UK West Coast Harbour Porpoise (*Phocoena phocoena*) Strandings

Report No: 358

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1. Crynodeb Gweithredol

Mae'r adroddiad hwn yn crynhoi dadansoddiadau o ddata ar lamhidyddion (*Phocœna phocœna*) sydd wedi tirio, a gasglwyd gan Raglen Archwilio Tiriadau Morfilod y DU (CSIP) ar gyfer arfordir gorllewinol y DU rhwng 1992 a 2017. Roedd y dadansoddiadau yn anelu at sefydlu patrwm gwaelodlin o diriadau llamhidyddion ac asesu cyfansoddiad y boblogaeth a diriwyd, gan ganolbwyntio'n bennaf ar baramedrau rhyw ac oedran a dosbarthiad oedran (newydd-anedig, ifanc, aeddfed). Mae'r dadansoddiadau'n darparu mewnwelediad i strwythur y boblogaeth a meysydd pwysigrwydd posibl ar gyfer grwpiau oedran neu brosesau biolegol penodol. Ymchwiliwyd i amrywiaeth ofodol o ran y rheswm dros y farwolaeth, gan ganolbwyntio ar resymau anthropogenig uniongyrchol (cael eu dal fel sgil-ddalfa a tharo gan longau) o gymharu ag achosion marwolaeth eraill. Nodweddwyd cyflwr cyrff y llamhidyddion ar arfordir gorllewinol y DU fel procsi ar gyfer asesu amrywiaeth amser-ofodol yn ffitrwydd y boblogaeth.

Mae tiriadau yn ganlyniad i brosesau biolegol, ffisegol a chymdeithasol, sy'n gydgysylltiedig drwy berthynas gymhleth a pherthyn rywfaint o ansicrwydd yn perthyn i bob un yn unigol. Mae hyn yn gwneud amcangyfrif marwolaethau ar y môr yn heriol a dylid ystyried y cafeatau hyn wrth wneud casgliadau ar lefel y boblogaeth yn seiliedig ar sbesimenau sydd wedi tirio. Serch hynny, mae cynlluniau gwyliadwriaeth tymor hir fel y CSIP yn caniatáu dadansoddi tueddiadau a phatrymau hanesyddol a sylfaenol ac ni ellir fel arfer gasglu'r wybodaeth sy'n deillio o feysydd trwy ddulliau eraill, felly bydd offer i wella ac ehangu defnyddioldeb y data hwn o fudd sylweddol i gadwraethwyr a'r rhai sy'n llunio polisi.

Cyfyngwyd y dadansoddiadau i ddwy o'r tair uned rheoli llamhidyddion y DU, sef uned reoli'r Môr Celtaidd a Môr Iwerddon ac uned reoli Gorllewin yr Alban (IAMMWG 2015), gan gwmpasu i bob pwrpas diriadau llamhidyddion ar arfordir gorllewin y DU o arfordir deheuol Dyfnaint i Benrhyn Parbh (Cape Wrath) yn yr Alban (gan fynd yr un ffordd â'r cloc). At ddibenion y dadansoddiadau hyn, rhannwyd yr arfordir yn bedwar rhanbarth: yr Iwerydd (gan gynnwys yr Alban, arfordir gogledd a gogledd-ddwyrain Gogledd Iwerddon ac eithrio arfordir deheuol Dumfries a Galloway), Gogledd y Môr Celtaidd (gan gynnwys tir mawr Lloegr i'r gogledd o Gymru, arfordir de-ddwyrain Gogledd Iwerddon, Ynys Manaw, ac arfordir deheuol Dumfries a Galloway), Cymru (gan gynnwys holl arfordir Cymru), a'r rhanbarth deheuol (gan gynnwys arfordir Lloegr i'r de o Gymru ac Ynysoedd Sili).

Ymhlith y canfyddiadau allweddol (a drafodir yn yr adroddiad) mae:

- Ceir y dwysedd mwyaf o diriadau llamhidyddion drwy gydol gorllewin y DU yn gyson yng Nghymru, yn enwedig yn ardal Bae Ceredigion. Mae'r ardal hon ar ei phen ei hun yn cyfrif am 25.8% o'r holl diriadau a gofnodwyd ar draws dyfroedd gorllewin y DU.

- Defnyddiwyd Modelau Adiol Cymysg Cyffredinol (GAMM) i feintioli natur dymhorol tiriadau, gan sefydlu patrwm gwaelodlin o diriadau a galluogi i newidiadau gael eu meintioli:
  - Mae amlder tiriadau ym mhob rhanbarth yn amrywio yn ôl y tymor.

  - Mae natur dymhorol y tiriadau yn amlwg iawn yng Nghymru, a gwelir y niferoedd mwyaf rhwng Mai a Hydref. Mae hyn yn cyd-fynd â'r tymor lloia.
  - Mae gan yr ardal ddeheuol frig o ran marwolaethau yn ystod y gaeaf, sy'n debygol o fod yn gysylltiedig â chyfuniad o ddosbarthiad anifeiliaid a sgil-ddalfeydd.

- Mae dosbarthiad tymhorol tiriadau yn ôl dosbarth oedran yn amrywio o ranbarth i ranbarth.
  - Anifeiliaid ifainc yw'r gyfran fwyaf o anifeiliaid sy'n tirio yn rhanbarth yr Iwerydd a'r Gogledd Celtaidd. Mae gan Gymru ddosbarthiad cymharol gyfartal o bob grŵp oedran. Mae gan yr ardal Ddeheuol nifer uwch o oedolion fel cyfran o'r boblogaeth a phrin iawn yw'r adroddiadau am rai newydd-anedig yn tirio yma.
  - Mae gan ranbarthau Gogledd y Môr Celtaidd a Chymru ddwysedd uwch o oedolion yn ystod misoedd yr haf (mis Mehefin i fis Hydref) o'i gymharu â gweddill y flwyddyn, sydd o bosibl yn arwydd o farwolaeth yn gysylltiedig â ffactorau sy'n achosi straen wrth atgynhyrchu.
  - Mae gan Gymru gyfran sylweddol uwch o lamhidyddion newydd-anedig tiriedig o gymharu â rhanbarthau eraill, sydd o bosibl yn arwydd bod yr ardal hon yn bwysig ar gyfer lloia i boblogaeth llamhidyddion yr arfordir gorllewinol.

- Mae gwahaniaethau rhanbarthol yn y gyfran o achosion sydd wedi derbyn diagnosis o farwolaeth yn sgil achosion anthropogenig uniongyrchol, gyda chyfartaledd dros gyfnod o 26 blynedd o 13.2% yn y gogledd (rhanbarthau'r Iwerydd a Gogledd y Môr Celtaidd), 16.7% yng Nghymru, a 44.7% yn y rhanbarth deheuol. Mae marwolaethau anthropogenig uniongyrchol ar gyfer llamhidyddion ar arfordir gorllewin y DU yn bennaf yn ganlyniad i gael eu dal fel sgil-ddalfa (98.5%) gyda'r 1.5% sy'n weddill yn cael eu taro gan longau.
  - Mae'r gyfran o farwolaethau anthropogenig wedi bod yn gymharol sefydlog yng Nghymru dros amser, tra bod gostyngiad bach wedi bod dros y degawd diwethaf yn rhanbarthau'r Gogledd a'r De .

- Ni chanfuwyd unrhyw dueddiadau amlwg o ran cyflwr cyrff yr anifeiliaid ar hyd arfordir gorllewin y DU:
  - Nid oes unrhyw wahaniaethau gofodol yn y berthynas rhwng pwysau a hyd llamhidyddion ar arfordir gorllewin y DU.
  - Er bod rhywfaint o amrywiaeth o ran cyflwr y cyrff o flwyddyn i flwyddyn ac o ranbarth i ranbarth, canfuwyd bod dosbarthiad cyflwr cyrff ar gyfer y rhan fwyaf o flynyddoedd ar gyfer pob rhanbarth yn gymharol gyfartal (rhwng da a gwael).
  - Mae diagnosis o achosion o newyn yn gymhleth a byddai angen dadansoddiad pellach i wella asesiad iechyd ar lefel y boblogaeth.

- Mae'r data y mae'r adroddiad hwn yn seiliedig arno yn cwmpasu'r rhan fwyaf o’r wyliadwriaeth barhaus dros y tri degawd diwethaf o diriadau anifeiliaid o deulu’r morfil yn y DU. Yn ystod yr amser hwn, mae ysgogwyr polisi a gwyddonol y cynllun wedi esblygu. Gan fod y gofynion ar gyfer y data wedi newid, awgrymir y dylid adolygu'r strategaethau gweithredu cyfredol ar gyfer y Rhaglen Archwilio Tiriadau Morfilod (CSIP) er mwyn cael y gwerth gorau allan o ddata'r cynllun yn y dyfodol wrth gynnal y dilyniant a gynigir gan y setiau data hirdymor hyn.

Mae'r dadansoddiadau a gyflwynir yn yr adroddiad hwn wedi darparu mewnwelediadau sylfaenol i batrymau tiriadau llamhidyddion o amgylch arfordir gorllewin y DU. Mae hwn wedi bod yn gam cyntaf hanfodol o ran asesu strwythur poblogaeth y tiriadau, ac mae wedi awgrymu bod natur dymhorol ac achosion marwolaethau yn amrywio o ranbarth i ranbarth. Ein gobaith yw y bydd yr wybodaeth hon yn darparu sail dystiolaeth gref i lywio polisi a chyngor yn y dyfodol. Dylai gwella'r arfau sydd ar gael i ddadansoddi data ar diriadau manteisgar fel hyn ein galluogi i ddeall yn well statws cadwraeth a dosbarthiad llamhidyddion a’r pwysau maent yn eu hwynebu.

2. Executive Summary

This report summarises analyses of harbour porpoise (*Phocoena phocoena*) strandings data, collected by the UK Cetacean Strandings Investigation Programme (CSIP) for the west coast of the UK from 1992 to 2017. Analyses aimed to establish a baseline pattern of harbour porpoise strandings and assess the composition of the stranded population, mainly focussing on sex and age parameters and age class distribution (neonate, juvenile, adult). The analyses provide insight into the population structure and potential areas of importance for particular age groups or biological processes. Spatial variation in cause of death was examined, focussing on direct-anthropogenic (bycatch and ship strike) versus other causes of mortality. The body condition of harbour porpoise on the West coast of the UK was characterised as a proxy for assessing spatiotemporal variation in population fitness.

Strandings are a function of biological, physical and social processes, which are inter-linked through a complex relationship and are all individually associated with a degree of uncertainty. This makes estimating at sea mortality challenging and these caveats should be taken into consideration when making population level inferences based on stranded specimens. Nevertheless long term surveillance schemes like the CSIP allow analysis of historical and baseline trends and patterns and the information derived from strandings usually cannot be gathered by other means, thus tools to improve and expand the utility of these data will be of significant benefit to conservationists and policy makers.

The analyses were restricted to two of the three UK harbour porpoise management units (MU); the Celtic and Irish Seas and the West Scotland MU (IAMMWG 2015), effectively covering harbour porpoise strandings on the UK west coast from the south coast of Devon clockwise to Cape Wrath, Scotland. For the purposes of these analyses the coastline was separated into four regions: the Atlantic (including Scotland, the north and north-east coast of Northern Ireland and excluding the south coast of Dumfries & Galloway), the North Celtic (including the English mainland north of Wales, the south east coast of Northern Ireland, the Isle of Man, and the south coast of Dumfries & Galloway), Wales (including the entire Welsh coastline) and the Southern region (including the English coast south of Wales and the Scilly Isles).

Key findings discussed in the report include:

- The highest density of harbour porpoise strandings throughout the western UK are consistently found in Wales, particularly the Cardigan Bay area. This area alone accounts for 25.8% of all strandings recorded throughout western UK waters.

- Generalised Additive Mixed Models (GAMM) were used to quantify seasonality of strandings, establishing a baseline pattern of strandings and enabling changes to be quantified:
  - There is region specific seasonality in strandings frequency.
  - Wales exhibits strong seasonality, with peak numbers observed from May through to October. This coincides with the calving season.
  - The Southern area has a winter peak in mortality likely related to a combination of animal distribution and bycatch.

- There is regional variation in the seasonal distribution of strandings by age class

  - The largest proportion of animals stranded in the Atlantic and North Celtic region are juveniles. Wales has a relatively equal distribution of all age groups. The Southern area has a proportionally higher number of adults and very few neonatal strandings reports.
  - The North Celtic and Welsh regions have a higher strandings density of adults in summer months (June to October) compared to the rest of the year.
  - Wales has a significantly higher proportion of stranded neonates compared to the other regions, potentially indicating this region is an important area for calving for the west coast population of harbour porpoise.

- There are regional differences in the proportion of cases that are diagnosed to have died of direct anthropogenic causes, with a 26 year period average of 13.2% in the North (Atlantic and North Celtic regions), 16.7% in Wales, and 44.7% in the Southern region. Direct anthropogenic mortality for harbour porpoise on the UK's west coast is largely bycatch (98.5%) with the remaining 1.5% being shipstrike.
  - The proportion of anthropogenic mortality has been relatively stable in the Welsh region over time, whereas both the North and the Southern regions have seen a slight decrease over the past decade.

