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Introduction

The harbour porpoise (*Phocoena phocoena*) is listed in many international conventions, directives and agreements including the Convention on the Conservation of Migratory Species of Wild Animals (CMS), Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic and North Seas (ASCOBANS), EU Habitats and Species Directive, Protocol for Special Protected Areas and Biological Diversity, Convention on International Trade in Endangered Species of Wild Fauna and Flora. Moreover, the harbour porpoise is the species most frequently listed in proposals for marine protected areas in north-western European waters (Hoyt, 2005). This resulted in the increase of requirements for monitoring harbour porpoise populations, for example through the harbour porpoise conservation plan in the North Sea or the harbour porpoise recovery plan in the Baltic Sea, both established under the ASCOBANS (Reijnders et al., 2009).

The harbour porpoise is vulnerable to anthropogenic activities, mostly interactions with fishery activities (competition and bycatch; Herr et al., 2009; ICES, 2017; Jefferson and Curry, 1994; Kirkwood et al., 1997; Leeney et al., 2008; Osinga et al., 2008; Tregenza et al., 1997; Vinther, 1999), contamination (Beineke et al., 2005; Bennett et al., 2001; Jepson et al., 1999; Pierce et al., 2008; Siebert et al., 1999; Weijs et al., 2010) and recently the exponential growth of industrial activities at sea (Gilles et al., 2009; Madsen et al., 2006; Teilmann and Carstensen, 2012). The existence of pressing conservation issues and the broad distribution of the harbour porpoise in European waters are thus strong rationales for large scale monitoring of their abundance and distribution, and a coherent assessment of threats such as foreseen in the EU Marine Strategy Framework Directive (MSFD) and the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR).

During the last 20 years cetacean stranding networks have aimed at contributing monitoring strategies by collecting data on *inter-alia* spatiotemporal patterns of occurrence, cause of death, health status, ecological traits and population structure (Jauniaux et al., 2002; Jepson et al., 1999; Kirkwood et al., 1997; Marçalo et al., 2018; Siebert et al., 2006, 2001; Spitz et al., 2006). The use of stranding data is often limited by the opportunistic nature of sampling and the difficulty to relate patterns and figures observed in strandings with processes affecting populations (Evans and Hammond, 2004). Nonetheless, the scientific use of strandings as a source of population indicators is encouraged by a variety of intergovernmental dispositions or recommendations (International Whaling Commission scientific report 2010; various agreements under the Convention for Migratory Species; International Council for the Exploration of the Sea; the OSPAR Convention; the Marine Mammal Protection Act; ASCOBANS...). This regulatory framework provided the rationale for research aiming to describe the processes involved in cetacean strandings and to have a better understanding and interpretation of stranding data (Doeschate et al., 2017; Koch et al., 2013; Meager and Sumpton, 2016; Peltier and Ridoux, 2015). The relationships between stranding records and the relative abundance of the cetacean species can be described by the equation:

$$N_{stranding} = f(\,Abundance, mortality, buoyancy, drift, discovery) \text{ (eq. 1);}$$

where $N_{stranding}$ is the observed number of stranded dead cetaceans; $Abundance$ is the total population size, $mortality$ is the mortality rate (including both natural and anthropogenic sources); $buoyancy$ is the probability of a dead animal to float; $drift$ is the probability of a floating dead animal to drift toward a coast and to get stranded; and $discovery$ is the probability of a stranded carcass to be discovered and reported (Peltier et al., 2016, 2014).

Recent studies have explored the representativeness of strandings, by accounting for drift conditions and observation effort (Authier et al., 2014; Epperly et al., 1996; Hart et al., 2006; Koch et al., 2013; Peltier et al., 2016, 2014, 2013, 2012), and provided relevant indicators on mega-vertebrate populations. The proportion of animals dying at sea and later found stranded was recently investigated by different studies and estimated at 0.02 (range: 0-0.06) in the Gulf of Mexico (Williams et al., 2011), 0.105 (CI 95%[0.05;0.18]) in Brazilian fisheries targeting white croakers *(Micropogonias furnieri)* (Prado et al., 2013) and 0.129 (CI 95% [0.047; 0.206]) in pair trawl fisheries operating along the French coast of the Bay of Biscay (Peltier et al., 2012). Methodology to model the distribution of dead cetaceans inferred from strandings was recently developped (Peltier et al., 2016; Peltier and Ridoux, 2015).

Here, we propose (1) to identify likely mortality areas at sea inferred from strandings in the eastern North Atlantic, from the Bay of Biscay to the English Channel and the North Sea, (2) to estimate mortality of harbour porpoises in this large area, with a focus (3) on mortality due to fishery activities on harbour porpoise population in the Bay of Biscay and the English Channel.

2-Materials and methods

2.1 General experiment design

The study area covered the Bay of Biscay, the English Channel and the North Sea (-8.50° W – 10.00° E; 43.00° N – 59.00° N), thus encompassing an extensive part of the species distribution in European waters. Stranding numbers of harbour porpoises were gathered from 1990 to 2014 for the general mortality analysis (all causes of death combined) from all countries bordering the study areas (see below and in fig 1). Because cause of death was not available for harbour porpoises everywhere, only animals with bycatch evidences recovered in the English Channel (UK and French coasts) and the Bay of Biscay were considered. Mortality related to fishing activities was estimated in the Bay of Biscay and the English Channel (-8.50°W – 4.5°E ; 43.00 N – 53.00 N) from 1990 to 2015.

2.2 Harbour porpoise stranding data

Harbour porpoise stranding time series from 1990 to 2015 were obtained from Denmark, Germany, the Netherlands, Belgium, the United Kingdom and France. Data on strandings, their location and cause of death when available (Bay of Biscay and English Channel), were collected. Live stranding events were not considered as their location is not supposed to be entirely determined by drift.

- British stranding network

The collaborative UK Cetacean Strandings Investigation Programme (CSIP, www.ukstrandings.org) as it is now known is a consortium of partner organizations funded by Defra and the UK Devolved Governments of Scotland and Wales. Partner organizations are the Zoological Society of London, Scottish Rural University College (Inverness), the Natural History Museum and Marine Environmental Monitoring. In Cornwall, strandings data are collected by the Cornwall Wildlife Trust Marine Stranding Network and necropsies are carried out by CSIP staff based at the University of Exeter. The CSIP is collectively tasked with recording information on all cetaceans, marine turtles and basking sharks that strand around UK shores each year and with the routine investigation of causes of mortality through necropsy of suitable strandings. Experienced pathologists and biologists carry out systematic necropsies of selected stranded cetaceans following a standardized protocol.

- Danish stranding network

The Danish stranding network is run by the Danish Nature Agency in collaboration with the Fisheries and Maritime Museum and the Zoological Museum, Natural History Museum of Denmark. Post mortems on stranded marine mammals are conducted by the National Veterinary Institute. The stranding network was founded in 1991 and relies on official personnel as well as reporting from the public.

- German stranding network

The German stranding network at the North Sea coast was established in 1988/89 during the first PDV-Seal-die-off. National Park Rangers and "Seal hunters" (seals are still listed under the hunting law even though hunting stopped in 1976) control the coastline regularly throughout the year ensuring a constant observation effort. In Schleswig-Holstein, marine mammal carcasses are collected and submitted for investigations. In Lower Saxony, National Park Rangers, members of the Federal Volunteer Service, *Wattenjagdaufseher* (gamekeepers who have successfully completed a further training about Wadden Sea animals and are responsible for hunting districts in the Wadden Sea Area which are under governmental control) and others report dead animals to the authorities. In both *Länder* marine mammal carcasses that can be retrieved are usually kept in a deep-freeze storage until necropsies can be carried out by official veterinarians. There is a database held at the Institute for Terrestrial and Aquatic Wildlife Research, Büsum and at the National Park Authority, Wilhelmshaven.

- Dutch stranding network

The Dutch strandings network consists of a consortium of a large number of organizations and volunteers. Coverage of the coast is very good along the south-western and western coasts of the country (approaching 100%) and in the westernmost Frisian island of Texel (coverage estimated 80%), but rather poor in the Wadden Sea and the remainder of the Frisian Islands, as some of these are uninhabited. The central digital database is kept by Naturalis Biodiversity Center (formerly called the National Museum of Natural History *Naturalis*) in Leiden. Data and photographs are made available on the internet (www.walvisstrandingen.nl). Post mortem research is carried out on a selection of the stranded cases (approximately 10-20% of all stranded individuals) since 2008 at the Faculty of Veterinary Medicine of Utrecht University.

