Spatiotemporal trends in white-beaked dolphin strandings along the North Sea coast from 1991–2017

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Abstract: The white-beaked dolphin (*Lagenorhynchus albirostris*) is an endemic species in the North Sea with an estimated population of around 36,000 individuals. Recently, concerns have been raised among conservationists regarding increasing water temperatures as a result of climate change, which could result in a decline in population numbers in certain areas of the white-beaked dolphin's range. Here we use stranding frequencies of white-beaked dolphins as an indicator of distribution and investigate whether there have been spatiotemporal patterns and changes in stranding frequencies in the south western North Sea in the last 27 years (1991-2017). A total of 407 strandings was recorded and the distribution of stranded animals throughout this period revealed a higher density of animals in the southern countries in earlier years, with slightly increased densities in the north western area more recently. This could be a first indication of a change in habitat use and population distribution from southern to northern regions. A potential explanation for the observed shift is climate change and its effect on prey distribution and availability. This study highlights the potential of using stranding records as a way to collect high resolution spatiotemporal data, making this a valuable addition to surveys of live animals assessing species distribution and abundance. Additional research into metrics such as causes of mortality, life history and diet parameters (all of which are currently largely unknown for this species) would provide a welcome contribution to assess more detailed measures of the status of the population.

Keywords: *Lagenorhynchus albirostris*, cetaceans, mortality, spatiotemporal analysis, distribution, conservation, North Sea.

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Introduction

The white-beaked dolphin (*Lagenorhynchus albirostris*) is a species endemic to cold temperate to subpolar waters across the North Atlantic and adjacent waters including the North Sea. In the North Sea, white-beaked dolphins are prevalent in the northern part, and sightings have also been common as far south as the eastern English Channel. Strandings have occurred along the southern North Sea coasts for decades, indicating that this is also part of their distributional range (Reeves et al. 1999, Evans et al. 2003, Reid et al. 2003, Camphuysen & Peet 2006, Canning et al. 2008, Hammond et al. 2012, Galatius & Kinze 2016). Large-scale abundance surveys resulted in estimates of around 22,600 (CV=0.23) individuals in 1994 and around 37,700 (CV=0.36) in 2005. Similar numbers have been reported more recently, with 36,300 (CV=0.29) in 2016 (Hammond et al. 2017). This suggests that there has not been a significant increase or decrease in total population size since 1994, and therefore the white-beaked population in the North Sea can be considered stable (Paxton et al. 2016, Hammond et al. 2017).

A stable population is defined by having age-specific fertility and mortality rates that remain more or less constant over time (Lotka 1968). Little is known about the reproductive behavior of white-beaked dolphins, but calving is believed to occur in summer months from May to September (Camphuysen & Peet 2006, Weir et al. 2007, Evans & Smeenk 2008, Galatius et al. 2013). A number of potential threats have been identified that could affect the species' conservation status (Hammond et al 2012), including direct anthropogenic pressures such as bycatch in fishing gear across the whole area of distribution (e.g. Couperus 1997). The reported removal rates are low, but data on potential effects on the conservation status of the population remain scarce. Furthermore, similar to other toothed whales from the North Atlantic Ocean and North Sea, relatively high levels of organochlorines as well as heavy metals have been measured in tissues from white-beaked dolphins stranded in other areas (Muir et al. 1988). No more recent studies and data on contaminant burden of white-beaked dolphins stranded along the North Sea are available. It is known that in terrestrial wildlife these pollutants can have profoundly deleterious effects on the health of individuals, including immunosuppression and reproductive impairment (e.g. Aulerich et al. 1977, Kannan et al. 2000, Jepson et al. 2016). In marine mammals, a high contaminant burden and its effect on the endocrine systems has been demonstrated experimentally in seals (e.g. Reijnders 1986, Brouwer et al. 1989), and was more recently also suggested to affect the health and reproduction success of common dolphin (*Delphinus delphis*) and harbour porpoise (*Phocoena phocoena*) (Pierce et al. 2008, Murphy et al. 2015, Jepson et al. 2016). Finally, infectious diseases detected in stranded white-beaked dolphins along the North Sea include infection with the epizootic morbillivirus (e.g. Visser et al. 1993, van Elk et al. 2014).