- No obvious trends were detected in the body condition of animals along the UK west coast;
  - There are no spatial differences in the relationship between weight and length of harbour porpoise on the UK West coast.
  - While there is some variation in body condition between years and between regions, a relatively equal distribution of body condition (between good and poor) was found in most years for each region.
  - Diagnosis of starvation cases is complex and further analysis would be required to improve the assessment of health at a population level.

- The data on which this report is based covers the best part of the last three decades of continuous cetacean stranding surveillance in the UK. Over this time, the policy and scientific drivers for the scheme have evolved. Since the requirements for the data have changed, it is suggested that the current operating strategies for the CSIP are reviewed in order to optimise the value of future data from the scheme whilst maintaining the continuity offered from these long-term datasets.

The analyses presented in this report have provided a first insight into patterns of harbour porpoise strandings around the west coast of the UK. This has been an essential first step in assessing the structure of the stranded population and indicated region specific seasonality and mortality. This information provides a strong evidence base to inform policy and guide future research and management priorities. Improving tools for analysis of opportunistic strandings data such as this should enable a better understanding of the conservation status, distribution and pressures faced by harbour porpoise.

3. Introduction

Harbour porpoises in UK waters are protected through a number of national and international legislative frameworks and are impacted by a range of anthropogenic pressures (IAMMWG et al, 2015). The next decade is expected to see significant expansion of anthropogenic activities in the marine environment, most notably from the burgeoning renewable energy industry. There is uncertainty regarding the potential effects of various anthropogenic activities and developments on the UK's harbour porpoise population, which has raised concerns among conservationists and policy makers aiming to conserve the species. The need to understand and quantify the consequences of these pressures at an individual and population level is critical to assess the need for - and design of effective mitigation measures, population monitoring and management.

Cetaceans are notoriously difficult and costly to monitor; they are highly mobile, range widely and spend most of the time underwater, making them difficult to detect. Nonetheless the coastline provides a powerful vantage from which to conduct surveillance. Stranded individuals provide a unique sample of the population that is difficult to obtain by any other means. The UK and devolved governments have funded continuous strandings surveillance, in the form of the Cetacean Strandings Investigation Programme (CSIP), since 1990 (Deaville and Jepson, 2011). Long term monitoring such as this enables the collection and assessment of population metrics indicative of population demographics. This includes evaluation of age structure, sex ratio, and fitness parameters such as body condition indicative of health. Analyses of these factors as well as stranding frequencies improves our understanding of species abundance and distribution, habitat use and critical areas for particular biological processes. Additionally, detailed pathological investigation of stranded marine mammals provides an opportunity to establish cause of death and gain information on sources of mortality and pressures and threats, and potential trends in these. This information can then be made available to inform environmental impact assessments and assist Statutory Nature Conservation Bodies (SNCBs) and regulators with policy, monitoring and advice.

In this report, the CSIP database was interrogated to establish a baseline pattern of harbour porpoise strandings on the west coast of the UK. The available metadata was used to assess the composition of the stranded population, mainly focussing on sex and age parameters which provides insight into the population structure and potential areas of importance for particular age groups. Spatial variation in cause of death and long term temporal changes in these were examined, focussing on direct-anthropogenic versus other causes of mortality. Finally, body condition of harbour porpoise on the West coast of the UK was characterised as a proxy for assessing spatiotemporal heterogeneity in population fitness.

This report thereby aims to provide first insights into patterns of strandings of harbour porpoise around the west coast of the UK as a first step in assessing strandings distribution, population structure, habitat use, and anthropogenic mortality, from which further hypotheses about the processes that generated these data can be specified to guide future research and management priorities.

4. Materials & Methods

4.1 CSIP

The UK Cetacean Strandings Investigation Programme (CSIP) has been running since 1990 in England and Wales and 1992 in Scotland and is funded by Defra and the Devolved Administrations. The principal requirement of this project is to provide a coordinated approach to the surveillance of cetacean strandings in the UK, and to investigate major causes of death of stranded animals (Deaville and Jepson, 2011). This was originally devised to identify any substantial new threats to their conservation status. The data generated from this programme contributes towards assessment and reporting requirements under a number of international directives and agreements, including the Habitats Directive, the Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS), the Convention for Migratory Species, the International Whaling Commission and the Stockholm Convention.

The main project management and coordination is done by the Institute of Zoology (IoZ), yet several organisations are part of and contribute towards data collection for the CSIP. In England (excluding Cornwall), the reporting, retrieval and transportation of stranded animals is co-ordinated by the Natural History Museum (NHM), with IoZ providing assistance where appropriate. In Cornwall, the Cornwall Wildlife Trust Marine Strandings Network (CWTMSN) co-ordinate stranding reporting, retrieval and transportation to the University of Exeter for post-mortem investigation. In Scotland, the reporting, retrieval, transportation, and post mortems of stranded animals is all co-ordinated by the Scottish Marine Animal Strandings Scheme (SMASS), part of Scotland's Rural College (SRUC). In Wales, the reporting, retrieval and transportation of stranded animals is co-ordinated by Marine Environmental Monitoring (MEM). Data on strandings in Northern Ireland is collected by the Department of Agriculture, Environment and Rural Affairs and data on strandings in the Isle of Man are provided by Department of the Environment, Food and Agriculture. A more detailed overview of the organisational structure of the CSIP can be found in Deaville and Jepson *et al.* (2011).

4.1.1 Data collection, recording and carcase triage

The strandings data collected by all organisations are combined and made available through the central CSIP UK database (available at http://ukstrandings.org/). Internationally standardised protocols are in place for post mortem examination (Kuiken and Garcia–Hartmann, 1991), and the process of data recording is largely harmonised across the CSIP organisations. Stranded carcases are individually assessed, and decisions taken on potential recovery for further examination based on a number of factors including the state of decomposition, accessibility, logistics and, with the exception of Scotland, prescribed limits on the number of carcases funded for necropsy.

While these protocols are in place, some geographical variation can be expected, with the individual consortiums working different operational strategies for carcase identification, triage and recovery. In general, attempts are made to maximise the amount of data that are collected per case. Scotland initiated a network of volunteers trained and coordinated by SMASS staff in 2014. Volunteers are particularly trained to record data of stranded marine mammals through provision of both photographic and accurate morphometric data, as well as the safe collection of a small set of tissues for age, genetic, isotope and toxicological analysis (teeth, skin, muscle, and blubber). Volunteers additionally assist with retrieval and occasionally transport carcases to a temporary storage facility or transport depot. In Cornwall, the CWTMSN also use dedicated volunteers to record data and photographs of strandings, and assist with carcase retrieval, facilitating post mortem examinations of suitable animals. No such formal network of trained individuals is operational in the rest of England or Wales, though carcase collection is assisted by various individuals and organisations such as local wildlife trusts, British Divers Marine Life Rescue (BDMLR) and Natural Resources Wales.

4.2 Data Preparation

Cases with a stranding location within the West Scotland and Celtic & Irish Seas harbour porpoise management units (IAMMWG 2015) were selected, starting at the border with the North Sea management unit at east Devon, to Cape Wrath in the north of Scotland, and including the Western Isles, the Isle of Man, the Scilly Isles, and the coast of Northern Ireland (Figure 1). To ensure equal temporal coverage across all areas, stranding records were selected from the first full year of the most recently initiated CSIP consortium, until the last full year of complete data collection available at the time of producing this report. This resulted in data from the last 26 years (period of 01-01-1992 to 31-12-2017). Records used for the analyses included, at a minimum, information on stranding date (day, month, year) and location. Cases that were assumed harbour porpoise but recorded as “species uncertain” were not included, leaving only animals that were confirmed as harbour porpoise. Animals that were reported as floating offshore were excluded. A subset of this final dataset was made for each analysis based on the requirements of the particular questions being addressed, as is further described in section 4.3 below.

Additional metadata on sex, length and/or age class, cause of death, and body condition indicators were included where available. Body condition was inferred from data on length, and weight. Data were checked for missing values and outliers. Where outliers were detected it was checked whether these were due to incorrect data entry, and values were corrected where possible. If the source of the outlier could not be traced the value was treated as “unknown”.

4.2.1 Region assignment

Harbour porpoise demographics are driven by ecological and environmental processes which are largely independent of the national borders or management units; yet for impact assessment and conservation purposes it is sensible to divide the UK west coast into smaller sections (IAMMWG 2015). For the analyses in this report, the coastline was divided in four different regions, taking into account national borders as well as management units (Figure 1). In absence of carcase drift models, for the purpose of allowing interpretation of the data in this report it was assumed that while movement between regions is plausible, animals stranded within a particular region had likely died within that region (a similar assumption was also used in Fontaine et al (2017) and is supported by Peltier et al (2012)). We acknowledge that this assumption is not without caveats, as is further discussed in Section 6.5.

The four regions comprised of:

A. Atlantic; including the north and north-east coast of Northern Ireland and excluding the south coast of Dumfries & Galloway (blue)
B. North Celtic; including the English mainland north of Wales, the south east coast of Northern Ireland, the Isle of Man, and the south coast of Dumfries & Galloway (green)
C. Wales; including the entire Welsh coastline (red)
D. South; including the English coast south of Wales and the Scilly Isles (orange)

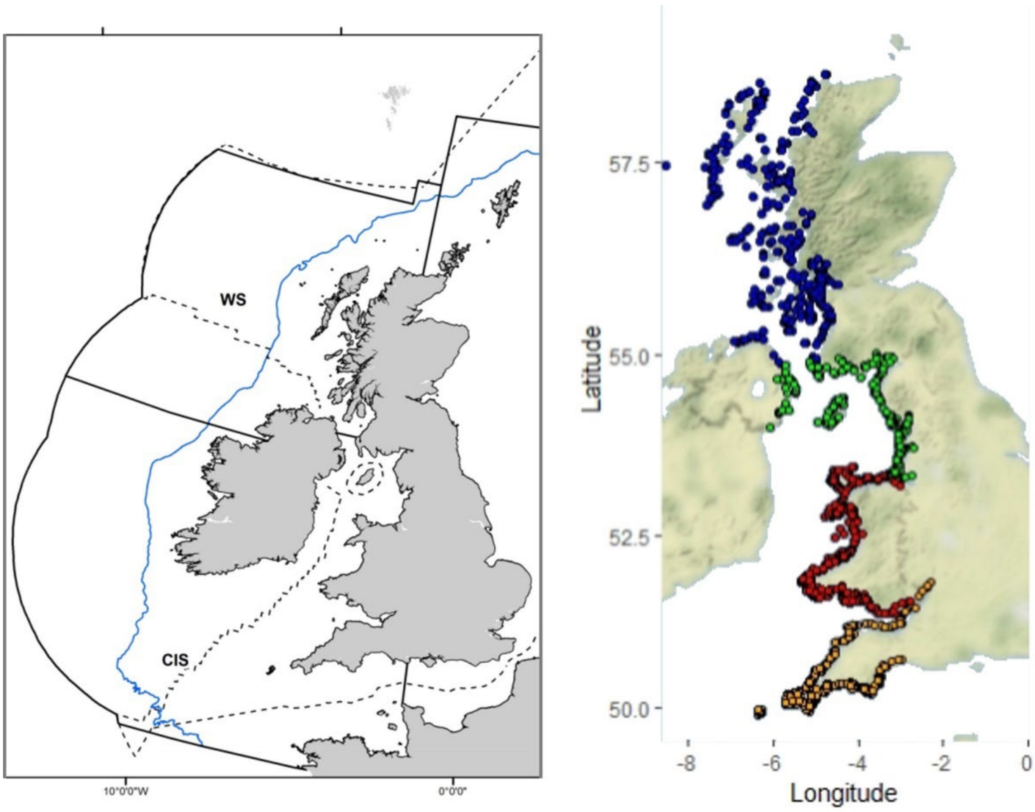

Figure 1: *Left*: UK management units for harbour porpoise (CIS Celtic/Irish Seas, WS West Scotland, taken from (IAMMWG, 2015).The UK EEZ is indicated by the dotted line, the 200m depth contour is indicated with a blue line. *Right*: Map showing all harbour porpoise strandings ok the UK West coast 1992 – 2017. Colours are representative of the regions Atlantic (blue), North Celtic (green) Wales (red) and South (orange)

4.3 Data analyses

Data exploration was applied following Zuur *et al*. (2010) prior to each analysis, with data being checked for outliers, heterogeneity of variance, and collinearity. All data exploration and analyses were performed using R version 3.5.1 (R Core Team 2018). Statistical significance was accepted at $p<0.05$.

4.3.1 Spatiotemporal analysis

The analysis examined baseline seasonal variation as well as long term temporal trends in stranding frequencies of harbour porpoise on the West coast of the UK. This was to determine whether a seasonal pattern of strandings exists for the individual regions, which can possibly be used as a baseline for future monitoring of unusual stranding frequencies. Annual totals were assessed for long term trends in stranding frequencies, possibly indicative of changes in mortality rate.