Experienced pathologists and biologists carry out systematic necropsies of selected stranded cetaceans following a standardized protocol.

- Belgian stranding network

Strandings have been collected in Belgium since the 1970's, but a dedicated and government supported network was established in 1990. It is organised and centralised by the Royal Belgian Institute of Natural Sciences (RBINS). RBINS maintains, in cooperation with the University of Liège, a single database which can partly be consulted online.

- French stranding network

The French stranding network is co-ordinated by the Joint Service Unit *Observatoire Pelagis*, UMS 3462 University of La Rochelle/CNRS, dedicated to monitoring marine mammal and seabird populations and funded by the Ministry in charge of the environment and the French Agency for Biodiversity. It is constituted of around 400 trained volunteers distributed along the French coast who collect data according to a standardized observation and dissection protocol. The network was established in the early 1970's and its organisation and procedures are considered unchanged since the mid 1980's. Data are centralized into a single database held by *Observatoire Pelagis*.

To estimate the total number of bycaught porpoises, only porpoises with bycatch evidences as described in Kuiken (1994) were retained. The indication of bycatch are good nutritional conditions, evidence of recent feeding, net marks on the skin, amputations, froth in the airways, oedematous lungs and the exclusion of any other cause of death. Bycatch diagnosis was deemed possible only on relatively fresh carcasses (decomposition code fresh to putrefied), and only carcasses examined by the French and British stranding networks were retained for analyses.

2.3 Mortality areas of harbour porpoises

This approach is geographically explicit and is based on drift back-calculations (thereafter named ‘reverse drift modelling’) in order to reconstruct the trajectory of every stranded harbour porpoise from its stranding location to its likely area of death at sea. The reverse trajectory of stranded examined animals was calculated by using the drift prediction model MOTHY, which predicts the drift of floating object under the influence of tides and wind (Daniel et al., 2002). The immersion rate was set at 90%, following a previous in situ and modelling experiment (see (Peltier et al., 2012).

Because the decomposition status of the carcass was not always documented, drift durations could not be determined on an individual basis. The decomposition status of stranded porpoises as determined by national stranding networks or from pictures of animals (in the case of the French data) was associated to a drift duration following criteria developed by Peltier et al. (2012). For each large area, histograms of the number of stranded porpoises per drift duration bin were constructed and smooth functions were fitted. Strandings with informed decomposition status (or pictures allowing drift duration to be determined by using visual criteria) during the period with highest stranding records were used (March to July for the western North Sea, April to August for the eastern North Sea, January to April for the English Channel and January to April in the Bay of Biscay**;** Peltier et al., 2013)**.** The function was converted into a probability for each porpoise to originate from each 10-hour segment of the reverse drift.

The number of dead stranded animals in each cell was then corrected by the cell-specific probability of becoming stranded (Peltier et al., 2013). The study area was sub-divided in cells of size 0.75° x 0.75°. In order to prevent the distortion of cell surface areas with latitude, an adjustment factor was applied. The probability of stranding for an animal dying in each cell

$p_{stranding}$, was estimated by computer simulations using MOTHY, a drift model for floating objects developed by MétéoFrance (Daniel et al., 2002) for every period of ten days from 1990-2015 (Peltier et al., 2016, 2013). The drift of uniformly distributed theoretical small cetaceans was predicted for 30 days in order to estimate $p_{stranding}$ for each cell at sea. The probability of a porpoise dying in a given cell to strand is the long-term frequency over the study period with which it was predicted to strand.

The number of dead porpoises found stranded in each cell was corrected by $p_{stranding}$ in order to estimate the total number of bycaught porpoises, irrespective of drift conditions. In order to reduce uncertainty around extrapolations made from rare events, cells with stranding probability $p_{stranding} < 0.1$ were removed from the study area, which implies that mortality of harbour porpoise occurring in these cells should not be documented from stranding data.

2.4 Estimating mortality and bycatch numbers based on strandings

Maps of harbour porpoise mortality inferred from strandings show the spatial distribution of dead and bycaught animals across the study area. The sum of dead porpoises in each cell provides an estimate of porpoise yearly mortality, uncorrected for the proportion of dead animals that sink to the sea floor and are therefore lost. Time series at the year level were then constructed and the estimated number of dead harbour porpoises was estimated by correcting by both drift conditions and the proportion of buoyant animals, estimated at 17.9% [9.3%; 28.8%] (Peltier et al., 2016), under the assumption that harbour porpoise and common dolphin (*Delphinus delphis*) carcasses are similar in this respect.

3. Results

3.1 General stranding data

A total of 16 517 stranded harbour porpoises were reported from 1990-2014 across the study area: 10 955 along the eastern North Sea coasts, 2 082 along the western North Sea coasts, 2 323 in the English Channel, and 1 157 along the coasts of the Bay of Biscay (fig 2 and 3, detailed results in annex 1). Until 2000, stranding records remained under 300 harbour porpoises per year across the whole study area. Since 2000, numbers increased to a maximum of 3 135 harbour porpoises stranded in the whole study area in 2013. Even if stranding numbers have been irregular since 2006, the general trend shows an increase in the number of stranded harbour porpoises.

A total of 895 animals with bycatch evidences were recovered from 1990-2015 along the coasts of the English Channel (n=533) and the Bay of Biscay (n=362) (fig 4 and 5). Before 1996, the number of stranded harbour porpoises with bycatch evidences in the UK and French part of the study area was very low, with < 5 individuals per year. Since 1997 numbers increased, with highest figures recorded in 2013 (161 strandings with bycatch evidence). More recently, a sharp decrease of strandings with bycatch evidence was detected in the last two years of the study period.

3.2 Estimating drift duration

The distribution of stranded harbour porpoises according to their drift duration, estimated by their decomposition status (Peltier et al., 2012), was analysed for each large area (fig. 6). For the Western North Sea and the English Channel, logarithmic curves provided the best fit, whereas polynomial curves fitted better to data for the Eastern North Sea and the Bay of Biscay.

3.3 Distribution of dead harbour porpoises inferred from strandings

3.3.1 General distribution

Since 1990, highest densities of dead harbour porpoises at sea were observed in the North Sea (fig. 7). Their distribution was widely extended in the eastern part of the North Sea, whereas mortality areas of porpoises along the western North Sea coasts remained very coastal. Over the years, densities increased, and slowly moved down to the south-eastern North Sea. Mortality areas were identified in the English Channel since the late 90’s and in the Bay of Biscay from the early 2000’s onwards. In the Bay of Biscay, the distribution of dead porpoises was located almost exclusively on the continental shelf.

3.3.2 Bycaught harbour porpoises in the English Channel and the Bay of Biscay

Until 1996, very few harbour porpoises were found stranded, therefore bycaught harbour porpoise distributions inferred from strandings were analysed from 1997-2015 (fig. 8).

From 1997 to 2004, the inferred distribution of bycaught harbour porpoises was mostly located in the western Channel and the Celtic Sea, and expanded to the Bay of Biscay in the 2000’s. The eastern Channel remained an area of high densities of bycaught harbour porpoises, and later the south of the Bay of Biscay close to the Spanish border.

3.4 Estimating mortality based on strandings

3.4.1 Total mortality

Confidence intervals are the projection of the 95% confidence interval around the buoyancy estimated at 17.9% [9.3%; 28.8%] (Peltier et al., 2016).

Across the whole study area, the average number of dead porpoises was 9 300 [5 780; 17 890] individuals per year from 1990 to 2014 (fig. 9). The number of dead porpoises increased slowly over the 2000's and was calculated at 47 000 [29 030; 89 880] individuals in 2013. From 2011-2014, the yearly average number of dead porpoises was estimated at 29 480 [18 320; 56 740]. A decrease was noticed in 2014, with 19 460 [12 090; 37 450] harbour porpoises.

