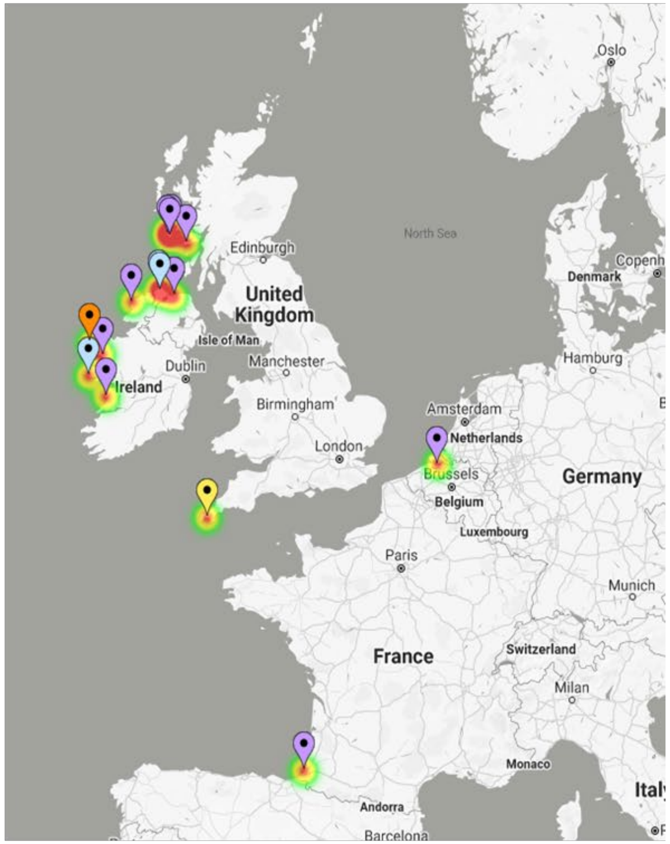
1990-1999 n=9

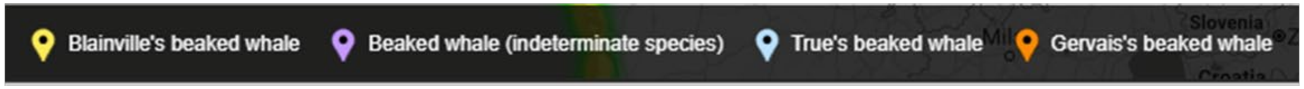


2000-2009 n=14



2010-2019 n=15





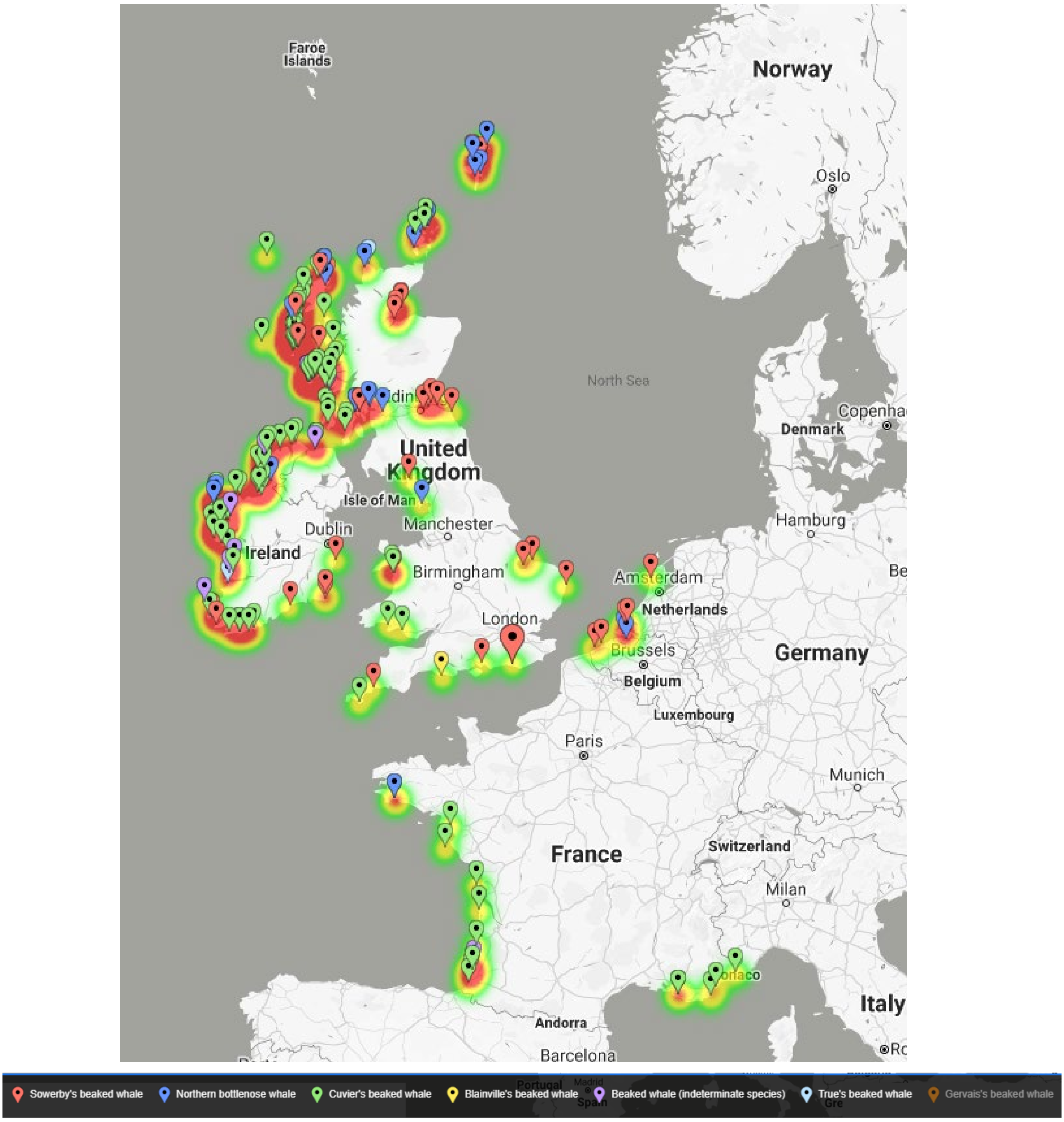


Figure A2. All beaked whale strandings 2017- 2020 (n= 209)

Table A1. Table of beaked whale strandings identified to species (no. of individuals stranding dead or alive) from Sweden to France ([1]one in Jan 2020)