Maps of the study area were created using the ggplot2 (Wickham 2009) and ggmap (Kahle & Wickham 2013) libraries available in R. Kernel density estimation was performed using the stat_density_2d function integrated within ggmap, which estimates the underlying probability density function of a stranding at a particular location. To facilitate data interpretation and visually assess potential shifts in strandings density distribution, the study period was divided into five time periods; 1992-1997; 1998-2002; 2003-2007; 2008-2012; and 2013-2017. These maps were also created taking only cases that were reported as freshly dead or with slight decomposition (code 2.1 and 2.2, see section 4.3.4) into account, to assess the strandings density distribution of fresh cases along the west coast.

A Generalised Additive Mixed Model (GAMM) was used to examine seasonal variation in stranding frequencies, using the nlme (Pinheiro *et al*. 2018) and mgcv (Wood *et al*. 2016) packages available in R. GAMMs allow the modelling of non-linear relationships and nested data structures and have previously been used for other areas of the UK (ten Doeschate *et al,*. 2017). Stranding reports from Northern Ireland, the Scilly isles, and the Isle of Man are collected on an ad-hoc basis in absence of a dedicated strandings coordination scheme. To ensure this would not confound results, only cases on mainland UK were selected resulting in a total of n = 4210 individuals included in this analysis. A count of number of strandings was modelled as a function of month to capture a potential seasonal effect; year to examine long term trends; and regions as described above to assess spatial differences. Models were fitted using a Poisson error distribution with a log-link function, and the appropriate level of smoothness was found by utilising the integrated smoothness estimation and cross validation function within the mgcv library in R. Autocorrelation can be expected in time series data, and this was assessed following the model fit. When detected through examination of residuals and (partial) autocorrelation plots, this was further assessed and correlation structures tested and added if required. Model selection was carried out by comparing different forms of inclusion of the variables month, year, and region applied through a backwards model selection process. Data exploration indicated that there is likely seasonality in all regions, but patterns were not identical across regions and interactions between the three variables were therefore considered in the model selection. The model structure best describing the data was identified through examination of scaled residuals, parameter estimates, and evaluation of the Akaike Information Criterion (AIC, Akaike 1974). Model validation was therefore carried out by evaluating diagnostic plots and residual variance using normalised Pearson residuals to verify underlying model assumptions and evaluate model fit. The residual scaled deviance to the residual degrees of freedom-ratio was calculated to examine possible over - or under dispersion.

4.3.2 Biological parameters

This analysis assessed the composition of the stranded population in terms of biological parameters, focussing on sex and age variables (using length as a proxy for age (class) in absence of absolute ages for the majority of the dataset). This provides insight into the population structure of harbour porpoise on the West coast of the UK.

Individuals were categorised into age groups based on their total body length, measured in a straight line parallel to the carcass from the tip of the lower jaw to the notch in the tail fluke, in cm. Length was recorded as certain for 2543 individuals. Porpoises <90 cm were classed as neonates, 91 to 130 cm considered juvenile, and >130 cm classed as adults (Lockyer 2003; Lockyer *et al.,* 2001). For some animals no accurate measurement information was available, yet a small selection of these were classified into an age group by the operating stranding scheme if there was enough evidence available (for example, animals were classed as neonates when vibrissae were present, or as adult when they were found pregnant). To exclude the influence of outliers, length data was truncated from 60cm (the reported minimum length at birth for harbour porpoise, Lockyer (2003)) to 180 cm, resulting in a subset of n= 1935 cases. Cases with an unknown length and/or age class were not included in this analysis. Sex was recorded for 1137 individuals upon postmortem, and an additional 1261 from either assessment of available photographs or when this was established by an experienced volunteer, resulting in a total of 2398 individuals with a known sex.

Sex ratio and age class composition were assessed per region and per year. Regional proportions were calculated and the distribution of age classes and sex ratio was examined to assess whether there are spatiotemporal differences in the composition of stranded animals along the UK’s west coast, possibly indicating population structure and areas of importance for biological processes such as reproduction.

These data were further analysed using generalised linear models (GLM) fitted with a binomial error distribution and logit link. Sex (recorded as 1 for males and 0 for females) was modelled to examine sex ratio as a function of body length (as a proxy for age), month to examine seasonal differences, year to assess potential long-term changes over time, and region to evaluate potential heterogeneity between regions. Model selection was carried out by comparing different model specifications including interaction terms, by means of a backward stepwise selection using the AIC to select the optimal model. Model validation was applied to verify the underlying model assumptions by evaluation of calculated dispersion parameters and diagnostic plots using Pearson residuals. Individuals for which a length was unknown or reported as “uncertain” were not included in this analysis.

4.3.3 Causes of death

Animals that had undergone post mortem examination were selected for this analysis (n=1144). Only a small number of animals were sent for necropsy in the North Celtic region compared to the other regions, hence the decision was made to combine these data with the Atlantic region. This resulted in the data being separated into three areas; the North, Wales, and the South.

4.3.4 Post mortem examinations

Carcases were routinely transported to the pathology laboratory of the operating stranding scheme for necropsy. All cetacean post-mortem investigations were conducted using standard procedures (Kuiken and Garcia Hartmann 1991, Deaville and Jepson *et al.,* 2011). Following this protocol, standard measurements are taken and a decomposition code is assigned to each carcase following the criteria established by Geraci and Lounsbury (1993). This system ranks carcases with code 2.1 being fresh cases, code 2.2 being cases with slight decomposition, code 3 representing cases in moderate decomposition, code 4 being cases in advanced decomposition and ‘NE’ indicating cases where decomposition status was not recorded.

Organs were systematically examined and routine tissue samples were collected for virological, microbiological, histopathological, and toxicological screening. Any observed lesions were also sampled for further diagnostic tests, depending on the suspected aetiology. These collective findings from post-mortem and other diagnostic investigations result in the assignment of a most probable cause of death for each individual case. The lead CSIP scientist and pathologist Dr Paul Jepson validates causes of death of all stranded animals examined at post-mortem in the UK on the basis of the post mortem information supplied by the individual consortiums. Causes of death may be amended and/or altered if new test results are generated or data becomes available, with an audit trail of amendments automatically recorded on the CSIP database.

4.3.5 Anthropogenic causes of mortality

Long term trends and spatial variation in anthropogenic causes of mortality were examined by focussing on direct-anthropogenic versus other causes of death. For this analysis, data on cause of death was therefore re-classified into those two categories. Only cases that were confirmed as acute direct mortality due to anthropogenic causes were assigned to the anthropogenic category, which included the following diagnoses:

- **Bycatch:** entanglement in fishing gear. This included cases that were known bycaught (reported by fishermen) or diagnosed on necropsy using established pathological criteria for by-catch diagnosis

- **Boat/ship strike:** physical trauma consistent with impact from a boat or ship. Includes blunt trauma to dorsal/lateral aspect of body wall and/or injuries consistent with propeller strike

Cases where the cause of death was indefinite (pending further ancillary tests to be done), or where mortality was attributed to either chronic or potentially multifactorial anthropogenic effects (eg contaminant burdens, prey depletion or climate change) were classed under the “other” category. As such, the results from this analysis should be interpreted as representing the minimum estimate of anthropogenic mortality.

Remaining cases that were categorised as “other” included (in alphabetical order): Dystocia, Gas embolism, Gastritis and/or Enteritis, Generalised Bacterial Infection, Generalised Mycotic Infection, Live stranding, Maternal separation/neonatal starvation, (Meningo)encephalitis, Neoplasia, Others (single unusual cases of non-direct anthropogenic origin), Physical Trauma (unknown origin), Physical Trauma following Bottlenose Dolphin Attack, Physical Trauma following Grey Seal Attack, Pneumonia, Starvation, and cases where a cause of death could not be established.

4.3.6 Body condition

This analysis focussed on spatiotemporal heterogeneity in body condition of harbour porpoise on the West coast of the UK.

Animals that were subjected to post mortem examination were selected for this analysis. Only a small number of animals were sent for necropsy in the North Celtic region compared to the other regions, hence the decision was made to combine these data with the Atlantic region, as also described under section 4.3.3. Data on body condition parameters used for this analysis included information on length (measured as stated in section 4.3.2) and weight in kg.

Body condition is commonly estimated through the calculation of indices based on relationships between certain measurable morphometric parameters (Kershaw *et al*, 2017). For smaller cetaceans like the harbour porpoise, a basic index of weight and length is thought to be the most appropriate for explaining variation in body condition as a metric to assess fitness of individuals (Pettis *et al*., 2004). Data on either weight or an accurate length were not available for 99 animals (36 from the North, 50 from Wales, and 13 from the South) that were sent for post mortem, resulting in a subset of 1045 cases that were included in this analysis. Power regression models were used to fit regression lines to data from each region individually, examining spatial differences in the relationship between body mass and body length. An analysis of covariance (ANCOVA) was then performed to test the significance of potential differences in the slopes and intercepts among regression lines. For the ANCOVA, a natural log transformation was applied to both the length and the weight data to ensure the underlying model assumptions of linearity and a normal residual error distribution were met. A backwards stepwise selection process was used to obtain the most parsimonious model best describing the data.

The residuals from this final model were then extracted per region and used as a proxy for body condition. Cases with a value above the model fit were considered to represent animals in a good body condition, and individuals with values below the model fit representing cases in poorer body condition. To assess spatiotemporal variation in body condition as a proxy of fitness of harbour porpoise stranded on the UK West coast, residual spread was visually examined for between year variation per region, as well as for seasonal variation for each region individually.

5. Results

Results are given per individual analysis and discussed in section 4 below.

5.1 Spatiotemporal analysis

A total of 4329 harbour porpoise strandings were recorded on the UK's west coast from 1992 – 2017. These comprised 617 (14.3%) from the Atlantic, 613 (14.2%) from the North Celtic, 1990 (46%) from Wales and 1109 (25.5%) from the Southern area. Stranding frequencies varied greatly over the study period (Figure 2). Annual totals slowly increased until 2001 when a steeper increase was observed annually with a peak of 354 animals in 2004. Annual numbers then slowly decreased, varying between roughly 140 and 190 animals between 2007 and 2015. Higher numbers were observed again in both 2016 and 2017 with 253 and 310 strandings respectively. Wales consistently has a higher number of strandings throughout the study period compared to the other regions (Figure 2Figure 2 & Figure 3Figure 3). The South followed a similar trend to the Atlantic and Northern Celtic regions, until 2002 when higher numbers were observed for this region annually. The peak observed in 2004 was mainly driven by an increase of strandings in the South and the two northern regions, with Wales contributing a smaller proportion to the annual total that year.

Mapping the stranding records according to five or six-year intervals (Figure 4) additionally shows that while the highest density of strandings are consistently recorded in Wales, there has been some spatial variation in strandings density during the study period. A higher number of strandings were observed in Northern England, Cornwall, and the Clyde area in Scotland in the previous five years compared to the earlier years of the CSIP. The density of fresh cases showed an almost identical pattern, and the maps showing the strandings density according to the five or six-year intervals can be found in Appendix 4.

There is a high density of strandings in the Cardigan bay region, accounting for 56% of the Welsh, and over 25% of all harbour porpoise strandings on the entire western coastline of the United Kingdom (Figure 5).

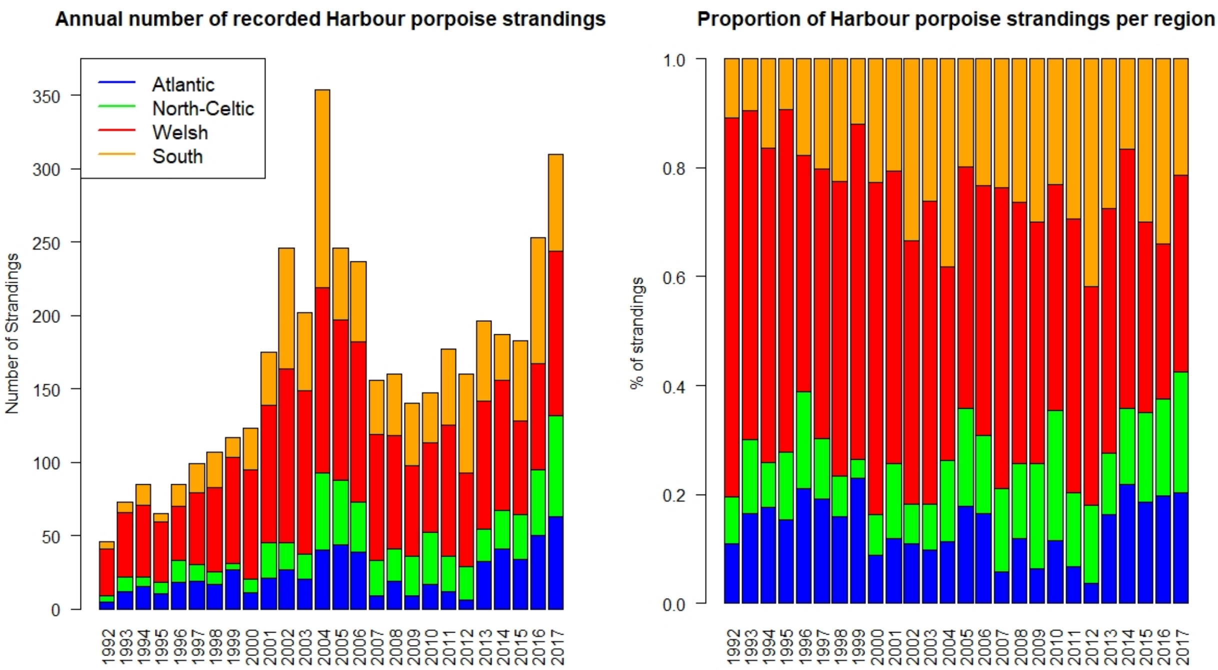

Figure 2: *Left*; stacked barchart with total number of stranded harbour porpoises in the entire study area per year, stacked per region. *Right*; stacked barchart showing the proportion of strandings per region per year.