3.4.2 Bycaught harbour porpoises in the English Channel and the Bay of Biscay

Until the mid 90's, very few bycaught harbour porpoises were recorded (fig. 10). Since then the numbers increased slowly to 2010 and more sharply since then. The average annual number of bycaught porpoises was estimated at 530 [330; 1030] individuals from 1990 to 2015. A decrease was highlighted in 2015. Since 2012 the yearly average estimate reached 1 300 [810; 2520] bycaught porpoises.

5. Discussion

5.1 General

Collating stranding data at a regional scale allowed us to gather more than 16 000 harbour porpoise stranding records. This work provides an overview over the past 25 years on the likely distribution of harbour porpoise mortality in the North Sea, the English Channel and the Bay of Biscay, inferred from stranding data. These results highlighted a southward shift of porpoise mortality distribution to the south-eastern North Sea in the late 90's, and a return of the species in the English Channel and the Bay of Biscay. Special attention was paid to harbour porpoises found stranded with lesions diagnostic of bycatch in the Channel and the Bay of Biscay. These results showed that coastal areas in the French eastern Channel, off Cornwall and south of the Bay of Biscay presented high numbers of bycaught harbour porpoises.

Two important features of this approach are its large spatial scale (from the northern North Sea to the southern Bay of Biscay) and long temporal span (25 years). Uncertainty in carcass drift modelling was estimated at a few 10s of kilometers (Peltier et al., 2012), well below the study area, sub-region and even grid-cell sizes. In addition, the size of the study area encompasses a large proportion of the harbour porpoise population distribution in north-western Europe and a scale at which changes in distribution were shown from 1994-2016 (SCANS surveys; Hammond et al., 2017, 2013).

To cover this large geographical scope and temporal span we have lumped together data sets from seven distinct national stranding schemes. Although this is an obvious strength of the study, it also introduces a source of heterogeneity that is difficult to assess as a result of the specific history and management of each of these schemes and the levels a public awareness on these issues (with is central in the reporting process) that have evolved at different rates between countries (possibly also within countries). Also, accessibility of the coastline and reporting rate of stranded animals are heterogeneous. While reporting effort can be considered stable since 1990 by long established French (Authier et al., 2014) and British stranding networks, the interpretation of stranding records before 2000 in in some parts of the eastern North Sea must be assessed with caution.

The use of strandings at regional scale rather than within the limits of each country is considered to be much more relevant from an ecological point of view than statistics analysed at national levels. Nevertheless, the increasing numbers of porpoise stranding observed since the 2000s along the Dutch, Belgian and northern French coasts (Camphuysen, 2004; Camphuysen et al., 2008; Haelters et al., 2011; Jung et al., 2009; Peltier et al., 2013; Thomsen et al., 2006) are consistent with changes detected in the sub-regions created for the present study. Increased stranding numbers reported from along the western North Sea and the Channel were also consistent with trends in stranding numbers recorded along the British coasts since the late 1990's (Leeney et al., 2008).

5.2 Mortality, abundance and distribution of harbour porpoises

The likely distribution of dead harbour porpoises changed from 1990-2014, across the whole study area. The raise of porpoise mortality in the Channel and the Bay of Biscay ranged over more than 20 years. It can be explained by simultaneous changes of the main cause of death or by a shift in abundance or distribution of the harbor porpoise population. This second explanation would be consistent with the hypothesis resulting from the SCANS, SCANS-II and SCANS-III surveys carried out in 1994, 2005 and 2016 (Hammond et al., 2017, 2013) (fig. 11). These surveys showed a southward shift in the harbour porpoise distribution to the south North Sea, the Channel and the Celtic Sea at a constant overall abundance. In addition to this, the species distribution expands further south into the Bay of Biscay down to the Spanish border in winter (Lambert et al., 2017), a season of peak stranding of porpoise in this area (Peltier et al., 2013).

An increase of harbour porpoise density along the coasts of Germany was observed by dedicated aerial surveys between 2002 and 2013 (Peschko et al., 2016). Similar conclusions were made during annual surveys on platform of opportunity in the Bay of Biscay and the English Channel between 1996 and 2006 (McLeod et al., 2009), and along the Dutch and Belgian coasts (Haelters et al., 2011).

The comparison and the relevance of results obtained in this study and sighting surveys conducted in the North Sea and adjacent waters considerably improve the value of using strandings as a monitoring tool by ground-truthing the trends observed in stranding data sets. Dedicated large-scale summer surveys provided snap-shot pictures of small cetacean distribution and absolute abundance at a decadal scale. The monitoring of strandings and the at-sea distribution of porpoise mortality inferred from carcass drift back-calculation could provide continuous and large-scale information, once the main biases related to the stranding process are dealt with in the analysis. The combined use of both tools would be relevant in the development of an efficient monitoring strategy, notably in the context of the ASCOBANS Conservation Plan for harbour porpoises in the North Sea.

5.3 Interactions between harbour porpoises and fisheries

As a coastal or neritic species, harbour porpoises are highly impacted by human activities like fisheries (both bycatch and competition) (Beineke et al., 2005; Herr et al., 2009; Jefferson and Curry, 1994; Leeney et al., 2008; Osinga et al., 2008; Tregenza et al., 1997; Vinther, 1999; Wright et al., 2013), contamination (Beineke et al., 2005; Bennett et al., 2001; Jepson et al., 1999; Mahfouz et al., 2014; Pierce et al., 2008; Siebert et al., 1999; Weijs et al., 2010) and recently the exponential growth of industrial activity at sea (Gilles et al., 2009; Madsen et al., 2006; Teilmann and Carstensen, 2012).

Interactions with fisheries remains currently the anthropogenic cause of death of most concern, as it represents up to 57% of the total mortality for this species in the Bay of Biscay and the Channel (annex 1). According to observer programs on fishing vessels across Europe, harbour porpoises were the most bycaught cetacean species in 2015 (ICES, 2017).

In the French and British waters, the Dover Strait, south of Cornwall and the southern Bay of Biscay seemed to be areas with the highest levels of harbour porpoise bycatch in recent years.

The major concerns for harbour porpoise would be incidental takes in gillnets, trammel nets, tangle nets and possibly also bottom trawls (ASCOBANS, 2015; Herr et al., 2009; ICES, 2017; Reijnders et al., 2009). In the English Channel and the Bay of Biscay, gillnets and trammel nets targeting mainly hakes (*Merluccius merluccius*) and monkfishes (*Lophius piscatorius*) were reported as sources of harbour porpoise bycatch by observer programs conducted under EU Regulation 812/2004 (Reijnders et al., 2009). This regulation requires the presence of fishery observers on >12m vessels. However, in 2016 82% of French net fleets operating in the English Channel and the North Sea were < 12 meters, and this was the case for 69% of the vessels in the Bay of Biscay (French Fishery Information System, http://sih.ifremer.fr). Considering the difficulties encountered in the implementation of observer programs (Peltier et al., 2016), the use of strandings constituted a relevant source of complementary information to identify and quantify mortality areas at sea related to the bycatch issue.

Dedicated aerial surveys in the English Channel and the Bay of Biscay in 2012 suggested a total abundance of harbour porpoises in the English Channel and the slope and shelf of the Bay of Biscay of 31 787 (CV=0.18) individuals (Laran et al., 2017). The estimated incidental takes of about 1300 individuals [810; 2520] would be far beyond the currently accepted threshold of sustainable anthropogenic takes of 1.7% of the population (ASCOBANS, 2015; IWC, 2000) (table 1).

The population structure of harbour porpoises described by OSPAR suggested two assessment units of harbour porpoises in the area considered: one comprising the Bay of Biscay, the Western Channel and the Celtic Sea, and the other comprising the Eastern Channel and the whole North Sea. Understanding the demography and population structure of the harbour porpoise is required for the accurate comprehension of the impact of fisheries in the Bay of Biscay and the English Channel. Nevertheless, the high levels of mortality rates suggested that bycatch is an important cause of death and a matter of concern for long term harbour porpoise conservation.

6. Conclusion

This work provided relevant information on the distribution of harbour porpoise mortality across the North Sea, the Channel and the Bay of Biscay over a period of 25 years. The detection of a southward shift in porpoise mortality areas in the northern North Sea, the Channel and the southern Bay of Biscay was consistent with the outcomes of the SCANS I-to-III dedicated surveys regarding changes in porpoise distribution in the north-east Atlantic.