H. ampullatus	**1970-79**	**1980-89**	**1990-99**	**2000-09**	**2010-19**
Sweden	0	0	0	1	0
Denmark	1	0	1	1	0
Germany	1	1	0	0	0
Netherlands	0	1	2	0	0
Belgium	0	0	0	0	0
UK	13	10	8	29	18
Ireland	1	1	5	10	5
Atl. France	2	3	2	2	2
Z. cavirostris					
Sweden	0	0	0	0	0
Denmark	0	0	0	0	0[1]
Germany	0	0	0	0	0
Netherlands	0	0	0	0	0
Belgium	0	0	0	0	0
UK	4	6	6	31	90
Ireland	1	6	3	17	53
Atl. France	17	22	12	27	20
M. bidens					
Sweden	0	0	0	0	5
Denmark	0	0	1	0	1
Germany	1	0	0	2	0
Netherlands	2	0	2	2	7
Belgium	2	0	0	0	0
UK	9	11	19	27	40
Ireland	0	0	1	8	9
Atl. France	4	3	0	8	2
M. mirus					
UK	0	0	0	0	0[1]
Ireland	1	2	1	1	3
M. densirostris					
Sweden	0	0	0	0	0
Denmark	0	0	0	0	0
Germany	0	0	0	0	0
Netherlands	0	0	0	1	0
Belgium	0	0	0	0	0
UK	0	0	1	0	0
Ireland	0	0	0	0	0
Atl. France	0	0	1	3	0
M. europaeus					
UK	0	0	0	0	0
Ireland	0	1	0	0	1
Atl. France	0[2]	0	0	0	0

Appendix 2. Survey coverage providing information on beaked whale species abundance & distribution

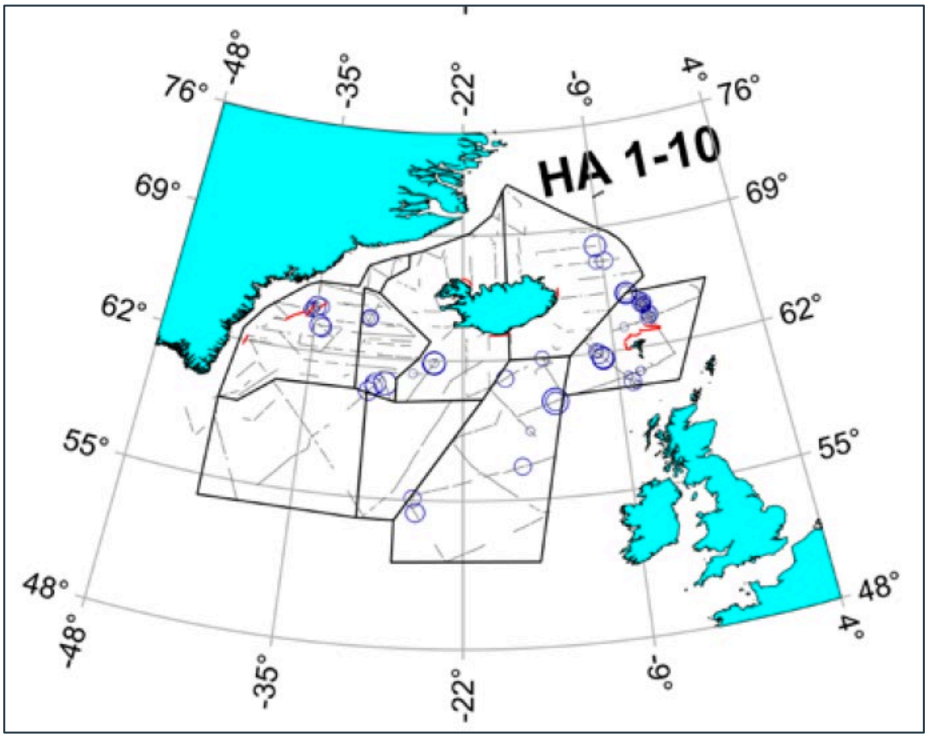


Figure A3. Realised NASS survey effort at Beaufort Sea State <6, and regions used for abundance estimates, with sightings of northern bottlenose whales plotted, June-July 2015 (from Pike *et al*., 2019)

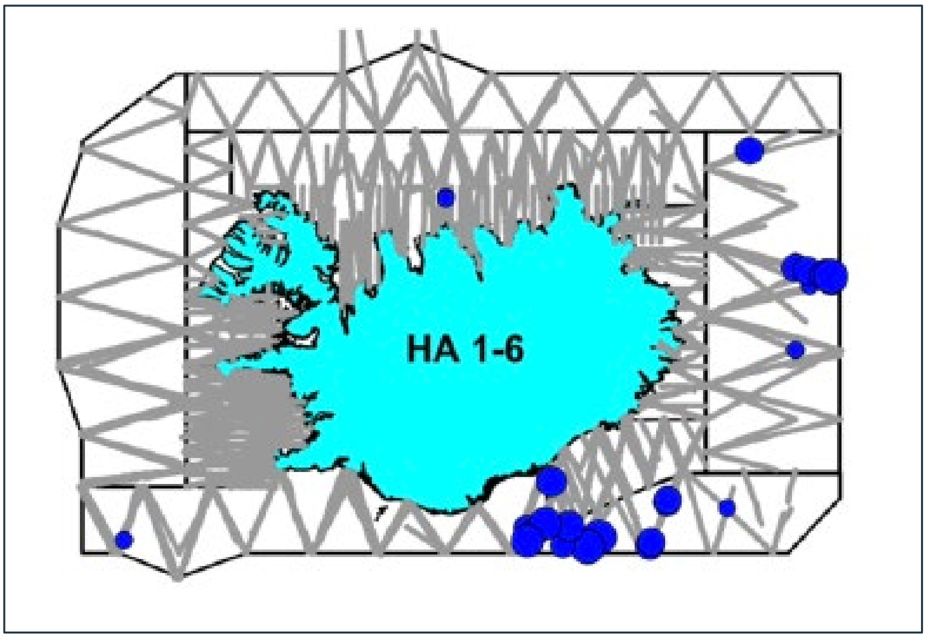
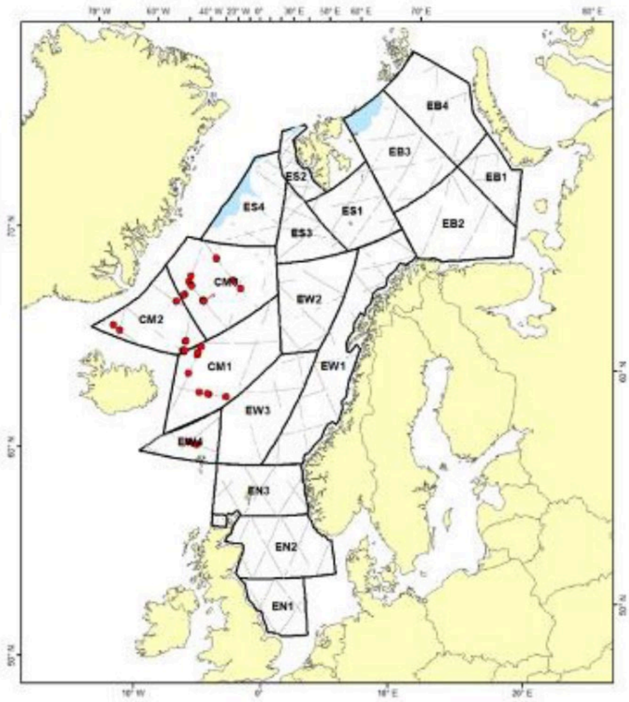