Several authors highlight the potential impact of increasing water temperature as a result of climate change on marine mammals and their prey (e.g. MacLeod 2009, Simmonds & Eliott 2009, Evans et al. 2010, Evans & Bjørge 2013). For cold-water species like the white-beaked dolphin, increasing water temperature may lead to reduced suitable areas for foraging and habitat loss, following changes in prey distribution (MacLeod et al. 2005, Evans & Bjørge 2013). MacLeod et al. (2005) presented a decline in the relative frequencies of strandings and sightings of white-beaked dolphins in north-west Scotland and suggested that climate change could have been the cause of this decline. If water temperatures continue to increase this could have serious implications for the white-beaked dolphin population of the North Sea (MacLeod et al. 2005, Simmonds & Eliott 2009) and it can be expected that white-beaked dolphin sightings and strandings in the southern regions of the North Sea will become rarer.

Here, we analyse stranding frequencies of white-beaked dolphins on the coastlines of Belgium, the Netherlands, Schleswig-Holstein (Germany), and the east coast of the United Kingdom, investigating spatiotemporal patterns and changes in occurrence over the past 27 years (1991-2017).

Methods

Data collection

Stranding records across the southwestern North Sea area are collected and maintained at a national level by individual stranding networks. For this study, the stranding databases of Belgium, Schleswig-Holstein (Germany), the Netherlands, and the United Kingdom (UK) were combined. Data held by the following institutions were collated: Royal Belgian Institute of Natural Sciences (Belgium); the Institute for Terrestrial and Aquatic Wildlife Research, University of Veterinary Medicine Hannover (Schleswig-Holstein, Germany); Naturalis Biodiversity Center, Leiden (the Netherlands); Cetacean Strandings Investigation Programme (CSIP; United Kingdom). For the UK, only cases with a stranding location along the east coast (North Sea coastline) were included, starting at Romney Marsh (Kent) in the south of England, to Skerray (Sutherland) on the north coast of Scotland, and including the Orkney Islands. Shetland was not included.

To ensure equal temporal coverage across all areas, stranding records of white-beaked dolphins were selected from the first full year of the most recently initiated stranding network, until the last full year of data collection. This resulted in data on stranding frequencies from the last 27 years (period of 01-01-1991 to 31-12-2017). Partial remains (e.g. loose bones or incomplete carcasses) were excluded from the analysis. Records used for analysis included information on: stranding date, location, and the number of animals involved in the stranding event. No attempt was made to analyse (changes in) causes of death or the age/sex structure of the stranded individuals within this study.

Data analysis

Stranding frequencies of white-beaked dolphins were investigated both spatially and temporally. Data exploration was applied following Zuur et al. (2010) prior to analysis. All analyses were performed using R version 3.3.3 (R Core Team 2017).

The selected North Sea coastline was split into three geographical regions with Scotland representing the north; England the central; and Belgium, the Netherlands, and Germany collectively representing the southern North Sea area. Maps were created using the ggplot2 (Wickham 2009) and ggmap (Kahle & Wickham 2013) libraries available in R. To better visualise point density, kernel density estimation was performed using the stat_density_2d function integrated within ggmap. This estimates the underlying probability density function of a stranding at a particular location and visualises potential shifts in distribution over the study period. To facilitate data interpretation, the study period was divided in three equal periods of 9 years each, being 1991-1999; 2000-2008; and 2009-2017.

To assess whether there are any indications for regional within-year variation in white-beaked dolphin strandings, a kernel density plot was created estimating the probability density function of a stranding in a particular month for each region individually.