This work also suggested that from 2012 onwards, a yearly average of 1300 harbour porpoises died in fisheries interactions in the English Channel and the Bay of Biscay. Following recent abundance estimations in these areas, such a mortality level could be unsustainable for porpoise populations in the medium or long term.

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Tables

Table 1: Estimate of bycatch rate, mortality rate of harbour porpoises due the fishery activity in the Bay of Biscay and the English Channel between 2012 and 2015 and the probability that the mortality rate due to bycatch exceed the 1.7% threshold.

Year	Mortality rate (mortaility due to bycatch/population estimation)	Mortality rate > 1.7% (probability)
2012	3.91%	1
2013	6.39%	1
2014	5.21%	1
2015	2.79%	0.91

Figures

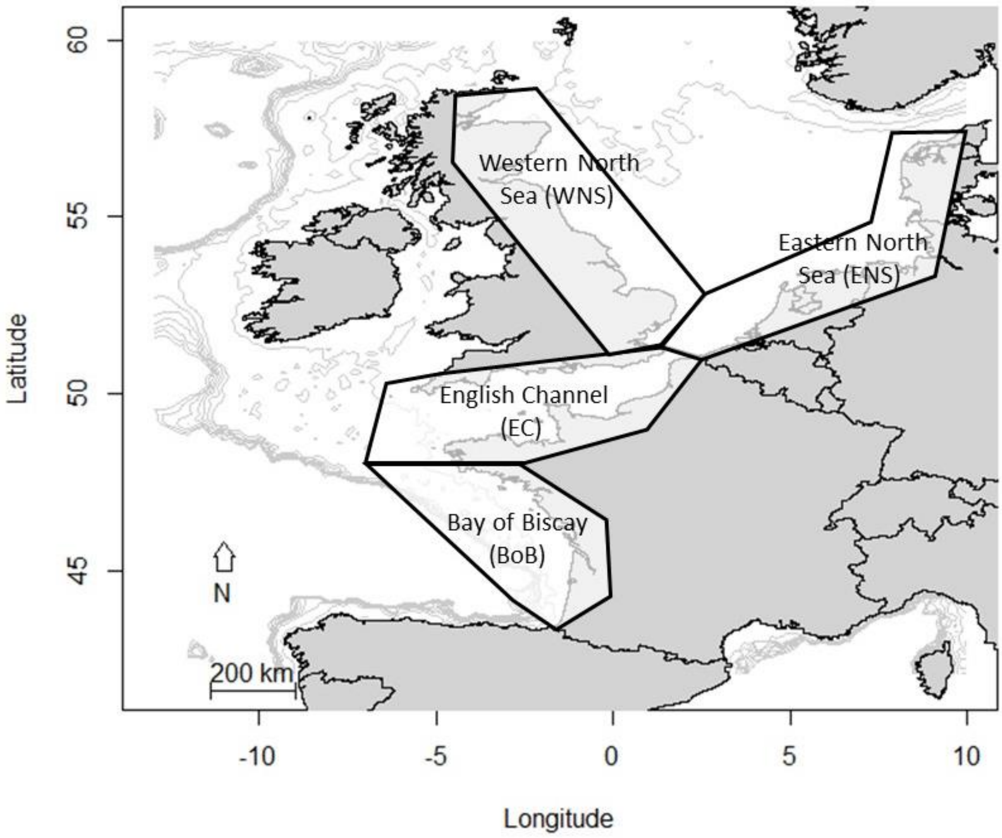

Figure 1: Subdivision of the study area.

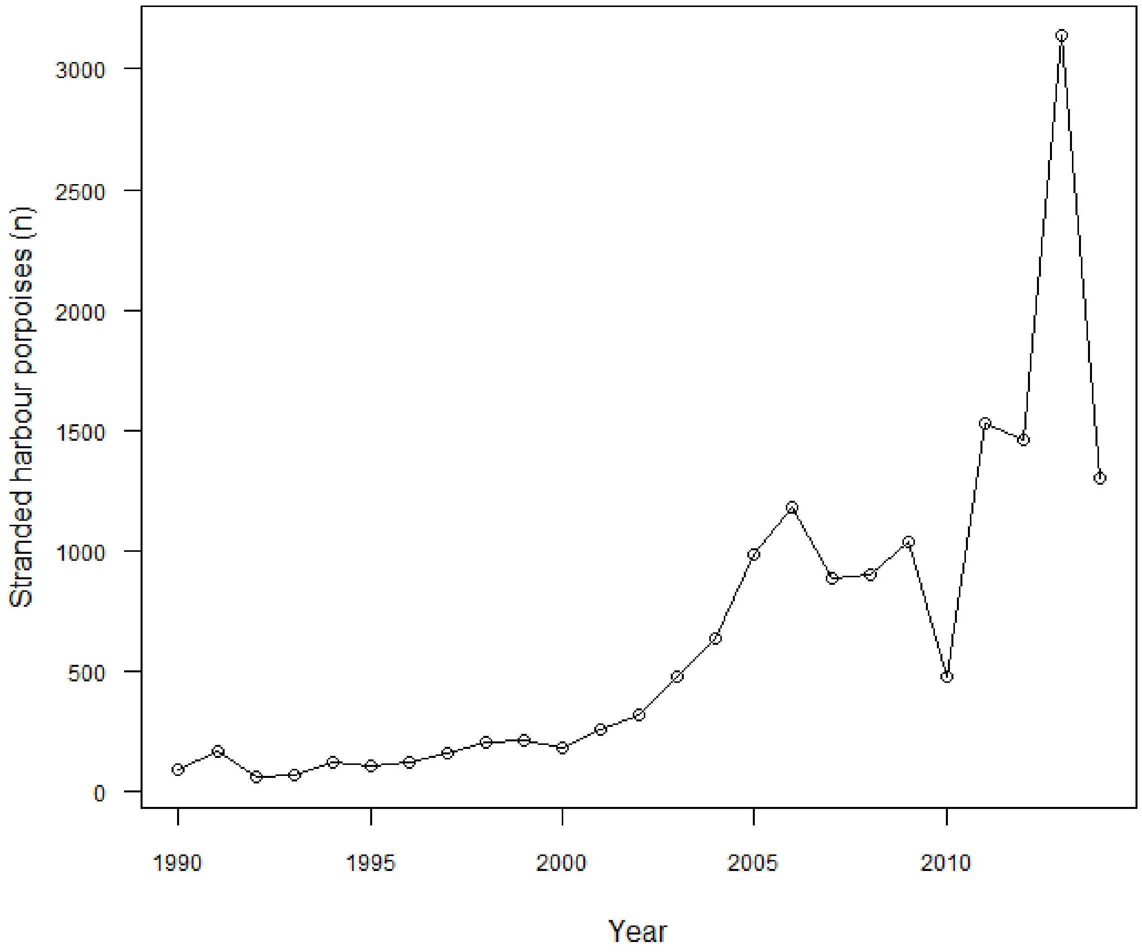

Figure 2: Annual numbers of stranded harbour porpoises from 1990 to 2014 (n=16 517) along the coasts of the North Sea, the English Channel and the Bay of Biscay.