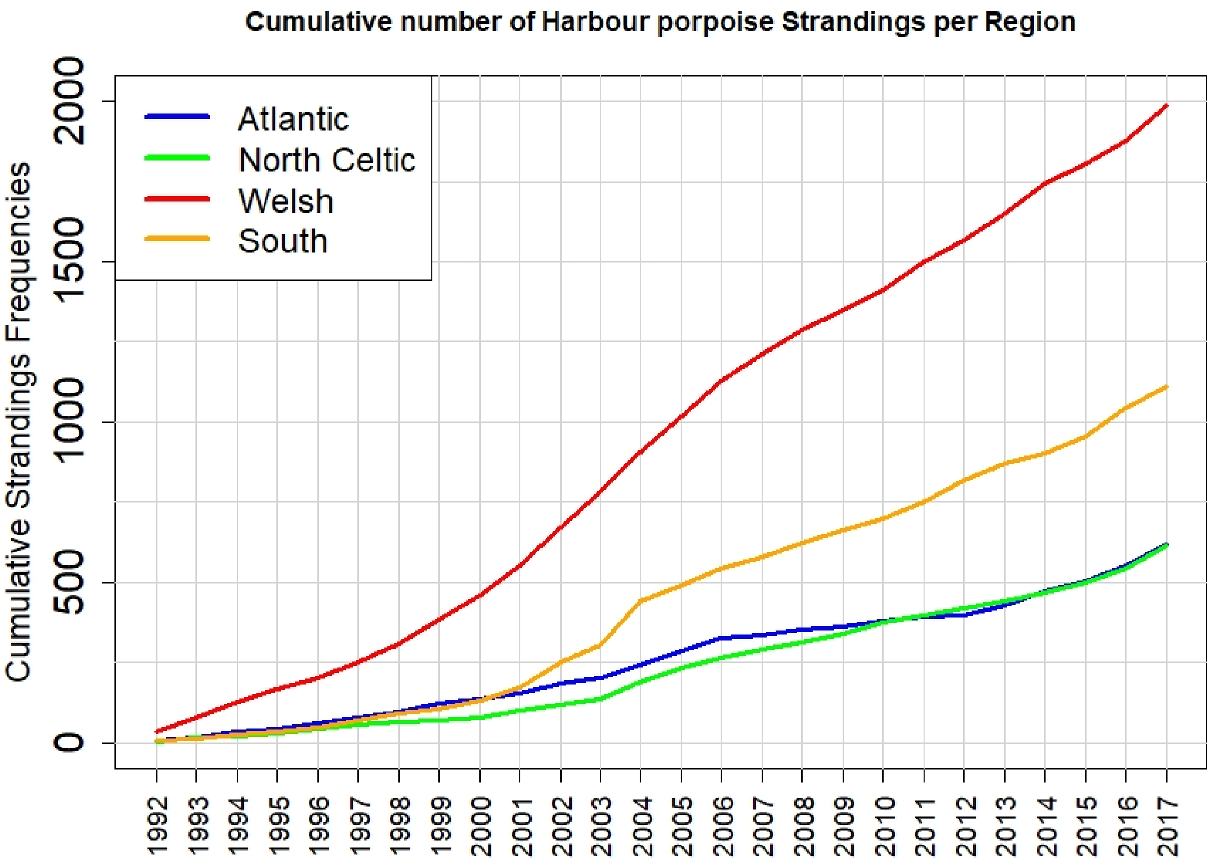

Figure 3: Cumulative number of stranded harbour porpoises per region over the study period

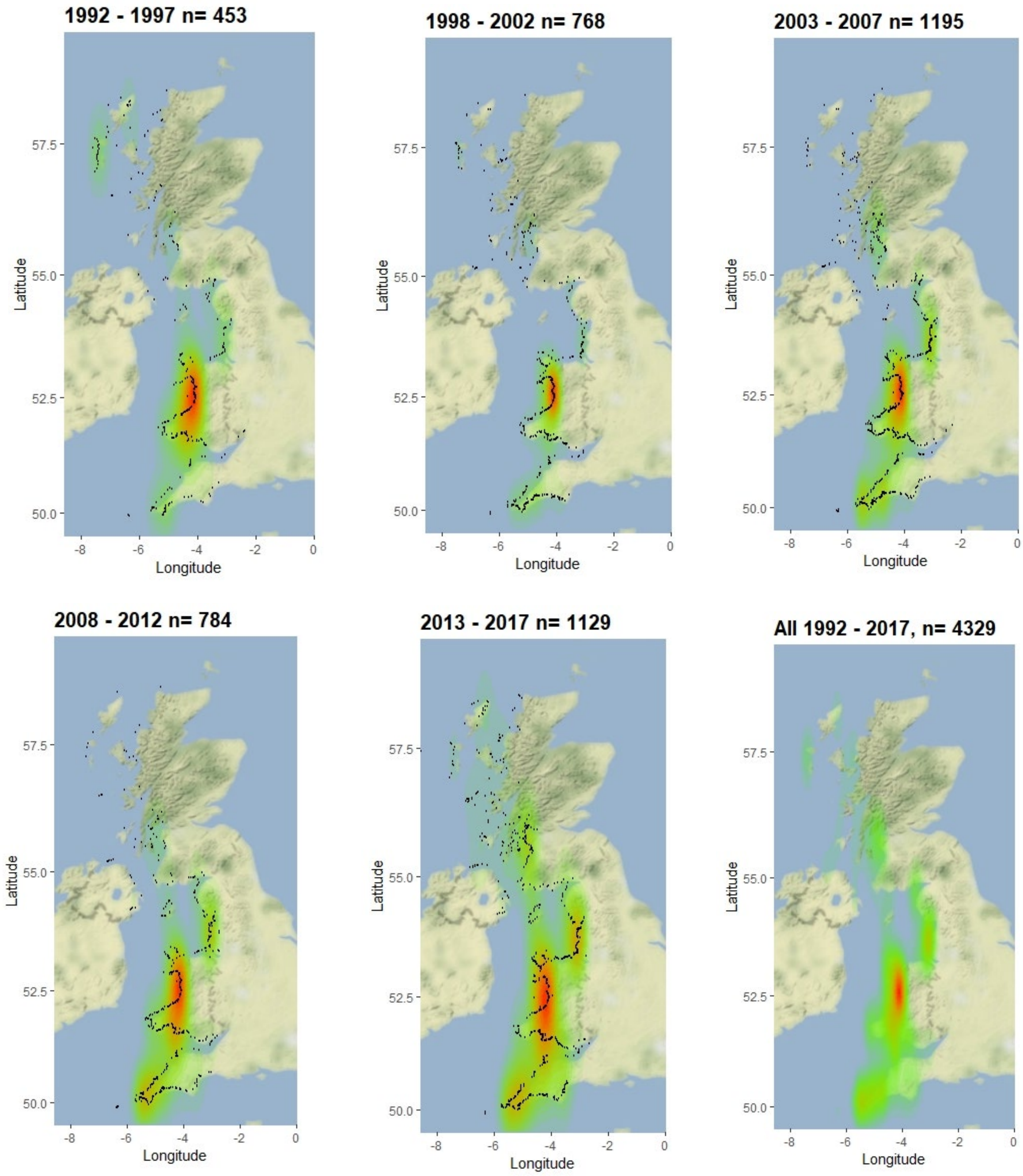

Figure 4: Study area showing the distribution density of harbour porpoise strandings over five time periods (1992 – 1997, 1998 – 2002, 2003 – 2007, 2008 – 2012, and 2013 – 2017) as well as a map taking into account the entire study period 1992 – 2017. Red areas represent the highest density of strandings per time frame, the black points show individual strandings.

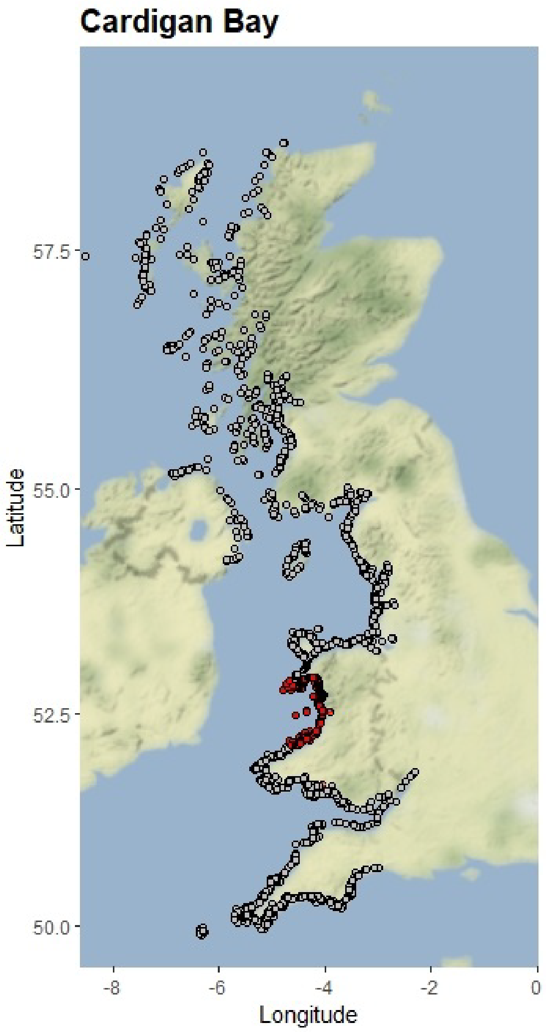

Figure 5: Cardigan Bay region in red, representing 25.8% of the total number of strandings of the western UK coastline between 1992 – 2017.

The monthly distribution of all stranding records is highly variable among years and regions (Figure 6). A table summarising the absolute and relative number of strandings is given in Appendix 1.

Monthly numbers in the Atlantic region were generally low and showed the least evidence of a clear seasonal pattern, with a relatively high between-year variation in monthly stranding frequencies. Similarly, low numbers were observed for the North-Celtic region, though a more consistent seasonal pattern is apparent with increasing numbers from May through to August, and autumn months being highly variable.

Porpoise strandings in the Welsh region have a well defined seasonality with an increasing number of strandings from April to a peak in June, after which numbers slowly decrease throughout the summer and autumn months to consistently low numbers from November through to March.

The Southern region shows an almost opposite pattern with the highest number of strandings from November to a peak in January after which numbers decrease to a more constant low throughout the summer months.

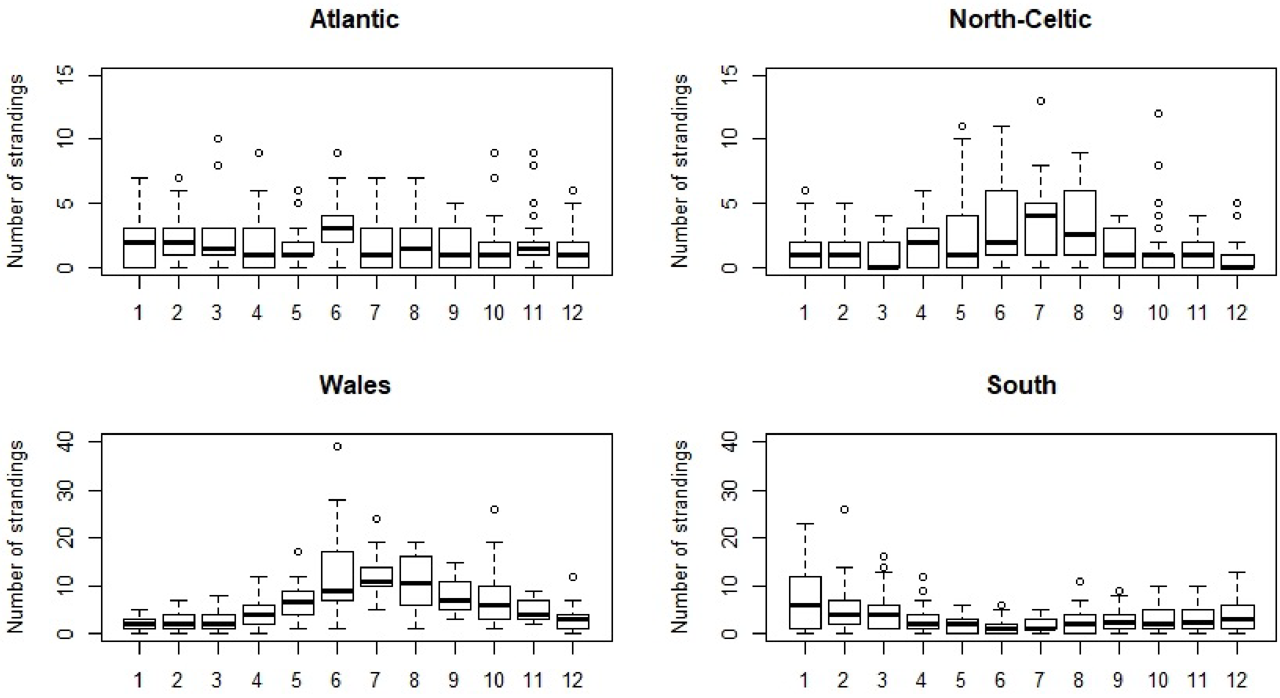

Figure 6: Boxplots showing monthly variation in strandings frequency per region. The median is indicated by the black line, the box is representative of the interquartile range (IQR, being the middle 50% of values between the first and third quartile). Whiskers represent scores outside the IQR with outliers being single points that are 3×IQR or more above the third quartile. Note the different y-axis for the two northern regions compared to the two Southern regions, where higher number of strandings were recorded annually.