Figure A4. Realised NASS survey effort at Beaufort Sea State <6, and regions used for abundance estimates, with sightings of northern bottlenose whales plotted, June-July 2015 (from Pike *et al*., 2020b)



c)

Figure A5. Distribution of northern bottlenose whales (+ blue and sei whales) sighted during (a) the Norwegian 2002–2007 surveys, (b) the 2008–2013 surveys, and (c) the 2014-18 surveys (showing only northern bottlenose whale sightings). The blue areas represent ice coverage (from Leonard & Øien, 2020a, b).

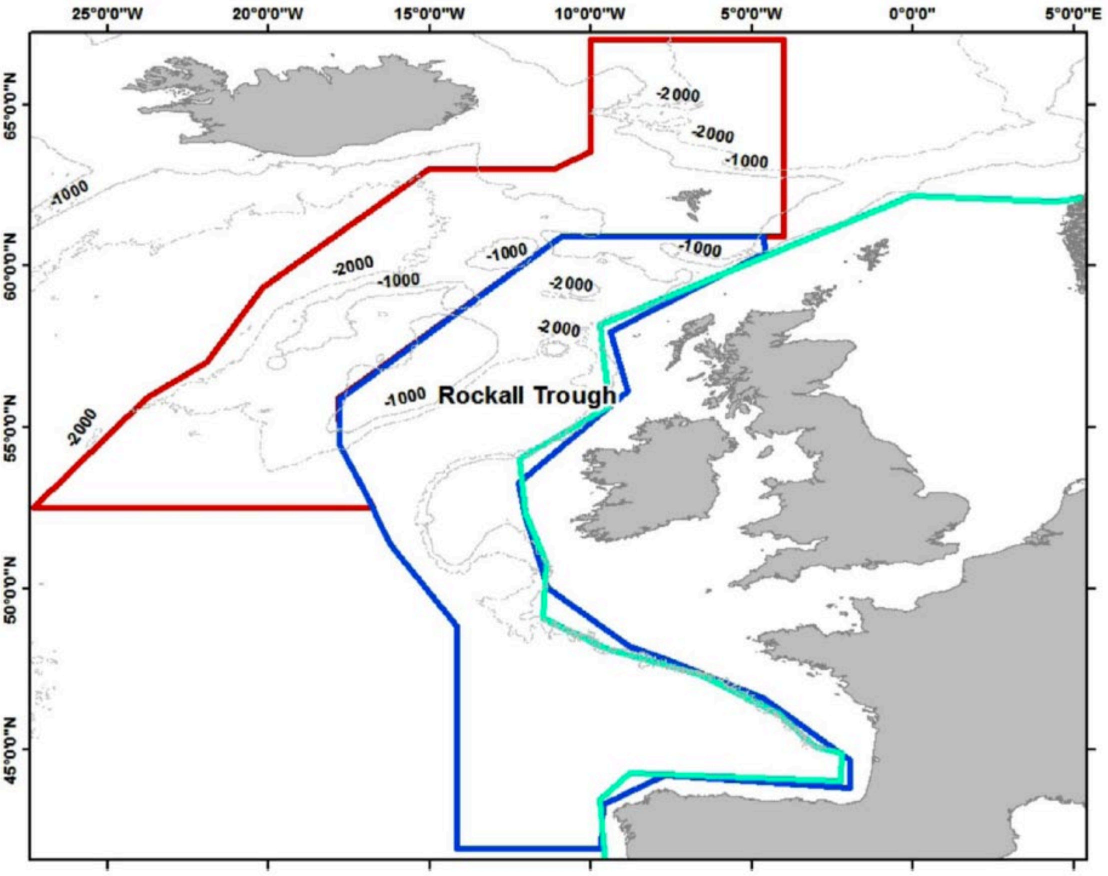


Figure A6. Survey areas: SCANS-II 2005 (outlined in cyan), CODA 2007 (outlined in blue), and the Faroese block of TNASS 2007 (outlined in red) and underlying bathymetry (showing 1,000 and 2,000m isobaths) (from Rogan et al., 2017).

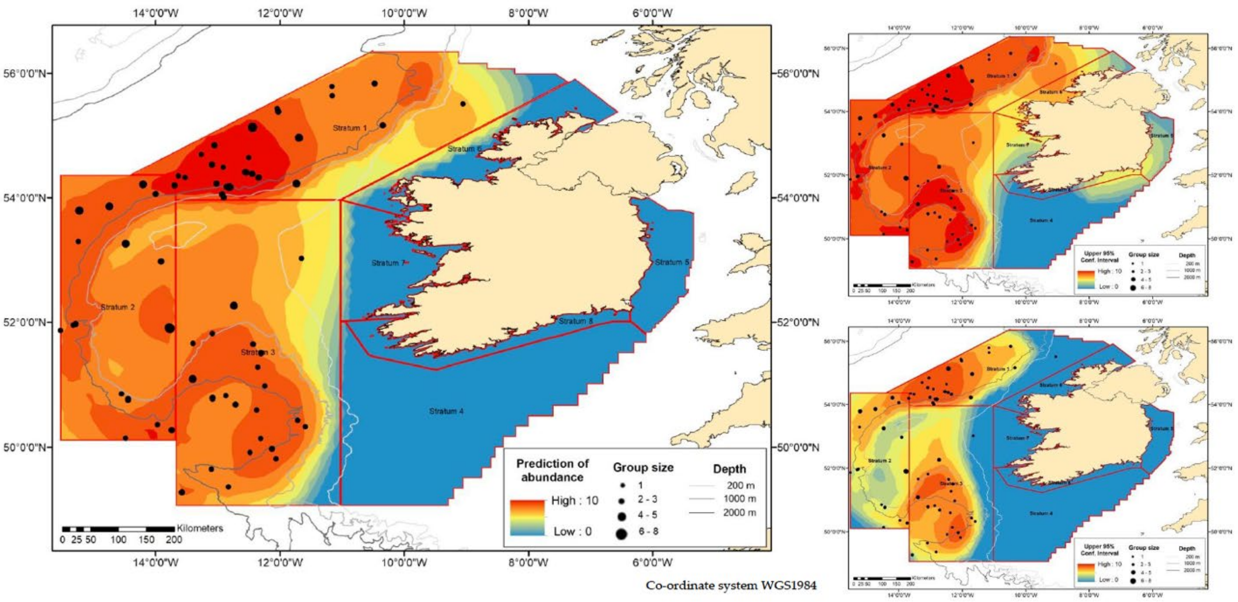


Figure A7. Predicted distribution of all beaked whales modelled using all sightings from both seasons and both years. Smaller figures to the right indicate the upper (top) and lower (bottom) 95% confidence intervals around predictions. Note that scale on density estimates is a relative figure which varies for each species and does not represent the abundance of animals (from Rogan *et al.*, 2018).