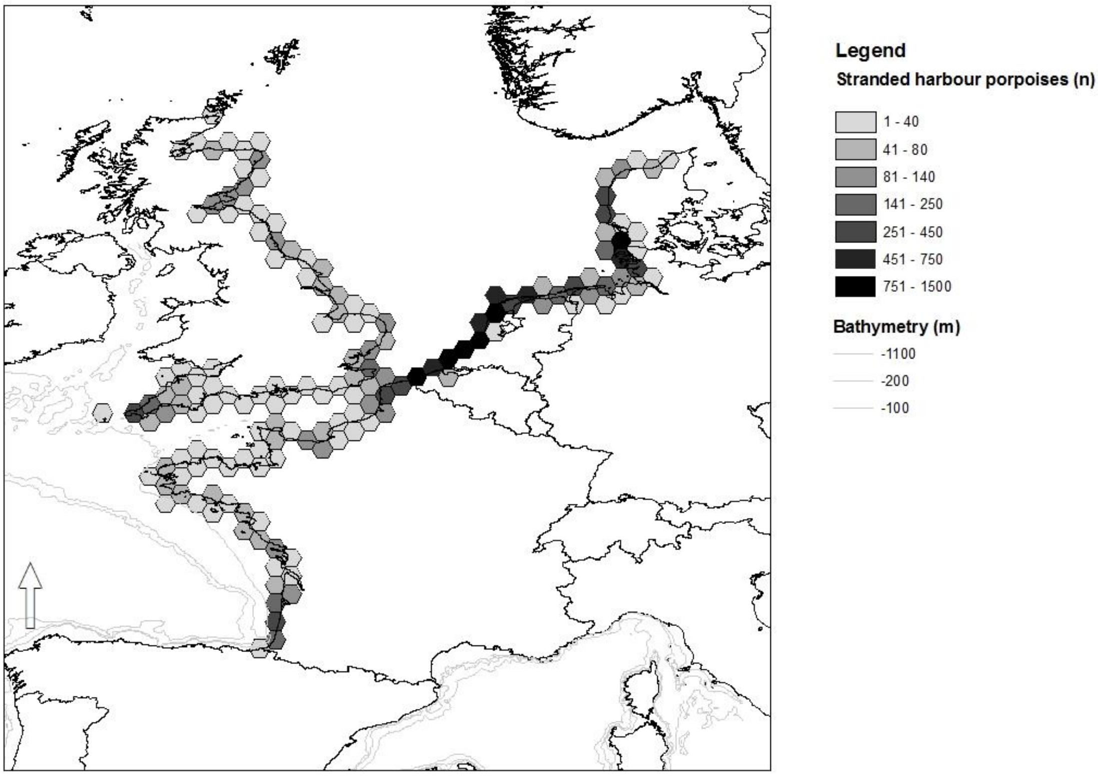

Figure 3: Spatial distribution of harbour porpoise strandings between 1990 and 2014.

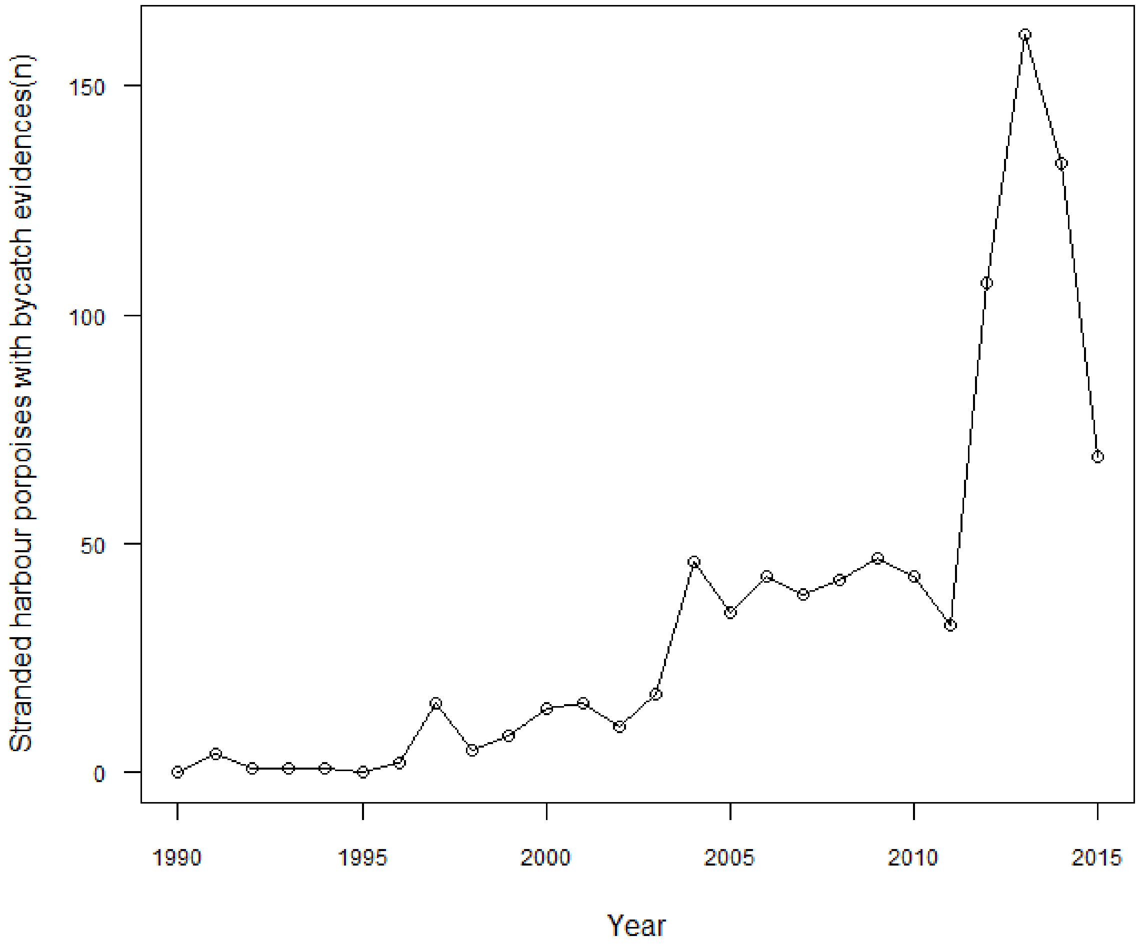

Figure 4: Annual numbers of stranded harbour porpoises with bycatch evidences from 1990 to 2015 along the coasts of the English Channel and the Bay of Biscay (n=895).

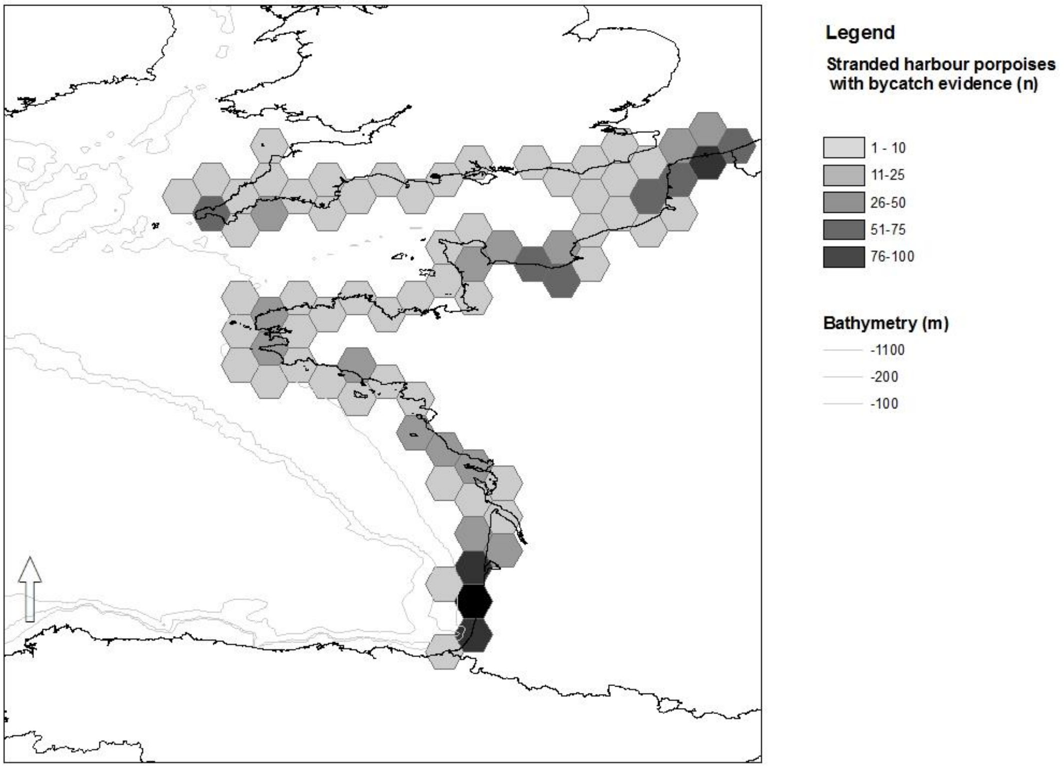

Figure 5: Spatial distribution of harbour porpoise strandings with bycatch evidence between 1990 and 2015.