Changes in stranding frequencies over time were then further investigated. A generalised additive mixed model (GAMM) was used to model annual stranding frequencies as a function of time and the geographic regions as described above. Models were fitted using a log -link function with a Poisson error distribution, using the nlme (Pinheiro et al. 2017) and mgcv (Wood 2006) package available in R. The integrated smoothness estimation available within the mgcv package was utilised to find the optimal level of smoothness. Model selection was carried out by comparing different forms of inclusion of spatial and temporal variables (year and geographic region as described above, and assessing potential interactions between these), following a backward stepwise selection process. Autocorrelation was expected given the time series, and this was assessed following each model fit. The most appropriate model was selected by examination of normalized model residuals and evaluation of the approximate Akaike Information Criterion (AIC) where a value difference >2 was judged to be an improved model. The residual scaled deviance to the residual degrees of freedom-ratio (rdev/rdf-ratio) was calculated to examine possible overdispersion in the model. Finally model validation was applied on the optimal model to verify underlying model assumptions and evaluate model fit.

Results

Between 1991 and 2017, a total of 407 white-beaked dolphin strandings was recorded comprising 15 animals from Belgium, 25 from Schleswig-Holstein, 109 from the Netherlands and 258 from the United Kingdom (with 103 from England and 155 from Scotland). The distribution of stranded animals throughout the time period is shown in figure 1. There was a higher density of stranded animals in the southern areas in the 1990s compared to the period after 2009, with stranding numbers being more concentrated around the northern area in more recent years.

Both the northern North Sea and the southern North Sea have a relatively equal distribution of strandings throughout the year with no obvious seasonality to stranding occurance, while the majority of the reported strandings in the central North Sea occur in June and July (figure 2).

When considering all regions an overall

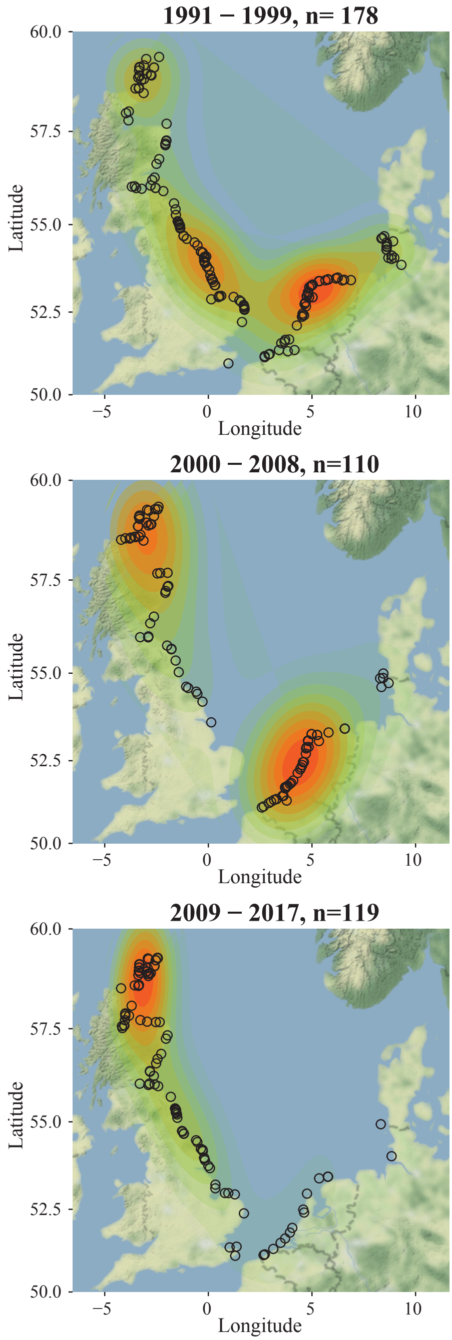

Figure 1: Study area showing the density of white-beaked dolphin strandings over three time periods (1991-1999; 2000-2008; 2009-2017) for the United Kingdom, Belgium, the Netherlands and Schleswig-Holstein, Germany.