Figure A8. Dedicated Cetacean Survey Effort, 1985-2018, from which sightings of beaked whales were made, as plotted in Figures A9 & A10. These include the following wide-scale surveys: SCANS, SCANS-II, CODA, ObSERVE, SWF Irish Sea vessel surveys, North Sea aerial surveys, ATLANCET, ROMA, PELTIC, PELGAS, & PELACUS surveys (for details, see Waggitt et al., 2020).

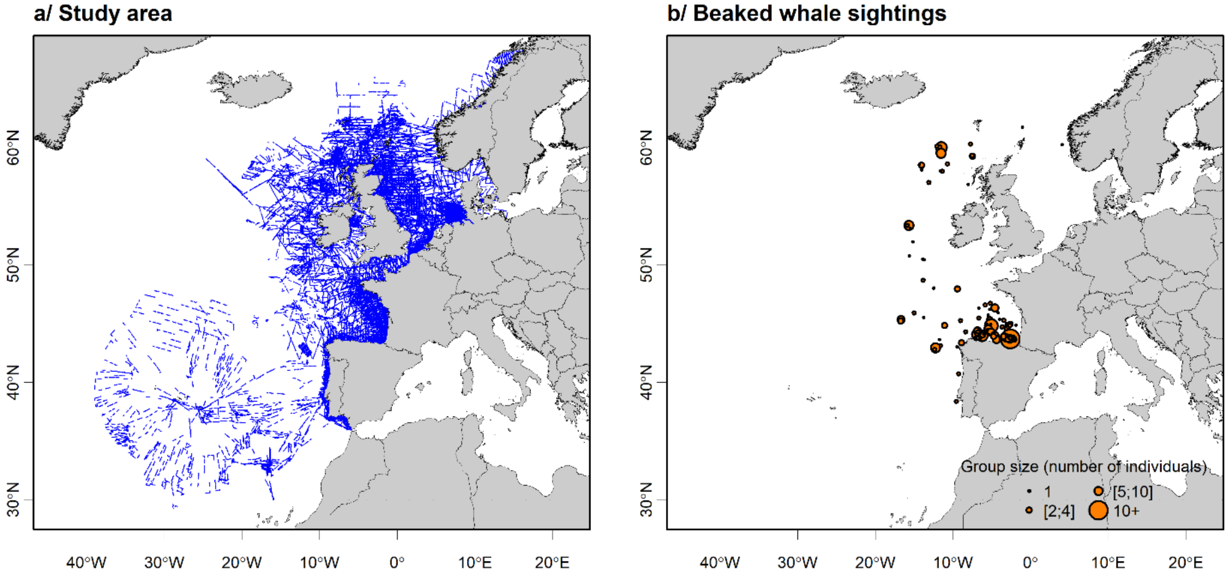


Figure A9. Study area showing assembled survey effort (a), along with beaked whale sightings (b) recorded during all surveys (adapted from Virgili et al. 2019). Surveys were carried out along transects following a line-transect methodology. Sightings were classified by group sizes with each point representing one group of individuals and point size representing the number of animals in a group.