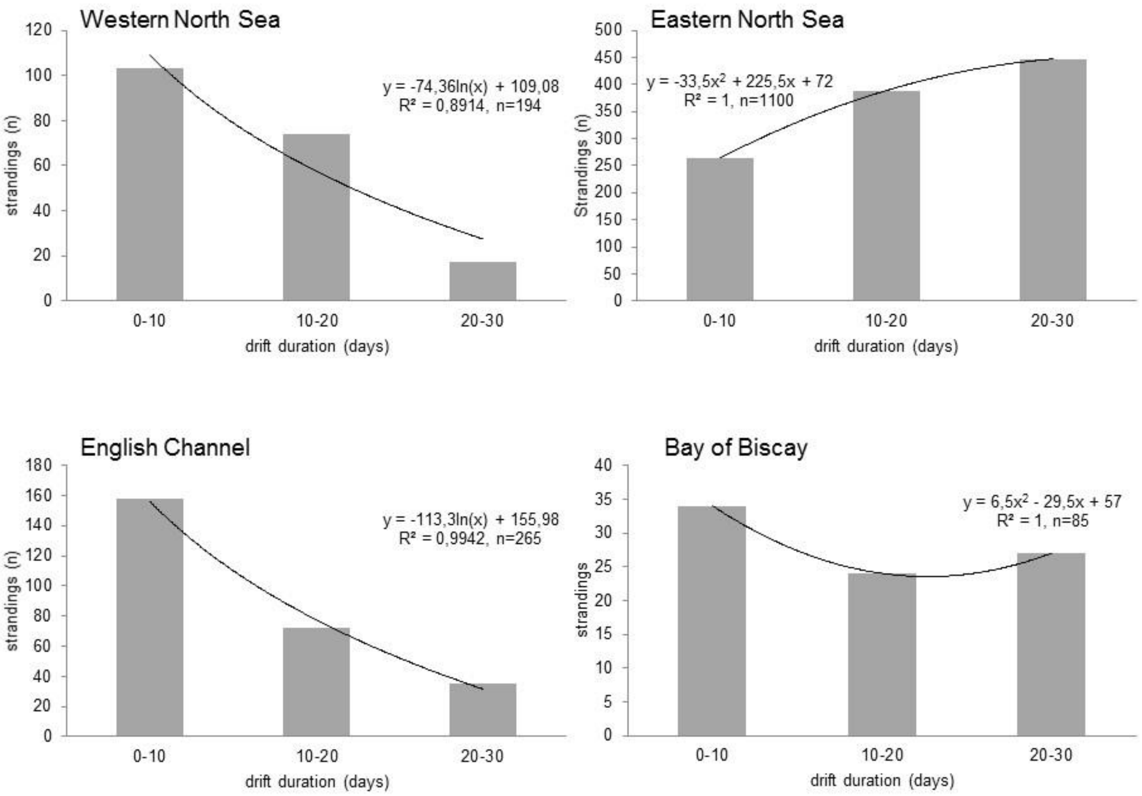

Figure 6: Histograms and smooth curves of distribution of stranded harbour porpoises according to their drift duration before stranding in the four large areas (n=1644).

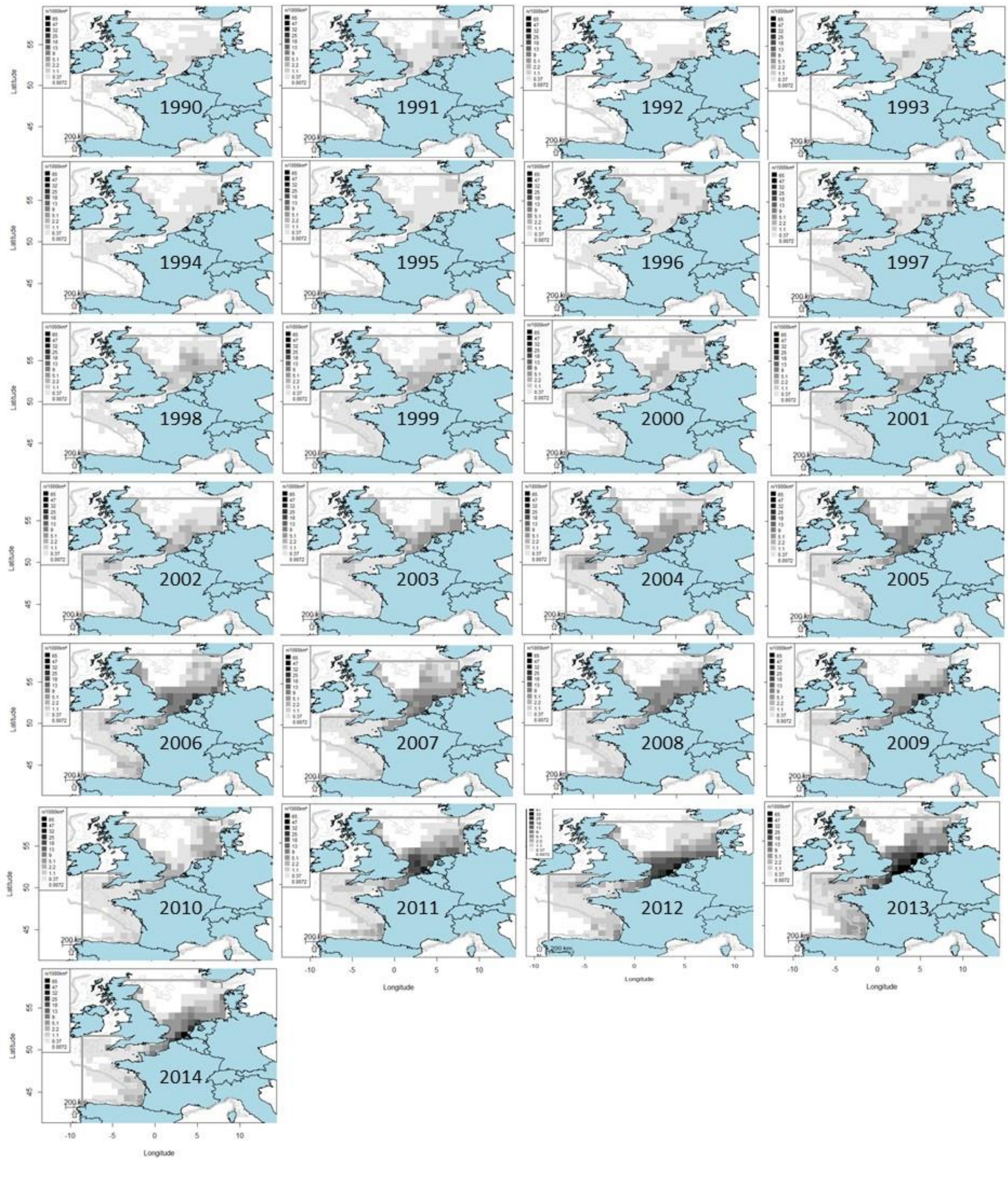

Figure 7: Distribution of dead harbour porpoises inferred from strandings from 1990 to 2014 across the study area.