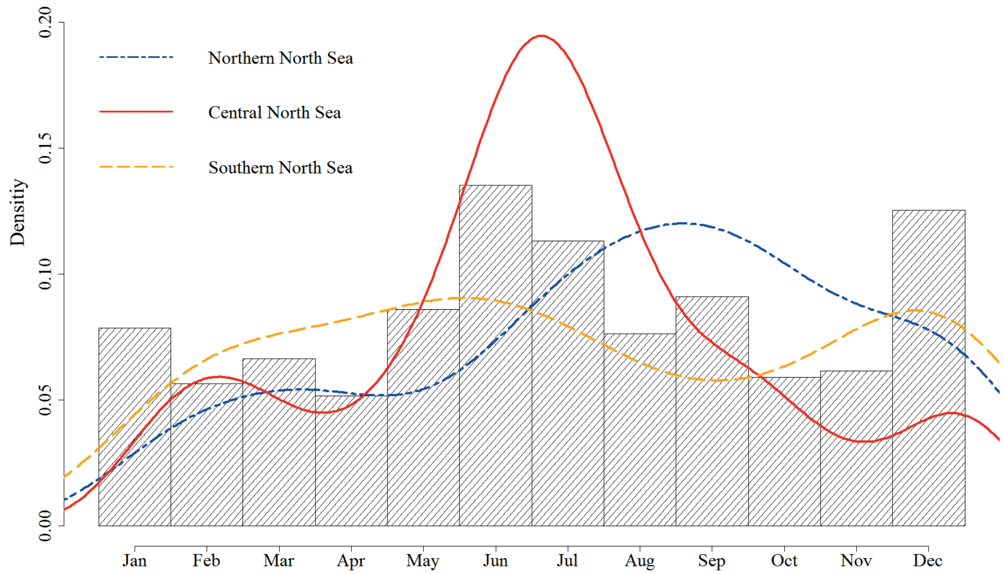

Figure 2: Density distribution estimation of white-beaked dolphin strandings per month using data from the entire study period 1992-2017. The coloured lines show kernel density estimates for the northern North Sea (blue dash and dotted line), the central North Sea (red solid line), and the southern North Sea (orange long dashed line) respectively.

Table 1. Results of the final Generalised Additive Mixed Model for the number of strandings with a separate smoother (circular regression spline) for year per region. Table values show the estimated degrees of freedom of each smoother (edf), and results from an F test of the significance of the smoothing effect.

	Smooth terms		
	edf	*F*	*P*
Northern North Sea	1.717	2.829	0.04
Central North Sea	4.626	8.798	<0.001
Southern North Sea	2.709	12.732	<0.001

decrease in stranding numbers is observed in the first five years of the study period, after which frequencies are relatively constant (figure 3A). Modelling stranding numbers throughout the study period, individual smoothers (cubic regression spline) describing the effect of year for each region individually, including an AR1 correlation structure (time lag of one year) accounting for autocorrelation throughout the study period, were finally incorporated into the final model. Each smoother was significant at the 0.05 level (table 1), and the model described above was preferred over a model with a single smoother for year (table 2), providing evidence for different non-linear trends over time for the northern North Sea, central North Sea, and southern North Sea coastlines respectively. The autocorrelation parameter, describing the autocorrelation left between the residuals separated by one year, was estimated to be 0.14. Normalised residuals were further assessed through (partial) autocorrelation plots and these results all indicated there was no strong evidence of autocorrelation left in the residuals. The rdev/rdf ratio was calculated at 0.345, meaning the values of the response variable were less dispersed than expected for a Poisson distribution. Underdispersion can lead to unnecessarily conservative parameter estimates which, given the model output, was not considered a problem for the interpretation of results presented here. The r^2 value, which is an adjusted value indicating the approximate variance explained by the model, was calcu-

Table 2. A selection of the model structures tested and their respective degrees of freedom (DF), Aikaike Information Criterion (AIC) estimate, and indication whether there were still patterns present in the model residuals. All are GAMM models with annual number of strandings as the response variable. All models were fitted using a log-link function with a Poisson error distribution, using the nlme and mgcv package available in R.