Appendix 3. Distribution of live sightings of beaked whale species

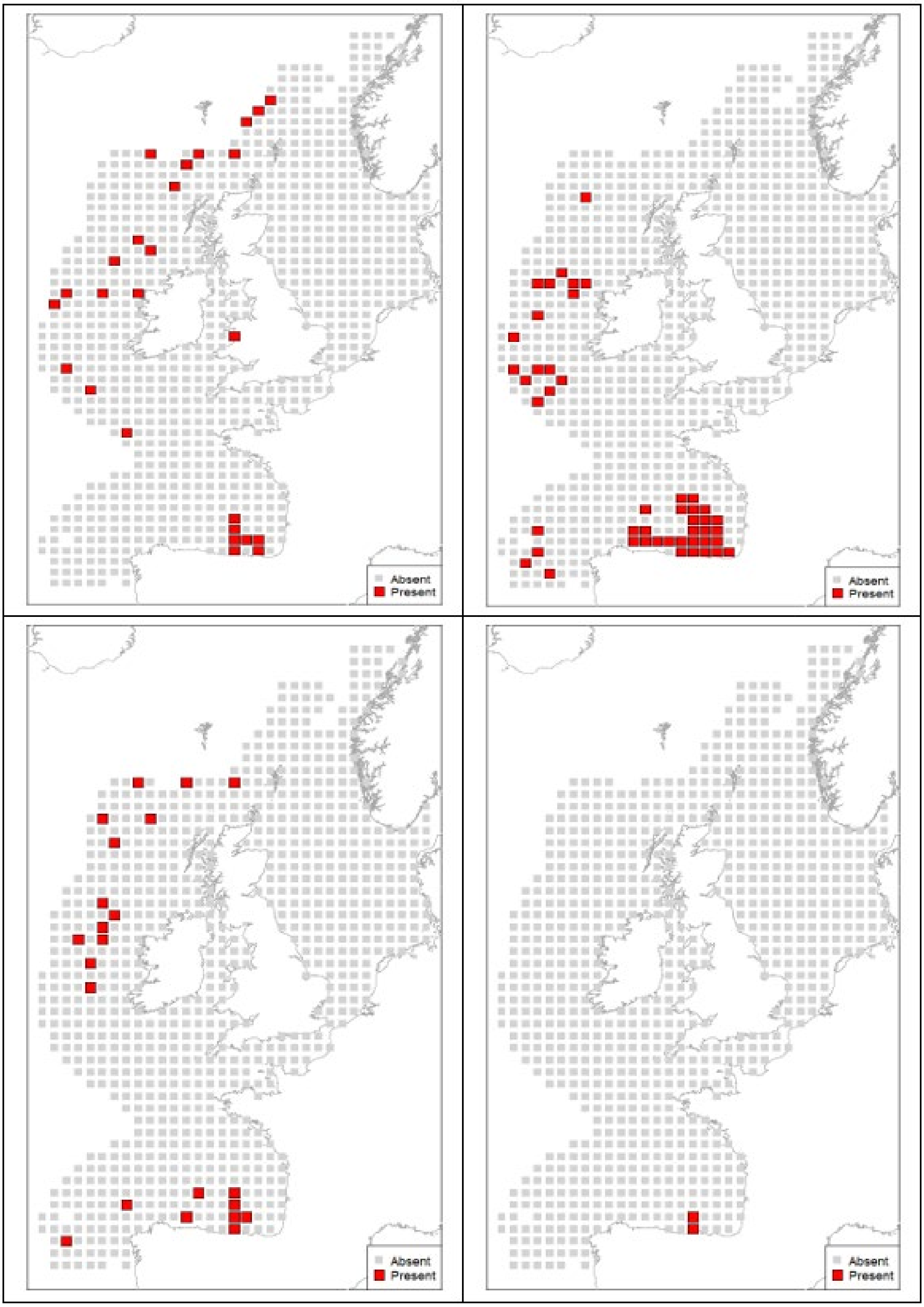


Figure A10. Maps of beaked whale sightings from dedicated surveys: TL is northern bottlenose whale, TR is Cuvier's beaked whale, BL is Sowerby's beaked whale, BR is True's beaked whale (from Marine Ecosystems Research Programme).

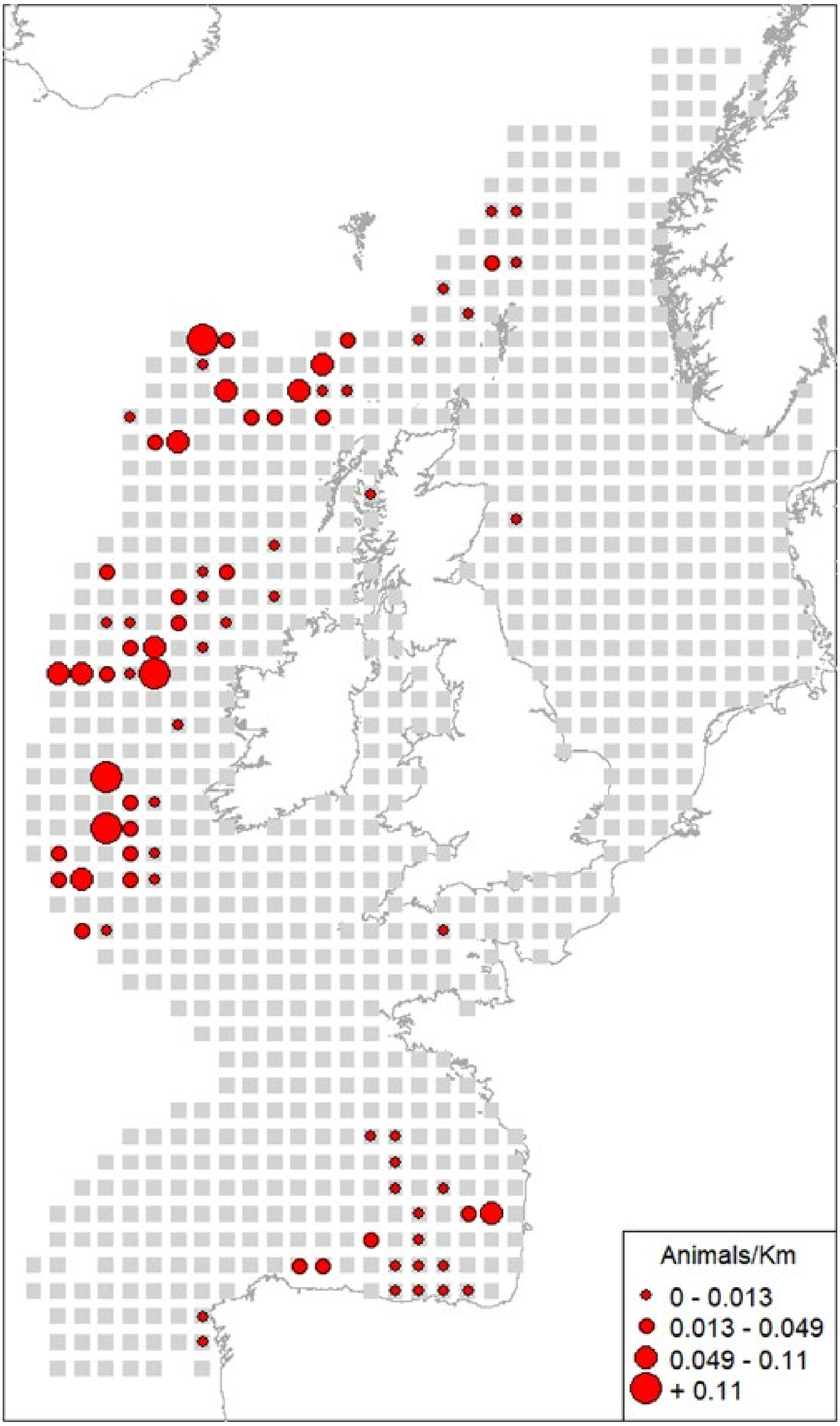


Figure A11. Map of sightings of unidentified beaked whale species from dedicated surveys. (from Marine Ecosystems Research Programme).