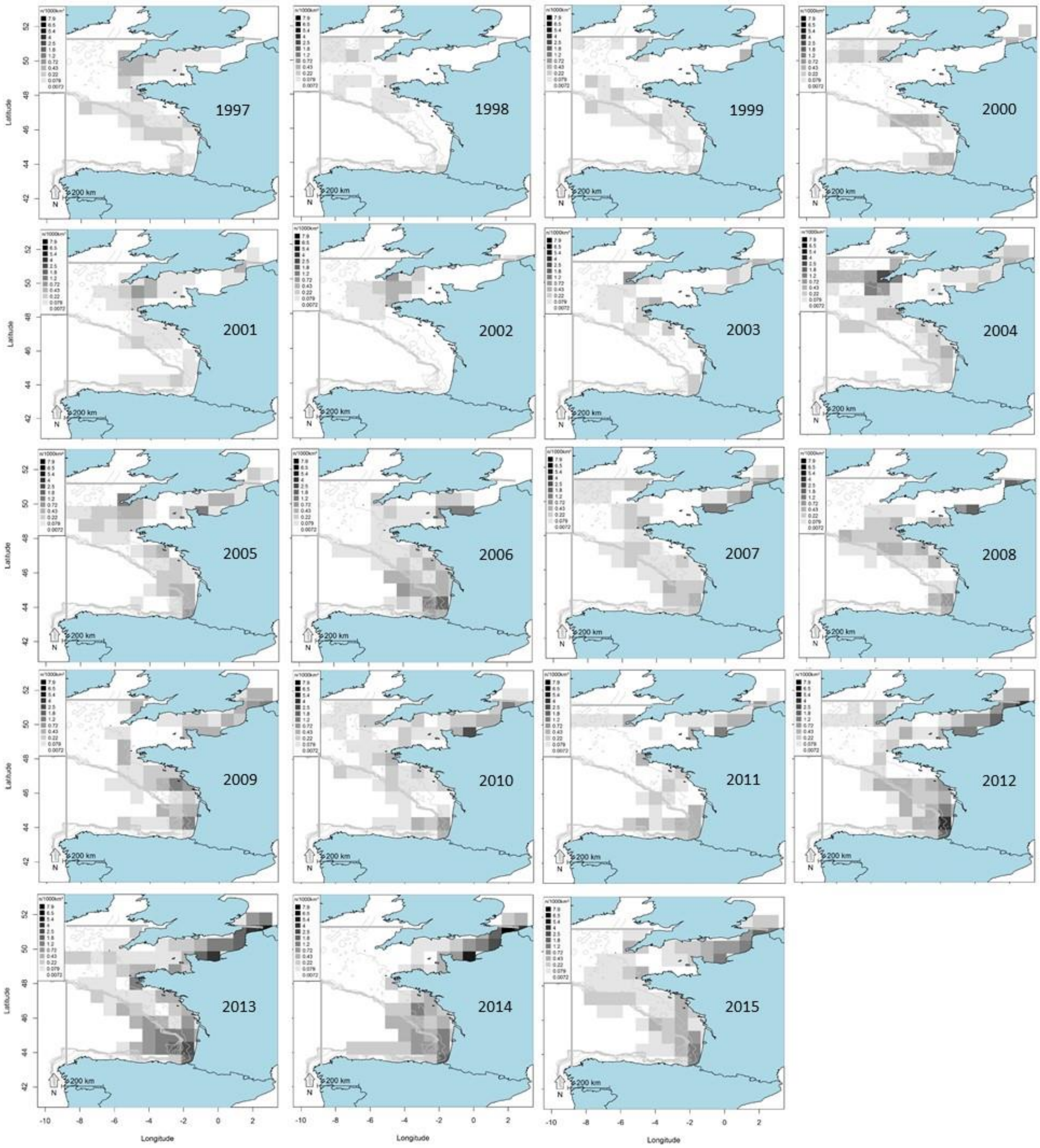

Figure 8: Distribution of bycaught harbour porpoises inferred from strandings from 1997 to 2015 in the English Channel and the Bay of Biscay.

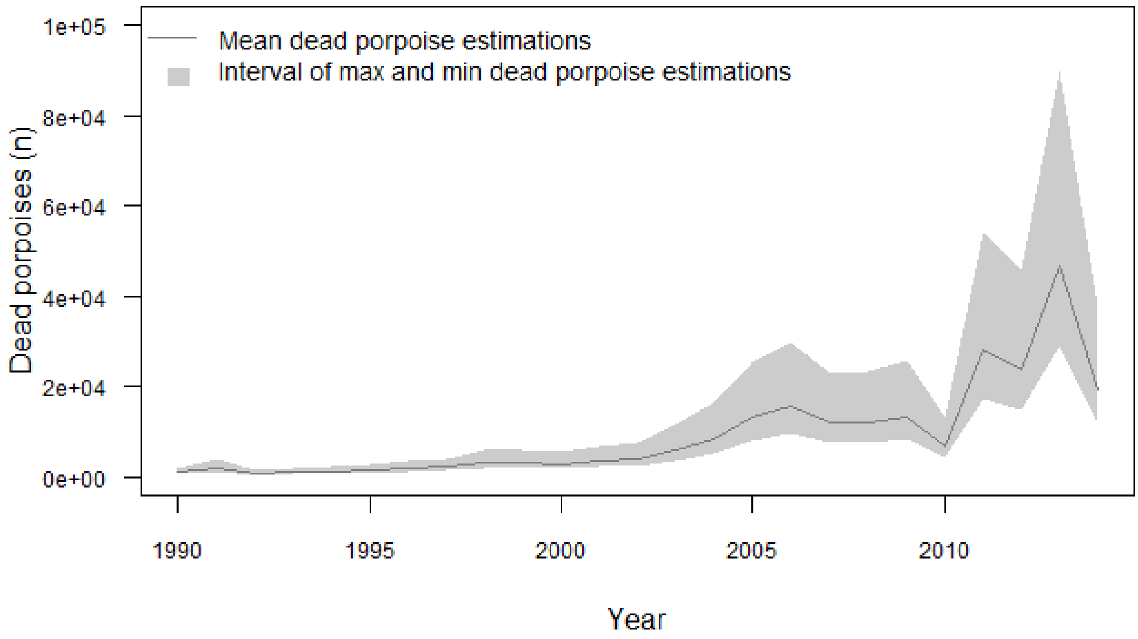

Figure 9: Estimate of total harbour porpoise mortality estimations (n individuals) inferred from strandings from 1990 to 2014 in the area considered.

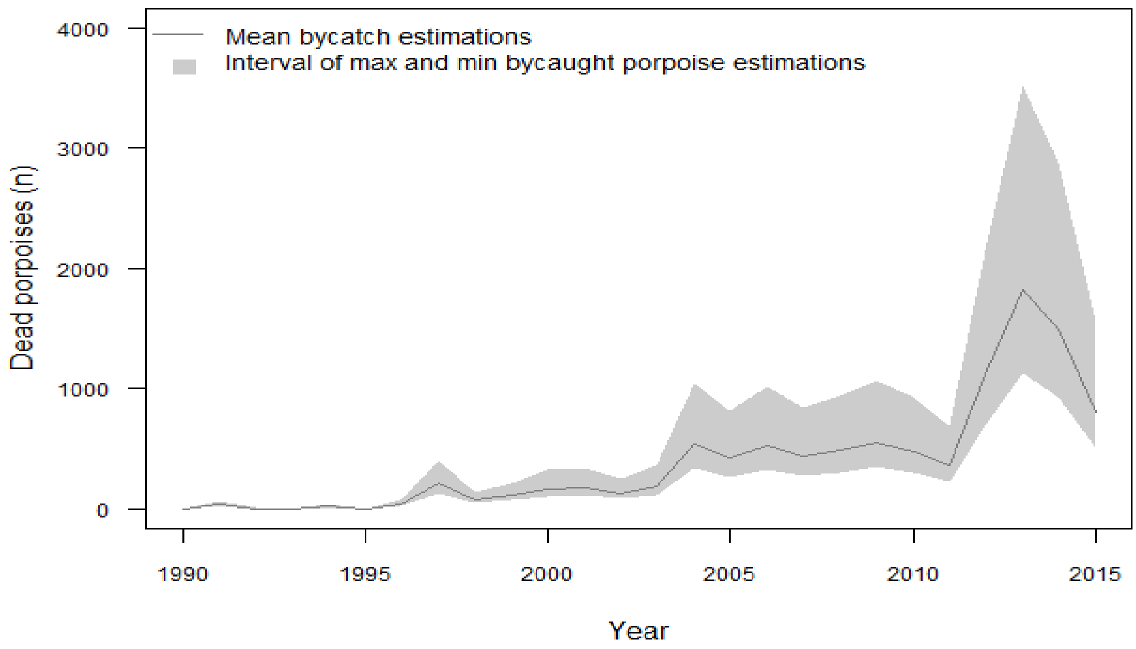

Figure 10: Estimate of harbour porpoise bycatch estimations (n individuals) inferred from strandings from 1990 to 2015 in the Channel and the Bay of Biscay.