Model structure	DF	AIC	Correlation/patterns present in residuals?
s (year) + Region	6	442.2526	Yes
s (year by region)	8	176.4462	Yes
s (year by region) + Region	9	167.8253	Yes
s (year by region) + Region + AR1 correlation structure	10	167.2261	No

lated at 0.413.

White-beaked dolphin stranding numbers on the northern North Sea coastline have been stable throughout the 27 years, with the model suggesting a marginal increase in annual numbers over the study period (figure 3B). For the central North Sea coastline, a pattern can be described of declining numbers from the beginning of the study period until around 2000 followed by a slight increase (figure 3C). Finally, for the southern North Sea coastline, a declining trend can be described during most of the time series, with annual numbers decreasing slowly between 1995 and 2010 (figure 3D). These findings all correspond to the pattern seen in figure 1 and suggest that the overall decline in stranding numbers on the selected coastlines is mainly a result of decreasing numbers in the southern area.

Discussion

This study utilised white-beaked dolphin strandings data to investigate spatial and temporal occurrence patterns in the last 27 years. Results demonstrate that the number of stranded white-beaked dolphins has recently declined along the southeastern North Sea coastline compared to the first ten years of the study period, while numbers in the more northerly regions have been largely stable or even slightly increased. This suggests a potential change in distribution, with fewer animals being present in the more southern regions and the large majority of the population of white-beaked dolphins likely residing mainly in the northern regions of the North Sea; a shift previously predicted by others (MacLeod et al. 2005, Simmonds & Eliott 2009).

Monitoring marine mammal populations through live survey methods is often logistically challenging, due to the temporal heterogeneity of the marine environment and the range and mobility of cetacean species. Despite the number of biases, data on stranded animals when interpreted appropriately can yield valuable information which can be used in addition to live animal abundance surveys for population monitoring purposes (e.g. ten Doeschate et al. 2017). Strandings are recorded opportunistically, and reporting effort has likely not been constant throughout the time period used here, but improved over time with increasing public awareness, improved technology which facilitates submission of stranding reports, and interest in marine animal conservation. While it is difficult to characterise the potential effect of this on the observed stranding frequencies, there is no indication that the increase in reporting effort has been different between the individual regions and it was therefore assumed that variation in effort was equal across areas, hence data from different regions were considered comparable. Notably however, with increased public awareness one would expect an increase in strandings reported if other conditions remain the same. Yet the combined data series shows an overall decrease in stranding numbers at the beginning of the