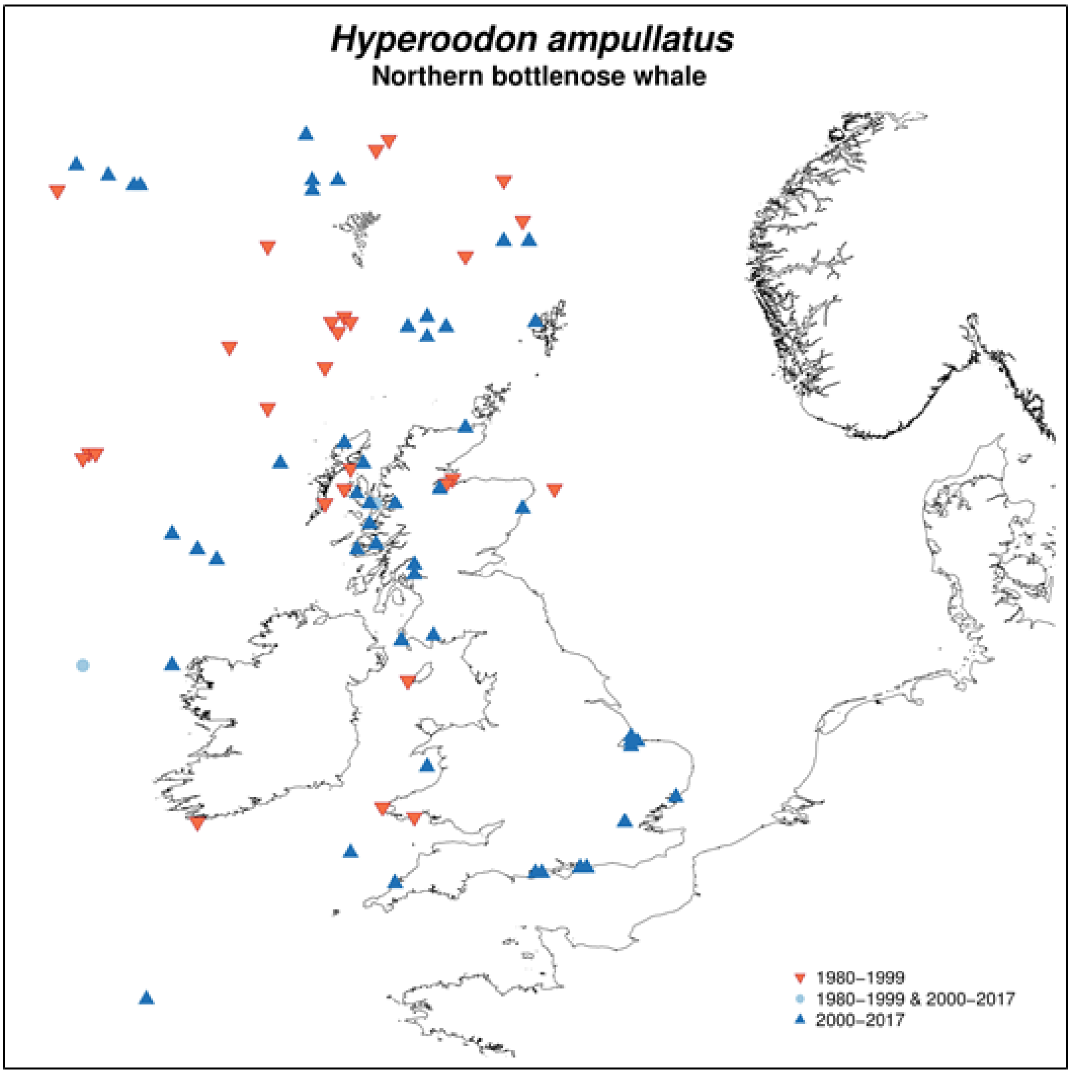


Figure A12. Distribution of live sightings of northern bottlenose whale, 1980-2017 (from Evans & Waggitt, 2020a).

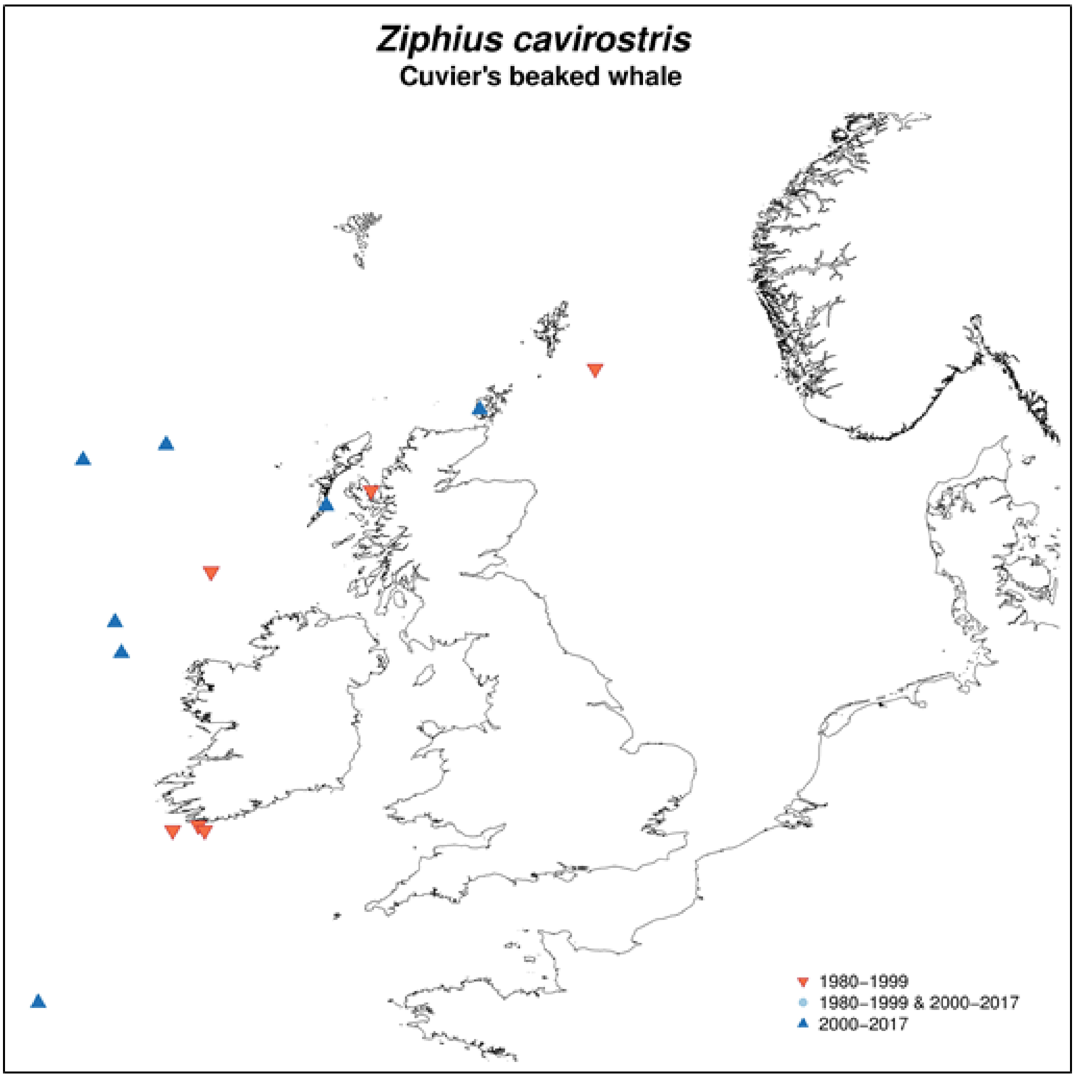


Figure A13. Distribution of live sightings of Cuvier's beaked whale, 1980-2017
(from Evans & Waggitt, 2020a).