5.1.1 Spatiotemporal models

This seasonality was further analysed using Generalised Additive Mixed Models (GAMM). Assessing the entire dataset collectively, the spatiotemporal model best describing the data incorporated a smooth seasonal effect per region, providing evidence that there is seasonality in stranding frequencies and that this pattern differs between regions (Figure 7). Evaluation and validation of this best-fit model indicated there was complex variation in the spread of residuals of both regions and years. Adding multifaceted variance structures to a GAMM is computationally intensive and often results in convergence issues (Zuur *et al*. 2007). To avoid these issues and not overcomplicate the model, it was decided to explore seasonality per region, and fit GAMM models for each region individually to allow assessment of deviations from the seasonal pattern per year (see ten Doeschate *et al* (2017) for details).

These individual regional models were fitted incorporating month of stranding fitted as a smoother (circular cubic spline) and including year as a random effect. These models thereby fix the seasonal pattern but permit for inter-annual variation in total numbers within this pattern. Figure 7 shows the estimated smoothing curves for each individual region model, on top of the scaled residuals for each month. The fit line represents the number of strandings for an average year as estimated by the model, and is indicative of the seasonal pattern in each region. These graphs show that while all smoothers were significant, the seasonal pattern was not very strong in the Atlantic and North Celtic region, but more clearly defined with less between-year variation in the Welsh and Southern regions (Table 1).

From this model, any change in the baseline seasonal pattern of strandings can be detected and quantified, by evaluation of the normalised model residuals. For each year, these should be centred around zero, with values outside the -2 and 2 confidence bands being considered lower or higher variation than expected by the model. Figure 8 shows this for the Welsh region, where points outside the dotted confidence bands can be considered variation outside the normal seasonal pattern (ten Doeschate *et al.*, 2017). There are a number of months in particular years where numbers were higher or lower than expected by the model, including June 2002, October 2004, and October and December 2017.

These residual graphs are made available for the remaining regions in Appendix 3.

Table 1: Results of the GAM model for the number of strandings modelled as a smooth function (circular cubic spline) of month with a random intercept for year for each individual region. Table values show parametric coefficients (top table), the estimated degrees of freedom of the smoother (edf), and results from an F test of the significance of the smoothing effect (bottom table). The variance of the random intercept for year indicates the between year variation; higher values meaning more variation between years. The r² value is an adjusted value indicating the approximate variance explained by the model.

Parametric coefficients:

Region	Estimate	Standard Error	T	P	Variance random intercept Year
Atlantic	0.4727	0.12	3.86	<0.001	0.568
North Celtic	0.1921	0.13	1.38	0.16	0.646
Wales	1.6491	0.07	22.63	<0.001	0.343
South	0.9472	0.15	6.284	<0.001	0.732

Smooth terms

Term	edf	F	p	r^2
Atlantic	3.055	1.47	<0.001	0.02
North Celtic	4.733	21.37	<0.001	0.18
Wales	6.048	60.81	<0.001	0.39
South	5.984	21.96	<0.001	0.09

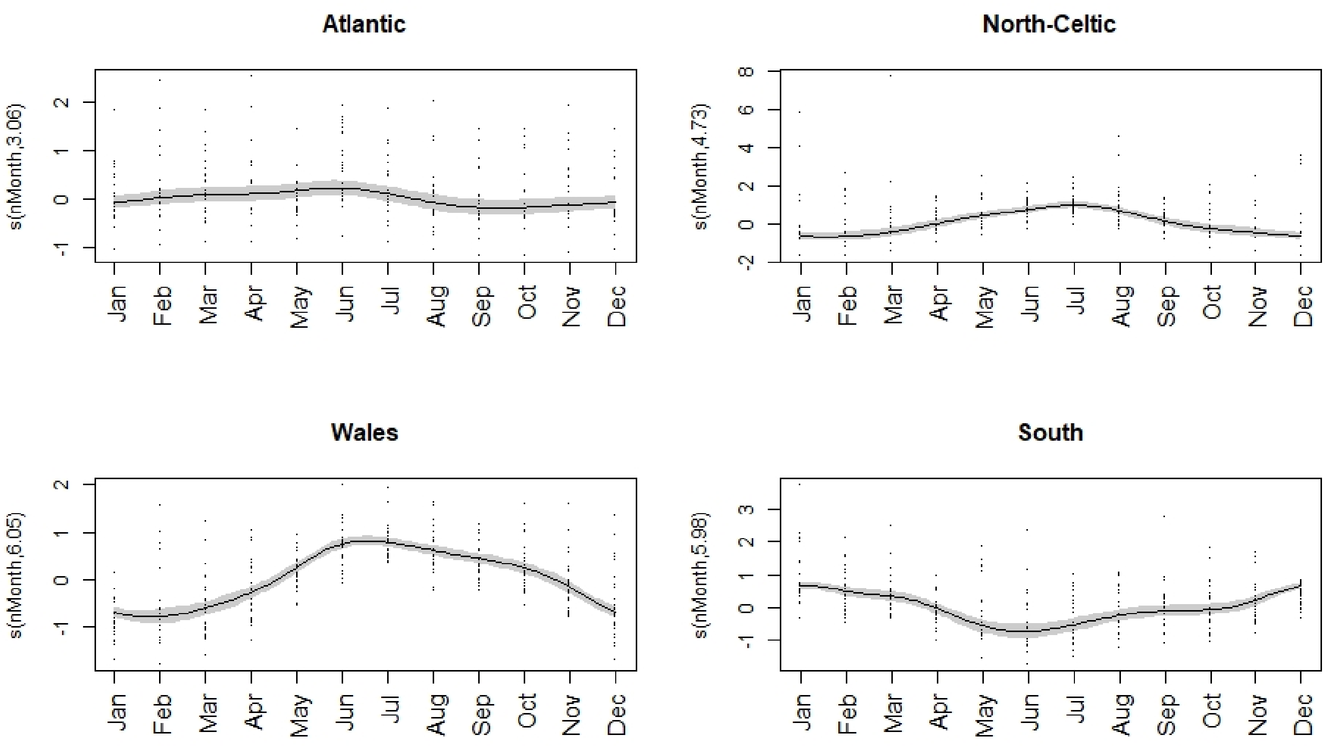

Figure 7: Estimated smoothing curves for the model incorporated a smoother for month for each region individually, showing seasonal patterns in number of strandings for an average year as estimated by the models. The shaded areas are 95% confidence bands and the points represent residual spread around the average pattern.

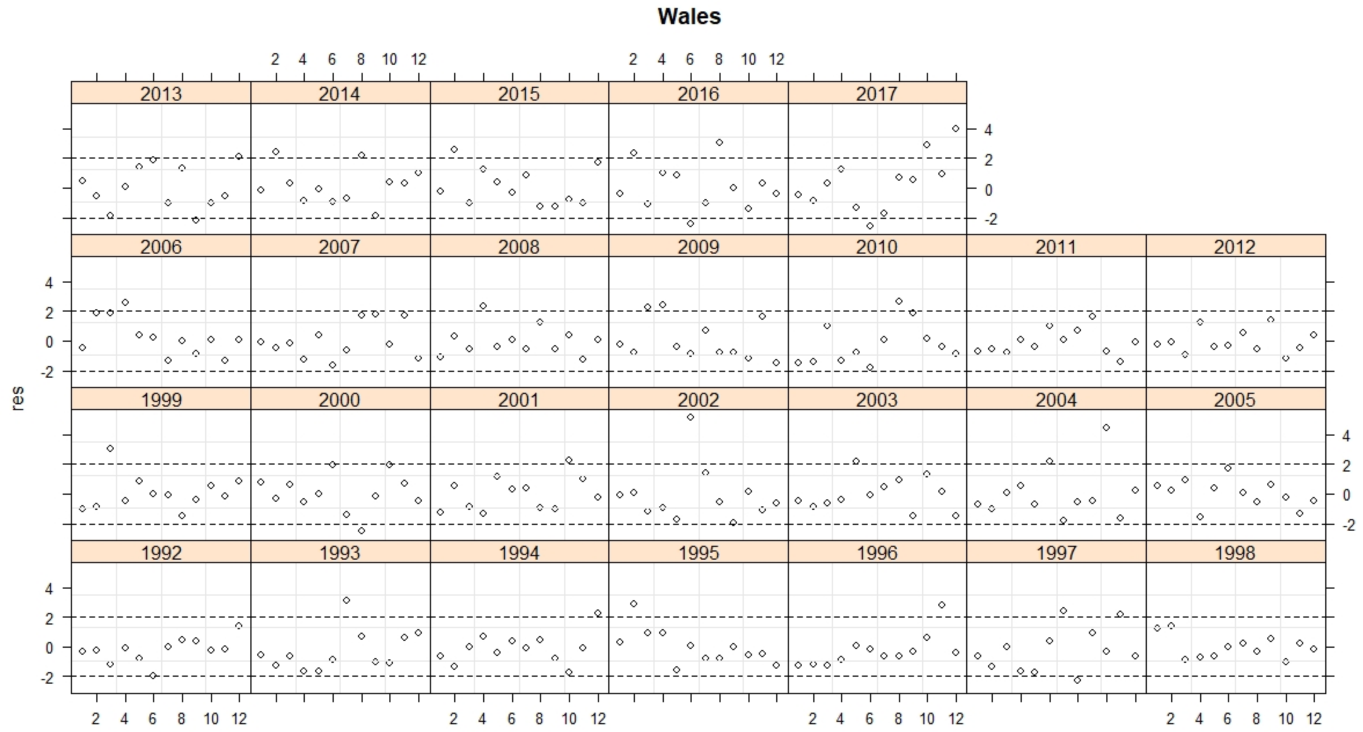

Figure 8: Pearson residuals extracted from the GAMM for the Welsh region, showing residuals per month for each year. The months are displayed on the x-axis, with residual variation indicated on the y-axis. For each window (year), points should be centred around zero, with values outside the -2 and 2 confidence bands being considered lower or higher variation than expected by the model.

5.1.2 Section summary of spatiotemporal analysis

- A total of 4329 harbour porpoise strandings were recorded on the UK's west coast from 1992 – 2017. These comprised 617 (14.3%) from the Atlantic, 613 (14.2%) from the North Celtic, 1990 (46%) from the Welsh and 1109 (25.5%) from the Southern area.
- The majority of the strandings are consistently found in Wales and particularly the Cardigan Bay area, to the extent that this area accounts for 25.8% of all harbour porpoise strandings on the West coast of the UK.
- There is region specific seasonality in strandings frequency.
- For Wales the seasonality was strongest, with peak numbers being observed from May through to October
- By using Generalised Additive Mixed Models to quantify this seasonality, any change in the baseline pattern of strandings can be detected and quantified

5.2 Biological parameters

Sex was recorded for a total of 2398 individuals (55.5%), comprising of n=1231 males and n=1167 females in the entire dataset. Age class was known or identified for 2981 individuals (68.9%) comprising n=376 neonates, n=1281 juveniles and n=1324 adults, leaving n=1348 cases with unknown age class. A breakdown of these numbers per region is given in Table 2, and an overview of sex and length data availability as proportions per region is presented in Figure 9.

Table 2: Summary of number of cases available for assessment of sex (females, males, unknown) and for the different age classes (adult, juvenile, neonate, unknown) per region.