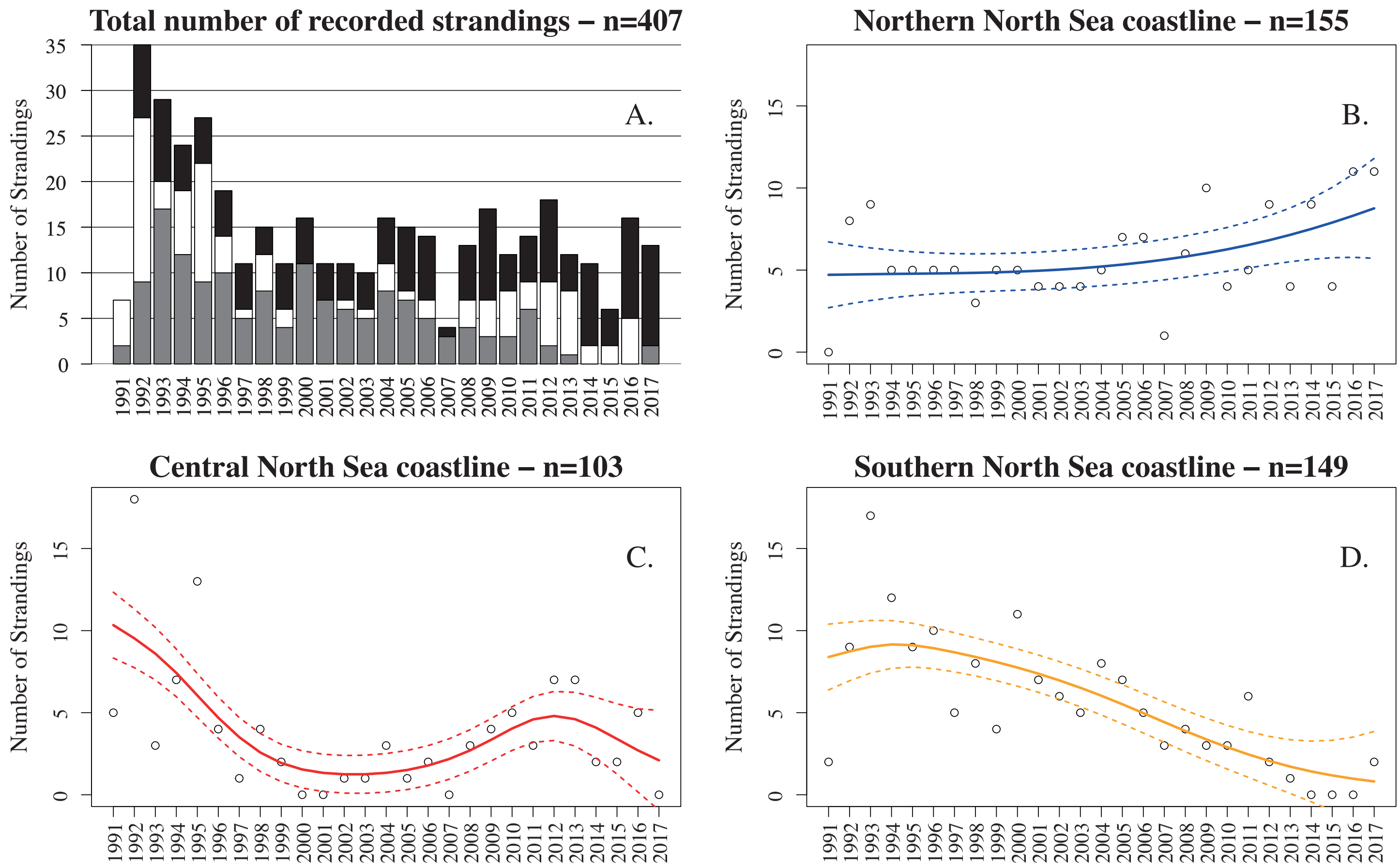

Figure 3. A: Total number of recorded strandings in the entire North Sea area partitioned by region being the northern (black), central (white) and southwestern (grey) North Sea coastline. B: Number of strandings and predicted values of model output for the northern North Sea coastline, with dotted lines representing 95% confidence intervals. C: Number of strandings and predicted values of model output for the central North Sea coastline, with dotted lines represent 95% confidence intervals. D: Number of strandings and predicted values of model output for the southern North Sea coastline, with dotted lines representing 95% confidence intervals.

time series, which suggests that the observed decrease in stranding frequencies may well be larger than can be demonstrated through the data presented here.

Large-scale decadal population survey results of SCANS revealed no significant change in abundance of white-beaked dolphins between 1994-2016; yet the results found here suggest a possible shift in population distribution during the period 1991 - 2017. Whilst these large scale abundance estimates are needed in order to assess population status and changes within this over time, smaller-scale distributional changes can have significant management consequences, especially when allocating marine protected areas or mitigating local threats. While extensively examining seasonality was beyond the aim and scope of this study, our data did suggest there may be within-year variability in distribution of white-beaked dolphins in the North Sea area, which would be useful information to consider when interpreting the more temporally limited large scale abundance survey outcomes.