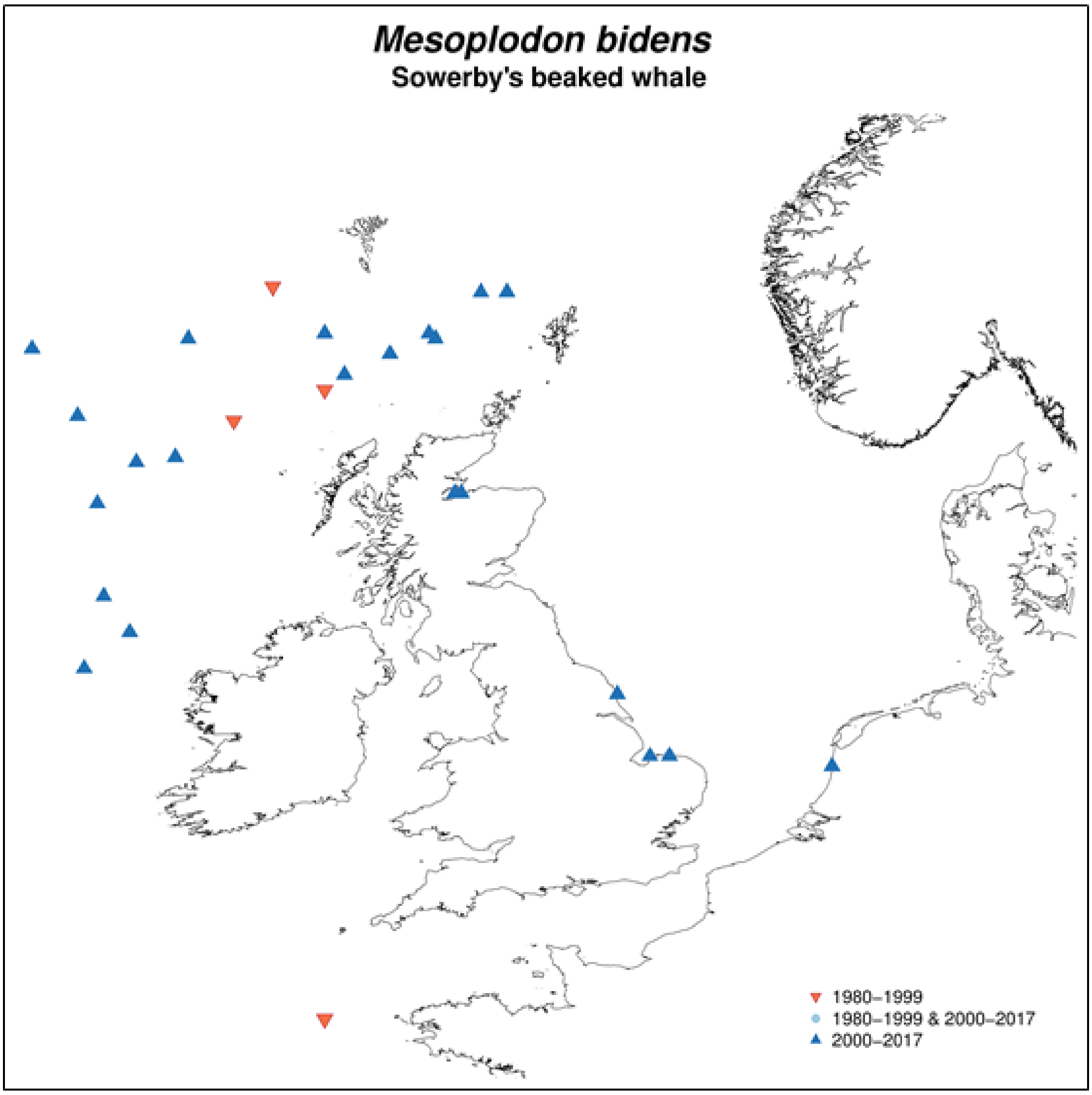


Figure A14. Distribution of live sightings of Sowerby's beaked whale, 1980-2017 (from Evans & Waggitt, 2020a).

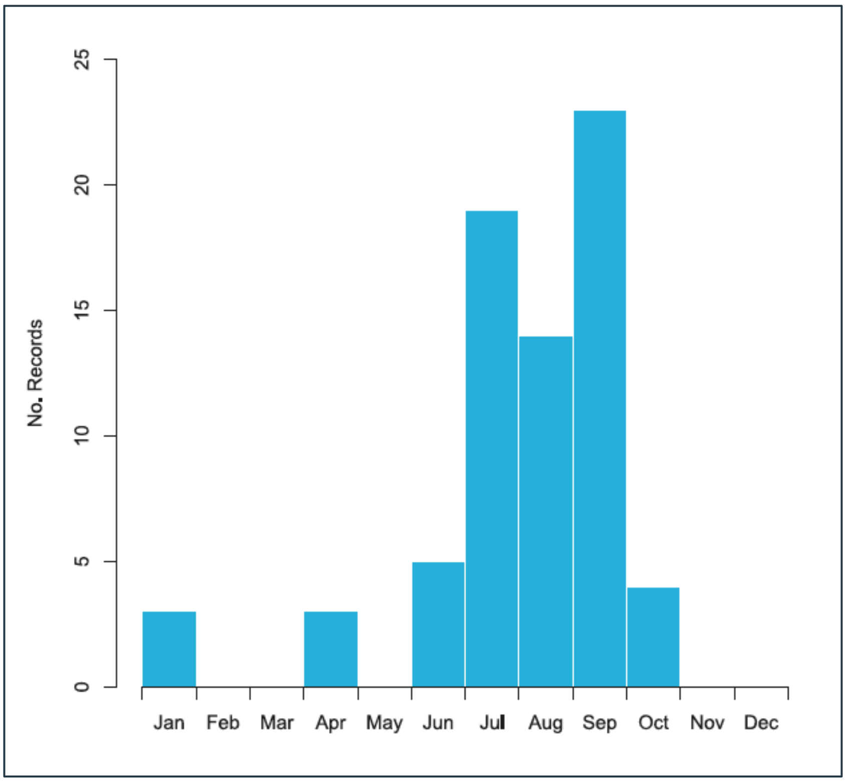


Figure A15. Seasonal Distribution of Live Sightings of Northern Bottlenose Whale, 1980-2017 (from Evans & Waggitt, 2020a).