Region	**Region total**	Sex: Female	Sex: Male	Sex: Unknown	Age class: Adult	Age class: Juvenile	Age class: Neonate	Age class: Unknown
Atlantic	**617**	175	167	275	228	218	47	124
N-Celtic	**613**	105	121	387	183	212	52	166
Welsh	**1990**	613	605	772	509	524	233	724
South	**1109**	274	338	497	404	327	44	334
Total	**4323**	1167	1231	1931	1324	1281	376	1348

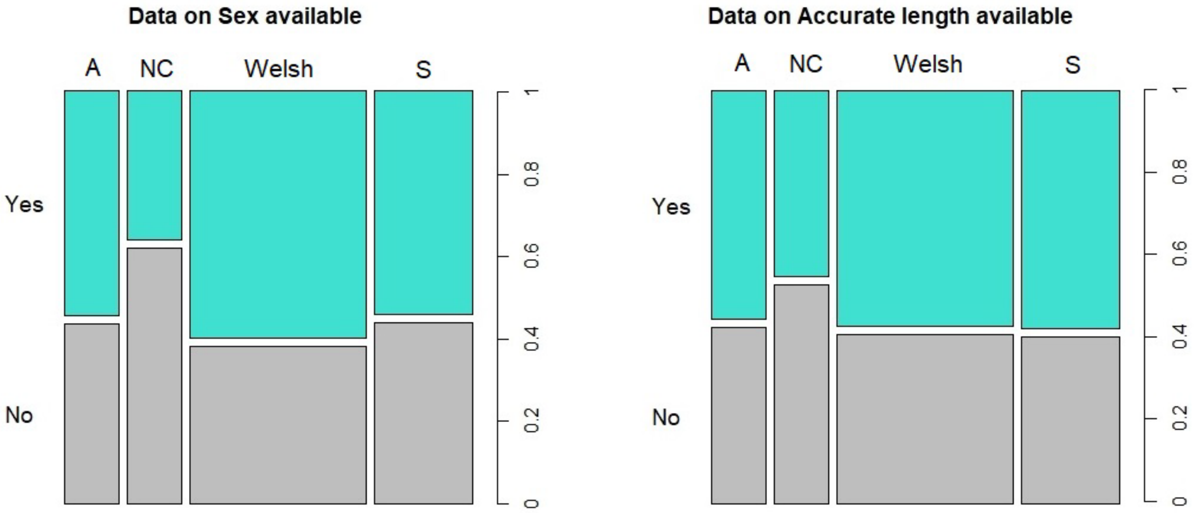

Figure 9: Mosaic plots of data availability for sex and accurate length (as a proxy for age) presented as proportions per region. The turquoise regions represent data available, grey means data was not available. The width of the bars reflects the total number of porpoises in the individual areas proportional to the West coast total. It should be noted that these are based on data being present and do not include a confidence metric. Only cases where the length was recorded as certain by the operating stranding scheme were considered

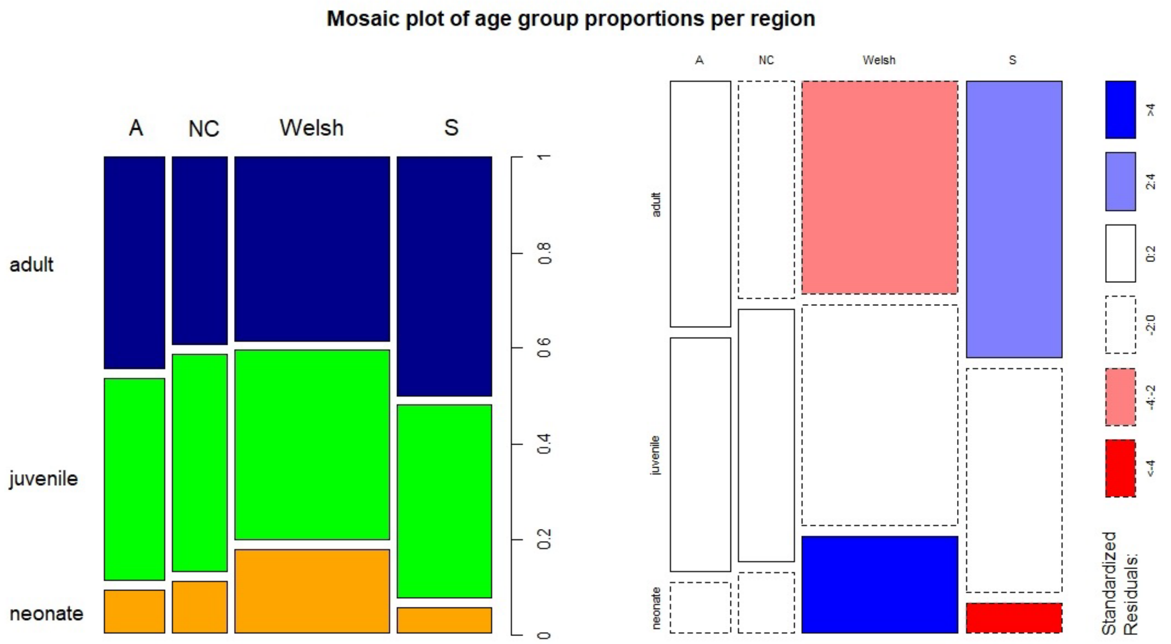

Figure 10: *Left:* Proportion of animals in each age group of which the age class could be determined per region. The width of the bars reflects the total number of porpoises in the individual areas proportional to the West coast total. *Right:* Mosaic plot of independence, coloured by departures from the assumption that the distribution of age groups are not associated to region. A residual value greater than 2 or less than -2 represents a significant departure from this assumption with blue meaning there are more observations than would be expected, and red showing groups with fewer observations than would be expected if age group and region were not associated.

5.2.1 Age-class results

The proportions of age classes (neonate, juvenile, adult) were calculated per region, corrected for the number of available cases for which this information was available (Figure 10). Wales was found to have a significantly higher proportion of neonate individuals compared to the other regions, where the South showed a higher proportion of adult strandings and a significantly lower proportion of neonates compared to the other regions. It should be noted that as these data are assessed proportionally with a limited number of categories, a decrease in one age group is usually reflected by an increase in another.

Figure 11 shows the distribution of lengths of the stranded harbour porpoise population per region, with density lines for each sex. Length was binned at 10cm intervals. The sex ratio appears to be relatively equal for all regions. Females tend to grow larger than males in harbour porpoises (Lockyer 2003), and this is reflected here with the largest individuals being female in all regions. The Atlantic and North Celtic region both have a higher number of animals between 115 – 125cm as well as adults at 145 – 155cm, compared to other lengths. Within Wales there is a relatively equal distribution of all lengths (and therefore age groups). The Southern area has a relatively equal distribution of animals between the lengths of 115 – 155cm, and only a very small number of small (neonatal) individuals, especially when compared to the other regions.

In the Atlantic region, adults are relatively equally spread throughout the year (Figure 12). Juveniles are less evenly distributed with more stranded juvenile individuals being found in March and April compared to the rest of the year (Figure 12). In the North Celtic and Welsh regions a higher density of adults was found in summer months from June to October compared to the rest of the year. The seasonal distribution of strandings of adults and juvenile individuals is similar for the Southern region. A separate density distribution for neonates was created to assess whether the calving season is similar across the entire west coast (Figure 13).

Overall, calves are found from May through to November, and some variation between regions can be detected (Figure 13). In the Atlantic region, the highest incidence of neonate strandings is June, with only a very small number being recorded throughout the rest of the calving season. A small number were reported in autumn months (September to November), whereas neonate strandings are largely absent in the other regions in those months. The North Celtic region has a wider distribution from May to August, with the majority of neonate strandings being found in July and August. In Wales neonates are found stranded between May through to October, though the majority are found between June and August. The Southern region only had a small number of neonates compared to other regions and age classes. The majority of neonatal strandings here are recorded in May, and a low number is found June through to August.

It should be noted that these graphs were based on age classes that were classified on length data only. Secondly, the total number of neonate individuals is generally low, and variable between regions, and results should therefore be considered an indication only.

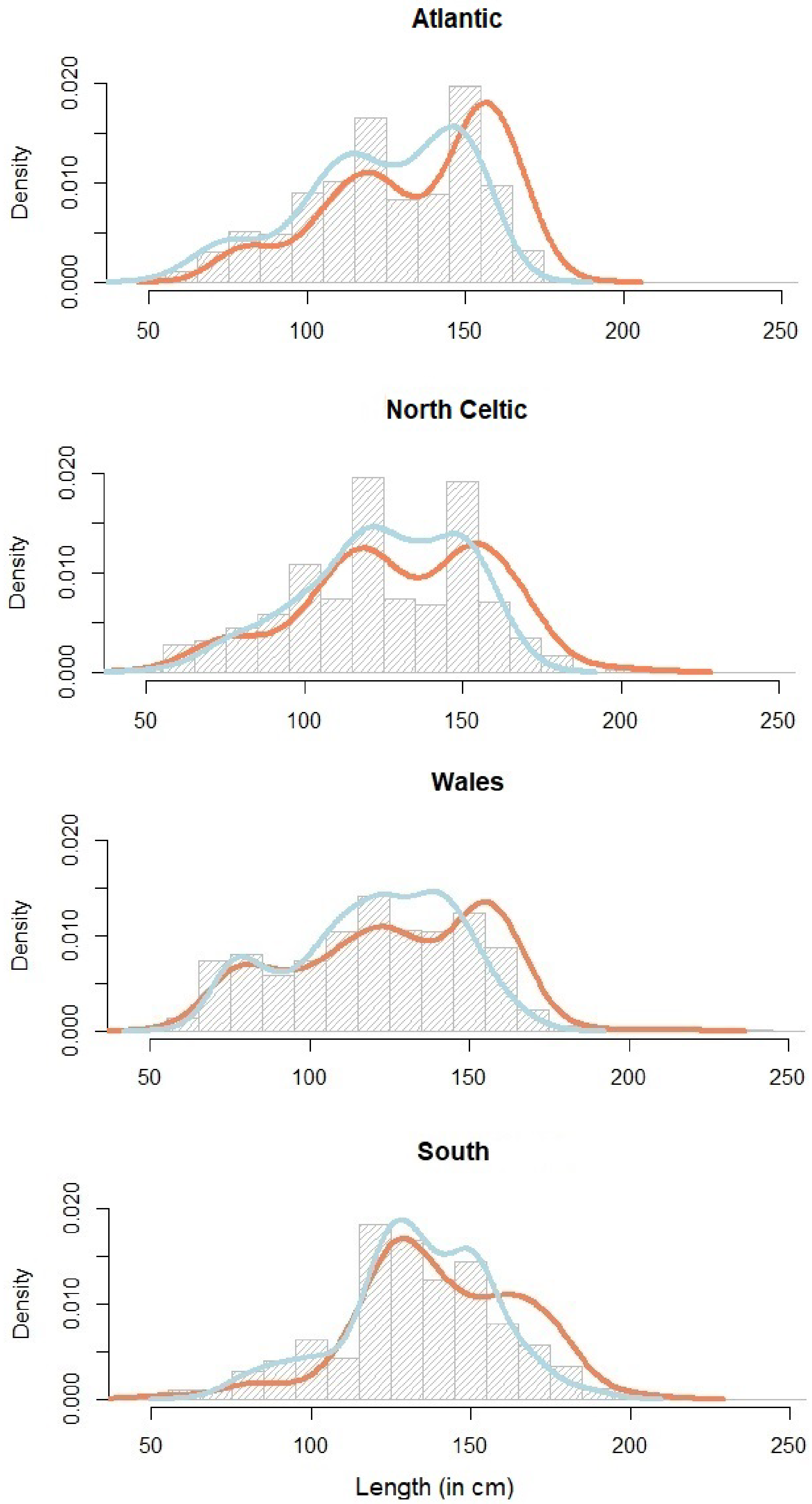

Figure 11: Density distribution of total length (in cm) of stranded population per region, with density lines for sex if this was known (see table 2). The orange line represents the distribution of females and the blue line represents the distribution of males over the length axis.

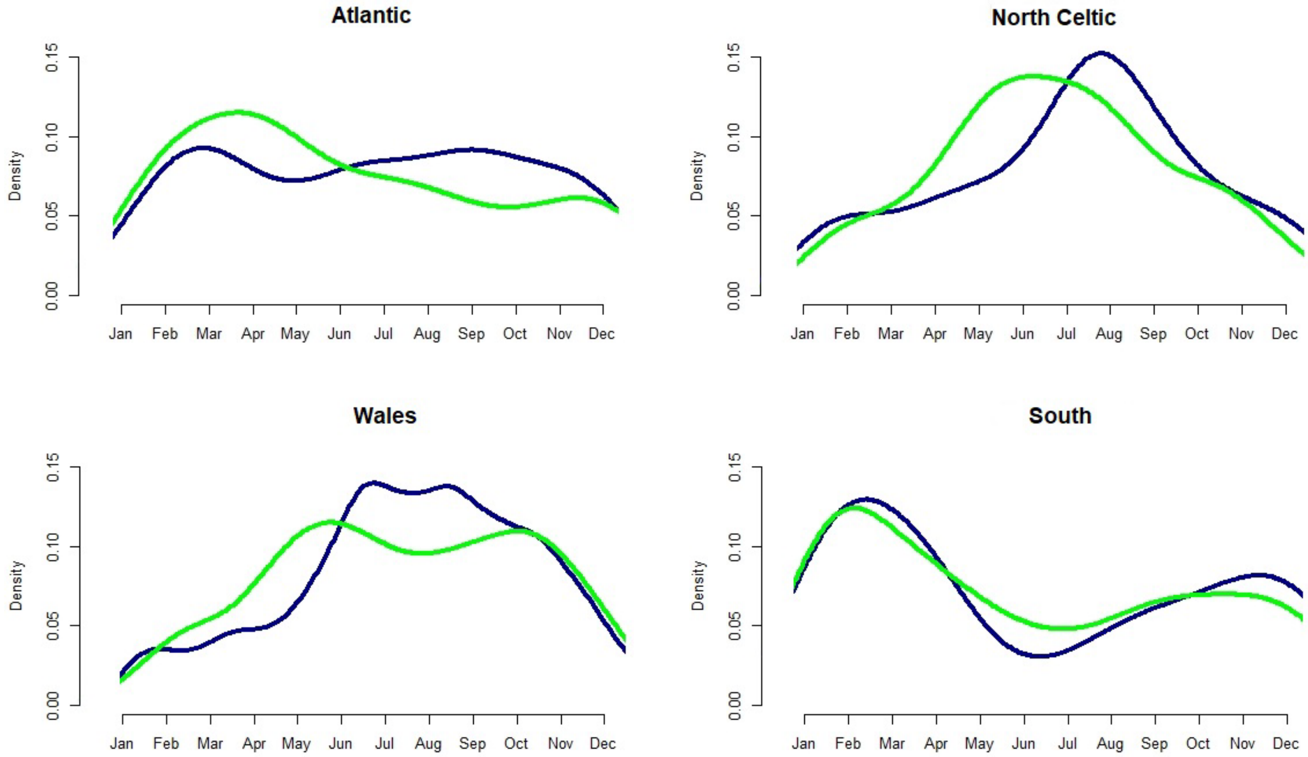

Figure 12: Density distribution of juveniles (green line) and adults (blue line) throughout the year for each region. Neonatal individuals were excluded from this graph.