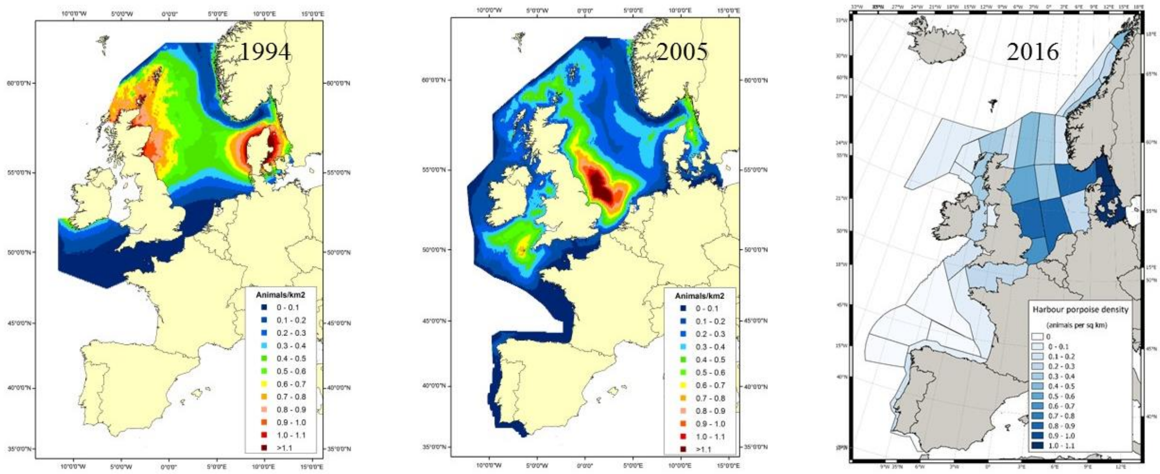

Figure 11: Distribution of harbour porpoises estimated during the SCANS survey (1994), the SCANS-II survey (2005), and harbour porpoise density per block estimated during the SCANS-III survey (2016) (Hammond et al., 2017, 2013).

Annex 1

Detailed results of strandings of harbour porpoises, strandings of harbour porpoises with bycatch evidence, bycatch rate (porpoises stranded with bycatch evidences/total harbour porpoise strandings), total mortality inferred from strandings of harbour porpoises, and mortality inferred from strandings related to fisheries.

A-Bay of Biscay

Year	Strandings (n)	Bycatch in strandings (n)	Bycatch rate (%)	Total mortality (n)	Bycatch mortality (n)
1990	3	0	0,0%	20 [10;30]	0 [0;0]
1991	5	1	20,0%	75 [45;145]	5 [2; 8]
1992	3	0	0,0%	55 [35;105]	0 [0;0]
1993	0	0	0,0%	0 [0;0]	0 [0;0]
1994	1	0	0,0%	8 [5;15]	0 [0;0]
1995	1	0	0,0%	20 [10;40]	0 [0;0]
1996	1	0	0,0%	30 [20; 62]	0 [0;0]
1997	15	7	46,7%	240 [150; 460]	100 [60; 190]
1998	4	2	50,0%	50 [30; 100]	30 [60; 190]
1999	15	4	26,7%	240 [150; 460]	60 [30; 110]
2000	19	8	42,1%	250 [160; 480]	90 [60; 180]
2001	21	6	28,6%	230 [140; 440]	60 [40; 120]
2002	16	0	0,0%	180 [110; 340]	0 [0;0]
2003	21	5	23,8%	200 [130; 390]	40 [30; 80]
2004	32	10	31,3%	350 [220; 670]	80 [50; 150]
2005	43	15	34,9%	550 [340; 1050]	160 [100; 310]
2006	86	29	33,7%	1030 [640; 1980]	360 [230; 700]
2007	34	13	38,2%	520 [320; 990]	160 [100; 310]
2008	54	15	27,8%	690 [430; 1330]	160 [100; 300]
2009	72	26	36,1%	800 [500; 1550]	320 [200; 620]
2010	45	17	37,8%	500 [310; 970]	180 [110; 340]
2011	111	16	14,4%	1350 [840; 2600]	170 [110; 330]
2012	144	58	40,3%	1430 [890; 2750]	570 [350; 1090]
2013	253	60	23,7%	2810 [1750; 5410]	710 [440; 1370]
2014	111	43	38,7%	1190 [740; 2290]	490 [310; 950]
2015	47	27	57,4%	570 [350; 1090]	330 [210; 640]

B- English Channel

Year	Strandings (n)	Bycatch in strandings (n)	Bycatch rate (%)	Total mortality (n)	Bycatch mortality (n)
1990	8	0	0,0%	80 [50; 150]	0 [0;0]
1991	11	3	27,3%	120 [80; 240]	30 [20; 50]
1992	3	1	33,3%	30 [20; 60]	2 [1; 5]
1993	4	1	25,0%	40 [20; 80)	0 [0;0]
1994	7	1	14,3%	110 [70; 210]	20 [10; 40]
1995	6	0	0,0%	80 [50; 150]	0 [0;0]
1996	9	2	22,2%	110 [70; 220]	40 [20; 80]
1997	19	8	42,1%	240 [150; 460]	110 [70; 210]
1998	18	3	16,7%	210 [130; 400]	40 [30; 80]
1999	24	4	16,7%	310 [190; 590]	50 [30; 100]
2000	34	6	17,6%	470 [290; 900]	80 [50; 150]
2001	46	9	19,6%	280 [360; 1110]	110 [70; 210]
2002	71	10	14,1%	890 [550; 1700]	130 [80; 250]
2003	79	12	15,2%	930 [580; 1800]	140 [90; 280]
2004	153	36	23,5%	1880 [1170; 3620]	460 [290; 890]
2005	85	20	23,5%	1020 [630; 1960]	260 [160; 500]
2006	104	14	13,5%	1230 [760; 2370]	160 [100; 310]
2007	106	26	24,5%	1140 [710; 2190]	270 [170; 530]
2008	99	27	27,3%	1220 [760; 2340]	340 [210; 650]
2009	102	21	20,6%	1210 [750; 2340]	240 [150; 460]
2010	113	26	23,0%	1300 [810; 2490]	300 [190; 580]
2011	140	16	11,4%	1680 [1040; 3230]	190 [120; 360]
2012	209	49	23,4%	2270 [1410; 4380]	550 [340; 1060]
2013	495	104	21,0%	5420 [3370; 10430]	1120 [690; 2150]
2014	191	91	47,6%	2080 [1290; 4010]	1000 [620; 1920]
2015	187	43	23,0%	2100 [1310; 4050]	470 [290; 900]

C- Western North Sea

Year	Strandings (n)	Total mortality (n)
1990	8	70 [40; 140]
1991	46	550 [340; 1070]
1992	15	160 [100; 300]
1993	20	280 [180; 550]
1994	33	280 [170; 530]
1995	27	290 [180; 560]
1996	42	560 [350; 1070]
1997	44	480 [300; 920]
1998	31	410 [250; 790]
1999	31	400 [250; 760]
2000	27	300 [190; 570]
2001	41	530 [330; 1010]
2002	59	730 [450; 1400]
2003	95	1220 [760; 2350]
2004	89	1020 [640; 1970]
2005	181	2170 [1350; 4170]
2006	160	2120 [1320; 4090]
2007	103	1380 [860; 2650]
2008	94	1190 [740; 2280]
2009	99	1160 [720; 2230]
2010	98	1140 [710; 2200]
2011	122	1480 [920; 2840]
2012	165	1760 [1100; 3390]
2013	330	4040 [2510; 7780]
2014	122	1340 [830; 2580]

D- Eastern North Sea

Year	Strandings (n)	Total mortality (n)
1990	73	740 [460; 1420]
1991	104	1260 [780; 2420]
1992	39	450 [280; 870]
1993	44	660 [410; 1270]
1994	80	880 [550; 1690]
1995	73	1000 [620; 1930]
1996	69	1040 [650; 2010]
1997	81	1160 [720; 2230]
1998	152	2350 [1460; 4520]
1999	143	2170 [1350; 4170]
2000	103	1760 [1100; 3390]
2001	152	2090 [1300; 4010]
2002	174	2030 [1260; 3910]
2003	284	3600 [2240; 6920]
2004	363	5290 [3290; 10170]
2005	672	9360 [5820; 18000]
2006	832	11050 [6870; 21260]
2007	643	8820 [5480; 16980]
2008	654	9020 [5610; 17370]
2009	762	10090 [6270; 19420]
2010	220	2890 [1790; 5550]
2011	1155	15910 [9890; 30620]
2012	1147	14720 [9150; 28340]
2013	2060	26360 [16380; 50740]
2014	876	11060 [6880; 21290]