Appendix 4. Predicted densities of beaked whale species

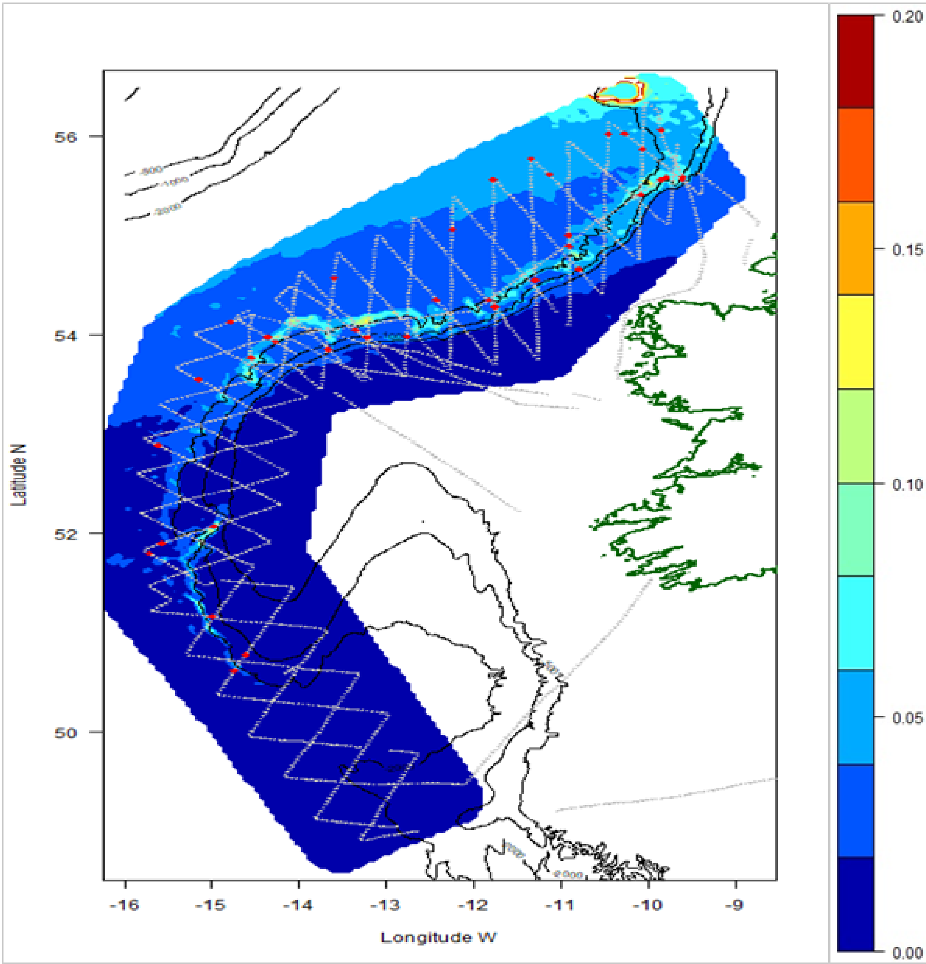


Figure A16. Predicted densities of Sowerby's beaked whales off western Ireland. The best model did not include depth, but showed a strong latitudinal gradient. The predicted densities also increased with maximum slope (from Berrow et al. (2018a).

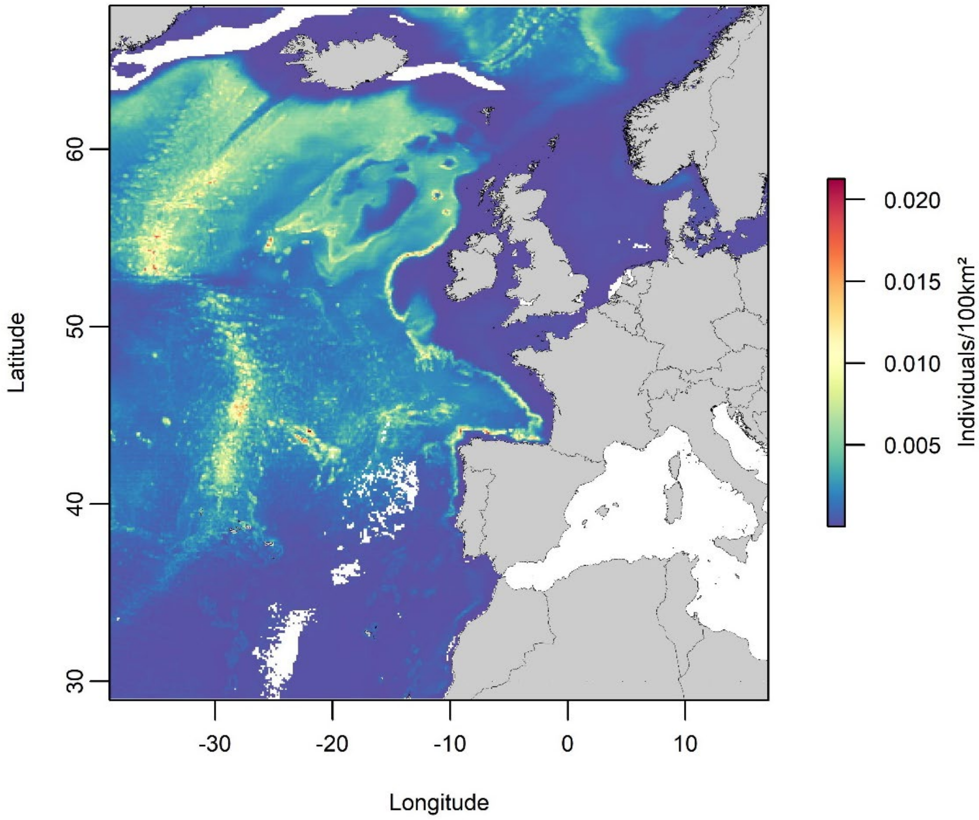


Figure A17. The predicted relative densities of beaked whale in the North East Atlantic Ocean. White areas represent zones where it was not possible to extrapolate the predictions.

Table A2. Abundance estimates & IUCN Red List Status for beaked whale species

Species	Region	Abundance [95% confidence interval]	Method & Reference	IUCN Red List status (globally)
Northern bottlenose whale *Hyperoodon ampullatus*	NE Atlantic (SCANS II, CODA, TNASS, 2007) Central & NE Atlantic (NASS, 2015) & Norwegian survey, 2016)	19,539 [95% CI: 9921–38,482] 23,528 (95% CI: 8,453-65,487)	Design based Rogan et al. (2017) Design based Pike et al. (2019), Leonard & Øien (2020b)	Data Deficient*
Cuvier's beaked whale *Ziphius cavirostris*	NE Atlantic (SCANS II, CODA, TNASS, 2007) Irish EEZ	2286 (95% CI: 942–5552) 237-765 (95% CI: 67-2960)	Design based Rogan et al. (2017) Design based Rogan et al. (2018)	Least Concern*
Sowerby's beaked whale *Mesoplodon bidens*	NE Atlantic (SCANS II, CODA, TNASS, 2007)	3518 [95% CI: 1570–7883)	Design based Rogan et al. (2017)	Least Concern*
True's beaked whale *M. mirus*	-	No data		Least Concern*
Gervais' beaked whale *M. europaeus*	-	No data		Least Concern*

* Most of the changes for beaked whales from Data Deficient to Least Concern resulted from the IUCN Guidelines changing the definition of Data Deficient and thus are not necessarily real changes in conservation status. To remain as Data Deficient, a species had to plausibly belong in any category from Critically Endangered to Least Concern. *IUCN Red List Assessments (2020)*