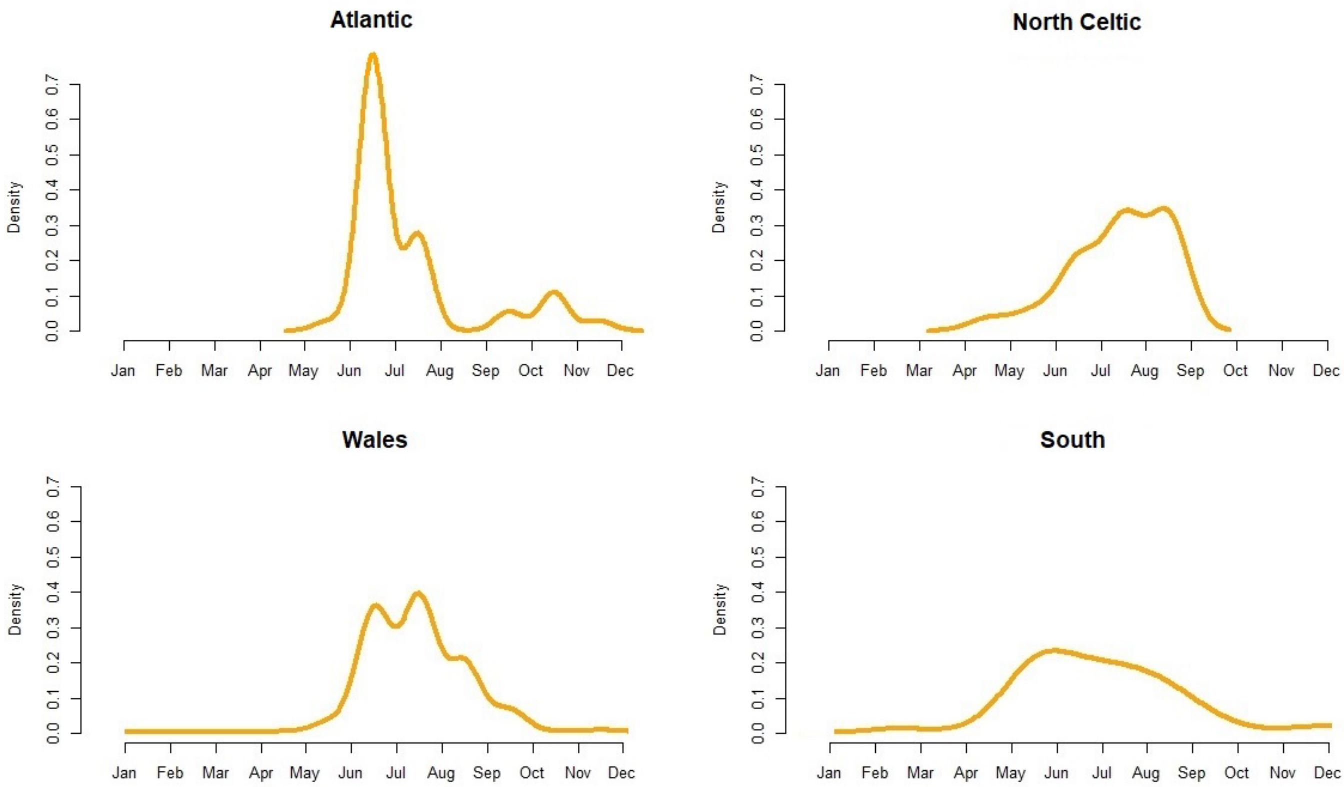

Figure 13: Density distribution of neonatal individuals (length <90cm) throughout the year for each region

5.2.2 Sex ratios

The composition of the stranded population in terms of sex ratio was examined in relation to length, age, month and year, to explore whether there was heterogeneity in biological parameters possibly indicative of stratification of the harbour porpoise population on the UK’s west coast. The optimal model included length and region, providing evidence of a significant relationship between sex and age and a different intercept for this relationship per region. Both month and year were not significant in explaining the difference in sex ratio, indicating that this relationship has been consistent over the study period. Results are visualised in Figure 14. For all regions the probability of a stranded porpoise being male is higher (>50%) in neonatal individuals, while an approximate equal distribution of males and females is found for animals of juvenile length (between 91cm and 130cm). The probability of a larger individual being female was higher for all regions. In Scotland, the probability of a harbour porpoise stranded on the coast being a female was higher for all animals larger than 125cm, indicating that the majority of adult individuals stranded there are female. An approximate equal distribution of males and females was found for all adult and even the larger lengths in the Southern region, indicating that males also grow to larger lengths in the south.

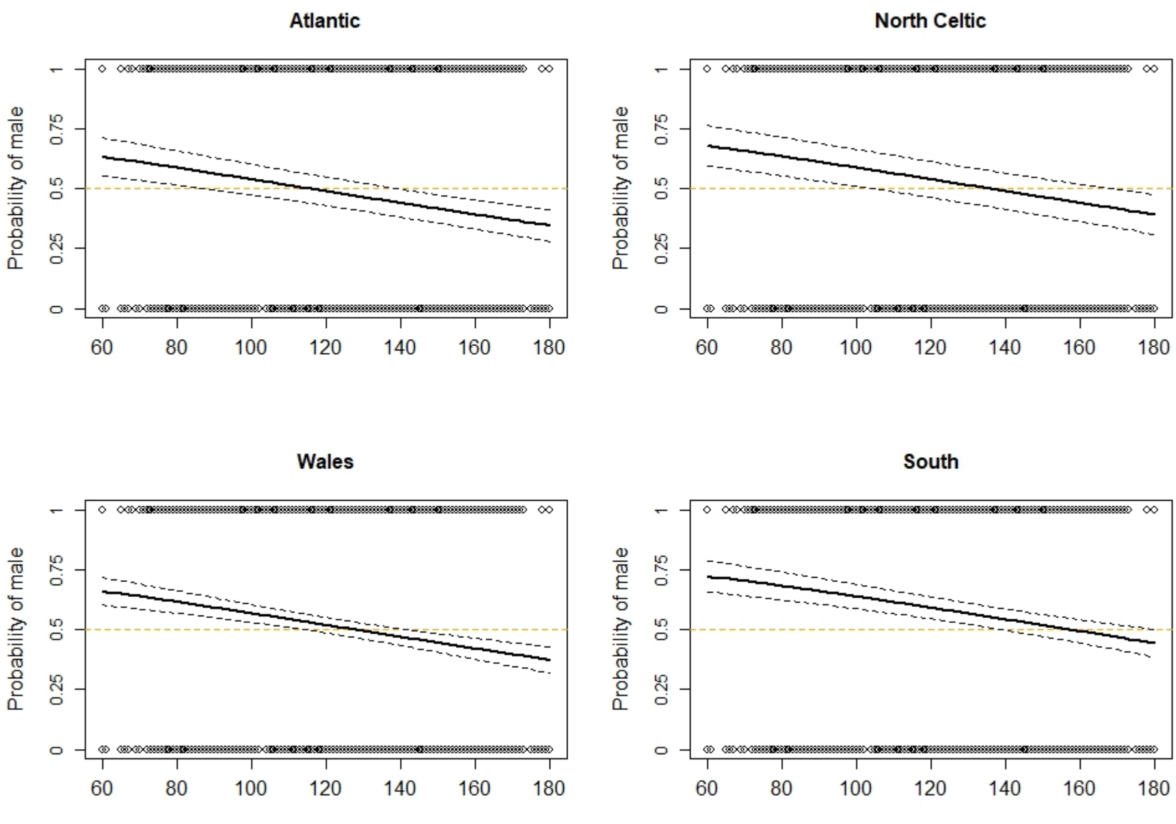

Figure 14: Model output of the optimal model representing the probability of a stranded harbour porpoise being male in relation to total body length (cm) per region. Dotted lines representing 95% confidence intervals.

5.2.3 Summary of biological parameters of porpoise strandings

- The largest proportion of animals stranded in the Atlantic region are juveniles, while the North Celtic and Welsh regions have a presence of all age groups. The largest proportion of animals stranded in the Southern region are of adult size, and neonates are rarely found here.
- Wales has a higher proportion of neonate individuals compared to the other regions
- The seasonal distribution of strandings of adults and juvenile individuals is the same for the Southern region indicating no obvious age specific mortality driving the seasonality here. The Atlantic, North Celtic, and Welsh regions have slight differences in the seasonal distribution of adults and juveniles.
- The North Celtic and Welsh region receive a higher density of adults in summer months from June to October compared to the rest of the year. The Atlantic region sees a peak in juvenile strandings in March and April, which are lower throughout the rest of the year.
- Sex ratio is relatively equal for all regions with an equal distribution of males and females for animals of juvenile length (between 91cm and 130cm). The probability of a stranded porpoise being male is slightly higher (>50%) in neonatal individuals and the larger individuals were found to be female in all regions.

5.3 Patterns in direct anthropogenic cause of death for necropsied animals

Of the 4329 strandings, 1144 animals were sent for necropsy comprising of 298 from the Northern region (with 218 from the Atlantic region and 80 from the North Celtic region), 561 from the Welsh region, and 285 from the South (Figure 15). A cause of death was recorded for 1137 of these animals at the time of production of this report, with seven cases being stored frozen pending necropsy. Prior to this analysis it is worth acknowledging the limitations of these data to facilitate interpretation of results.

5.3.1 Influence of decomposition state of necropsied animals

Decomposition and the freeze-thaw process introduces artefacts which can both mimic or mask sensitive ante-mortem pathological processes (such as bycatch) and this should be taken into account as a metric of confidence when establishing and finalising a cause of death diagnosis. Results of the following analyses should therefore be interpreted as a minimal estimate of anthropogenic mortality.

As can be seen in Figure 15, a high proportion of cases (46.7%) were stored frozen pending necropsy in the Welsh region, in contrast to only 16.5% in the Atlantic region, 24% in the North Celtic region, and as little as 6% in the Southern region. The majority of the carcases were fresh (code 2.1) or showed signs of slight decomposition (2.2) at the time of necropsy for most regions, with the exception of the South where the majority of the animals examined were in a moderate state of decomposition and only a small proportion of the cases were freshly dead with little signs of decomposition (Figure 16).

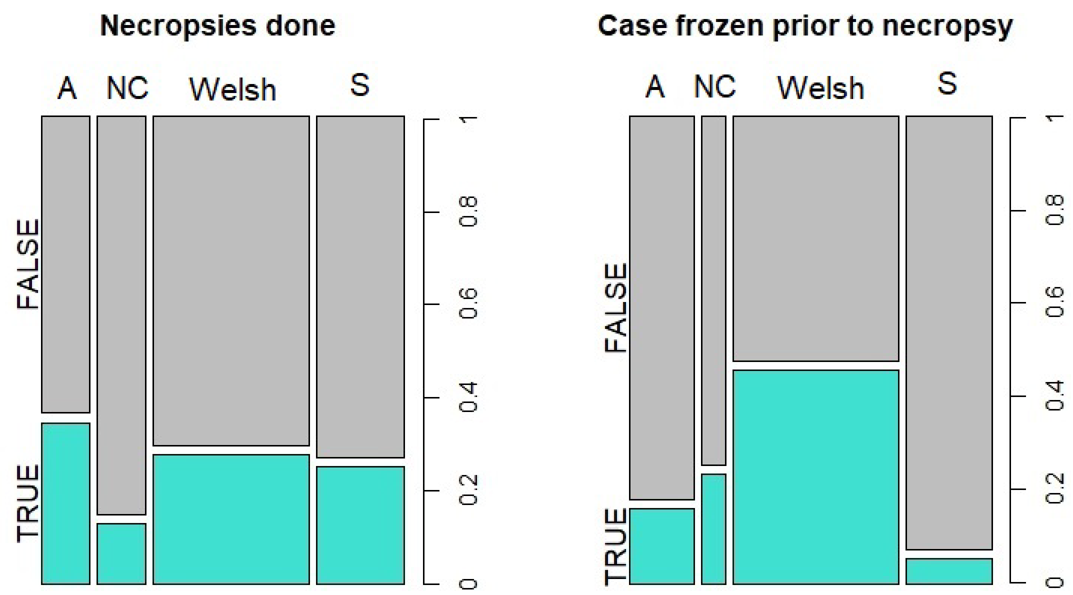

Figure 15: *Left:* Overview of percentage of cases sent for necropsy (true) in relation to cases not sent for necropsy (false) per region. *Right*: Overview of percentage of cases stored frozen prior to necropsy (true) per region. These include cases that were sent for necropsy only. For both graphs, the width of the bars reflects the total number of porpoises in the individual areas proportional to the West coast total.