The observed trends as presented in this study may have been driven by yet unknown underlying factors. Nevertheless the potential explanations for the observed change in distribution are largely anthropogenic in origin, for example climate change and its effect on habitat suitability and prey distribution and availability, as well as potentially increasing marine industry activities in certain regions. Coastal development, habitat degradation, and chemical or noise pollution all can result in ecosystem changes which influence population numbers and species composition in an area (Aguirre & Tabor 2004, Moore 2008, Wassmann et al. 2011). Marine mammals, like the white-beaked dolphin, can be used as sentinels for monitoring of marine ecosystems, as they are relatively long-lived, highly mobile species which feed at or near the top of the food chain (Aguirre & Tabor 2004, Moore 2008, Bossart 2011). Using apex predators as indicators however requires knowledge on abundance and distribution, including the establishment of reproduction and mortality parameters; most of which is currently unknown for this species.

This study focused on the analyses of stranding numbers and changes through time and between locations, but did not involve an assessment of causes of strandings and biological characteristics of stranded animals. These additional data would be required in order to assess more detailed metrics of population status, such as causes of mortality, life history and diet parameters. The regional Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS) aims to achieve and maintain a favourable conservation status for small cetaceans. White-beaked dolphins are listed as native in the ASCOBANS agreement area. The data on population size and trends is however assessed as poor, and whilst the species is considered as 'least concern' on the IUCN red list, it seems undeniable that there is a deficiency in data and knowledge (Galatius & Kinze 2016). With limited information available on population biology, abundance trends, and threats and pressures affecting this species, the population of white-beaked dolphins warrants more intensive research in order to better assess its current status. Strandings provide a unique sample and data of the population that is difficult to obtain by most other means of surveillance, and can be collected continuously achieving a high spatial and temporal resolution. This study highlights the potential for using stranding records for spatiotemporal analysis assessing species distribution, providing a valuable addition to surveys of live animals particularly in a region like the North Sea with well-established systematically operating stranding networks.

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Samenvatting

Trends in ruimte en tijd in strandingen van de witsnuitdolfijn langs de Noordzeekust van 1991–2017

Hoewel de witsnuitdolfijn (*Lagenorhynchus albirostris*) gezien wordt als een inheemse soort in de Noordzee, suggereren recente studies dat de populatiegrootte in dit gebied afneemt als gevolg van een toenemende watertemperatuur door klimaatveranderingen. Dit kan resulteren in een daling van de aantallen witsnuitdolfijnen in bepaalde delen van het verspreidingsgebied. Wij hebben de aantallen gestrande witsnuitdolfijnen in de Noordzee geanalyseerd om veranderingen in de laatste 27 jaar (1991-2017) in tijd en ruimte te onderzoeken. Tussen 1991 en 2017 werden in totaal 407 strandingen van deze soort geregistreerd. De verspreiding van de gestrande dieren gedurende de onderzoeksperiode bracht een hogere dichtheid in de zuidelijke landen in eerdere jaren aan het licht, met een licht toenemende dichtheid in het noordelijke deel in recentere jaren. Dit kan een eerste indicatie zijn van een verschuiving van de populatie van zuidelijke naar meer noordelijke delen van het studiegebied en een daarmee samenhangende verandering van habitatgebruik. Mogelijke verklaringen hiervoor zijn klimaatveranderingen en de effecten hiervan op de verspreiding en beschikbaarheid van prooisoorten. Deze studie benadrukt de potentie van het gebruik van strandingsgegevens als een manier om gegevens in ruimte en tijd te verzamelen die met andere surveillancemiddelen nauwelijks kunnen worden verkregen. Dit maakt dat dergelijke analyses een waardevolle aanvulling kunnen vormen op studies die zich richten op de verspreiding en het voorkomen van soorten. Aanvullend onderzoek naar onder andere sterfte, reproductie- en dieetparameters is echter vereist om de populatiestatus van de witsnuitdolfijn meer gedetailleerd te kunnen beoordelen; hierover is nog weinig bekend.

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