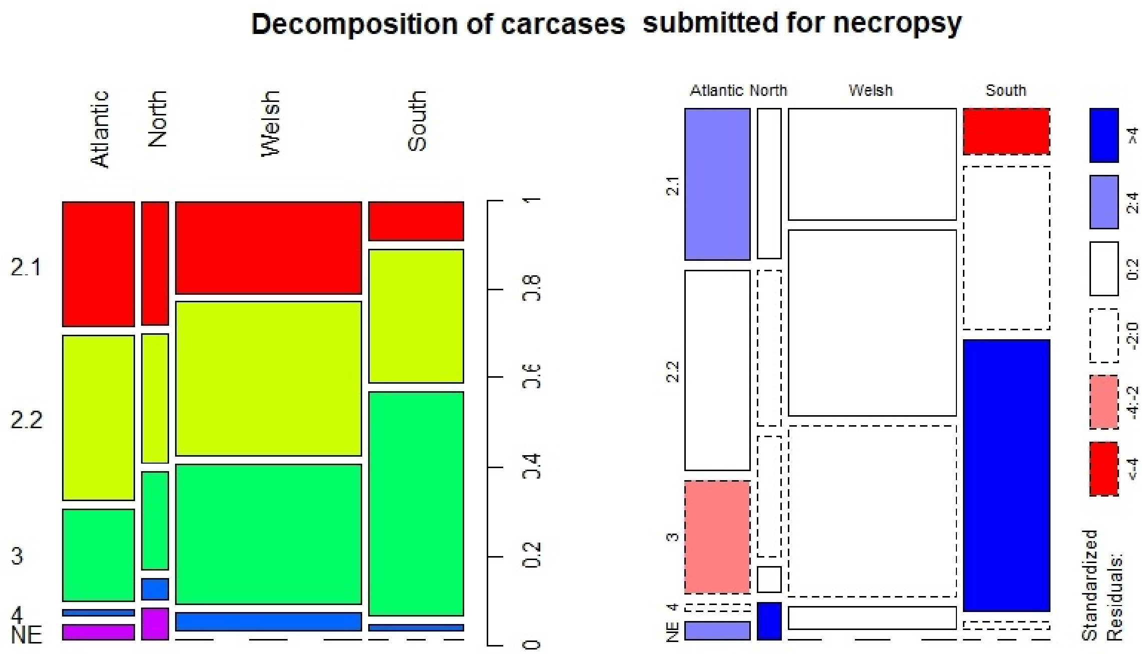

Figure 16: *Left:* Proportion of each decomposition code of carcases submitted for necropsy per region, with code 2.1 being fresh cases, code 2.2 being cases with slight decomposition, code 3 representing cases in moderate decomposition, code 4 being cases in advanced decomposition and NE being cases where decomposition status was not recorded. The width of the bars reflects the total number of porpoises in the individual areas proportional to the West coast total. *Right:* Mosaic plot of independence, coloured by departures from the assumption that the distribution of decomposition codes are not associated to region. A residual value greater than 2 or less than -2 represents a significant departure from this assumption with blue meaning there are more observations than would be expected, and red showing groups with fewer observations than would be expected if decomposition status and region were not associated.

5.3.2 Level of examination

As well as carcase condition, confidence that the attributed cause of death is accurate is influenced by pathological experience and completion of the appropriate ancillary tests. Some causes of death can be diagnosed to a reasonable degree of confidence by gross examination alone. These are usually factors which leave clear pathological signals, resilient to the processes of post mortem change or the effects of freezing. In contrast, other causes of death require a number of diagnostics tests to confidently attribute causation or exclude other differentials, or have pathological indicators which are ambiguous, labile or sensitive to the effects of autolysis or freezing. In these more complex cases, confidence in an accurate diagnosis requires a suite of ancillary testing such as histopathology, microbiology and in some cases toxicology to confidently attribute causation. Table 3 shows an example of this for three commonly diagnosed causes of mortality for harbour porpoise. The levels of examination are listed in the rows and provide an indication of tests required to accurately diagnose the causes of death listed in the columns.

Table 3: Example of level of pathological investigation required to accurately attribute different causes of death.

Level of Examination	Bottlenose dolphin attack	Bycatch	Infectious disease	Starvation
Detailed photographs	Indicative	Indicative	Possibly Indicative	Indicative
Gross necropsy	Confirmatory	Indicative	Indicative	Indicative
Histopathology	Extra / Baseline data	Confirmatory	Indicative	Indicative
Microbiology	Extra / Baseline data	Extra / Baseline data	Confirmatory	Indicative
Specific test	No	No	Yes	No
Compromised by freezing?	No	Yes	Yes	Yes

5.3.3 Anthropogenic vs other causes of mortality

Figure 17 and Figure 18 show the proportion of mortalities due to direct anthropogenic causes per year and month, for each region. These charts show cases with a known or diagnosed acute direct mortality due to bycatch (n=256, 98.5%) and ship strike (n=4 1.5%), versus all other causes of death diagnoses (n=877), and as such should be interpreted as showing the minimum proportion of human-induced mortality over this period. Charts representing other categories for cause of death such as infectious disease and bottlenose dolphin attack can be found in Appendix 2.

In the northern region (being both the Atlantic and North Celtic areas), the proportion of cases recovered at necropsy for which bycatch or ship strike was the proximal cause of death have remained low, with a period average of 13.2%, and a slight decrease over the past decade compared to earlier years. In contrast the Southern region has seen a much higher proportion of bycatch cases with a period mean of 44.7%, although this too has shown a slight decrease over the past ten years. The Welsh coast has remained stable, with anthropogenic mortality accounting for around 16.7% of diagnosed causes of death.

Assessing seasonality in these data shows a slight decrease in incidence in late spring and summer months compared to other times of year for all regions. The Southern region shows a clear seasonality with a notable increase in the December to March period, both in total stranding numbers and proportion of anthropogenic mortality, with a clear peak in January.

5.3.4 Summary of cause of death analysis

- There are regional differences in the proportion of cases that are diagnosed to have died of direct anthropogenic causes with a period average of 13.2% in the North, 16.7% in Wales, and 44.7% in the Southern region. This percentage has been relatively stable in the Welsh region, where for the North and the Southern regions this has seen a slight decrease over the past decade compared to earlier years.
- Confidence that the attributed cause of death is accurate is a function of carcase condition, pathological experience and completion of the appropriate ancillary tests, and these results should therefore be interpreted as a minimum measure of direct anthropogenic mortality.

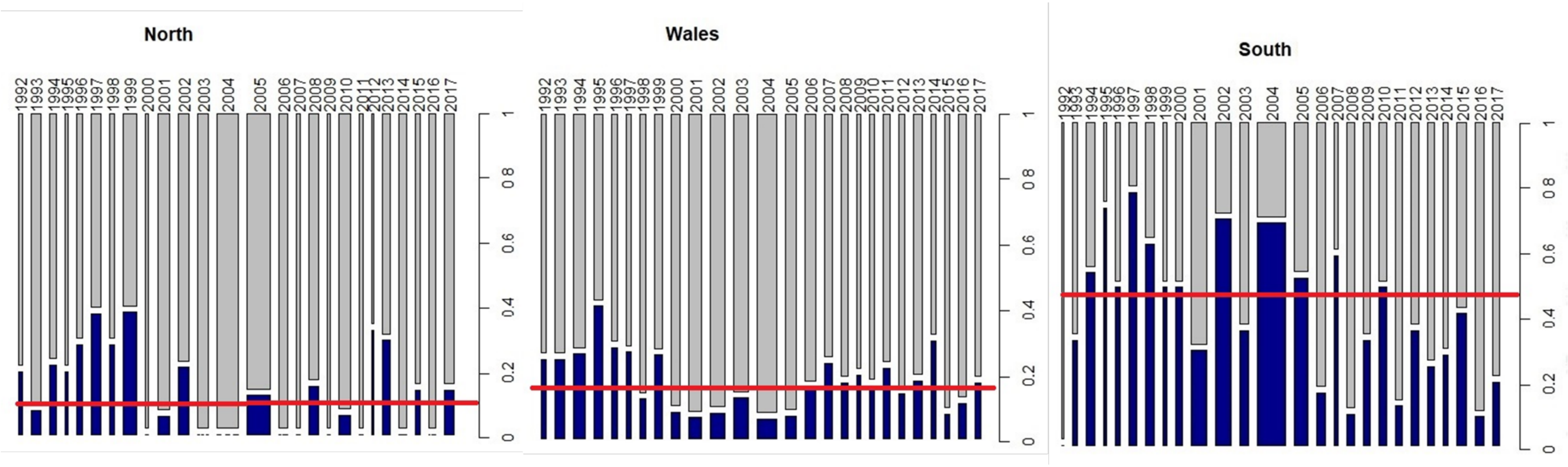

Figure 17: Overview of direct anthropogenic cause of death (dark blue) vs all other causes of death per year for each region. The red line indicates the 26 year proportional mean of anthropogenic cause of death for each region: 13.2% for the North (including both the Atlantic and North Celtic), 16.9% for Wales, and 44.7% for the South. The width of the bars reflects the total number of porpoises in the individual years proportional to the region's total number of animals sent for necropsy.

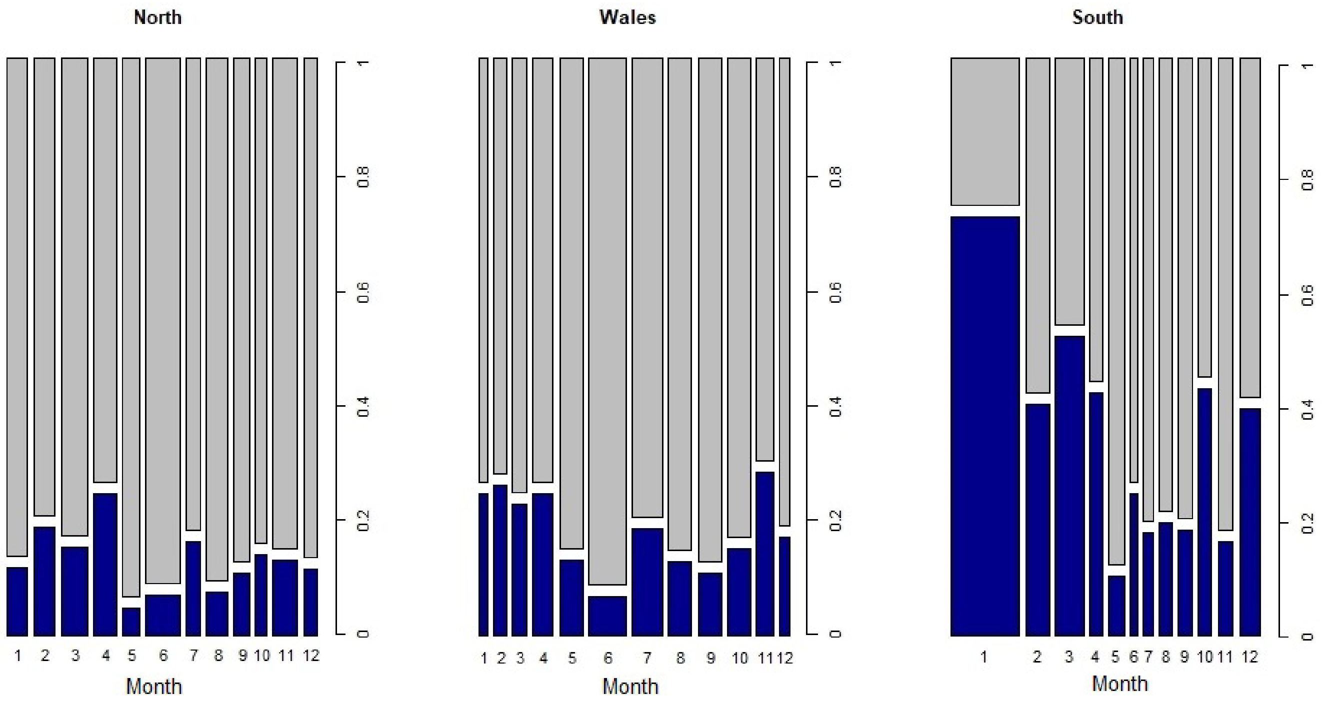

Figure 18: Overview of direct anthropogenic cause of death (dark blue) vs other causes of death per month for each region. The width of the bars reflects the total number of porpoises in the individual years proportional to the region's total number of animals sent for necropsy

5.4 Body Condition

Individual regression lines fitted to the weight/length data indicated that the slope was similar between regions, suggesting no spatial heterogeneity in the relationship between weight and length. The ANCOVA confirmed this, finding no significant regional differences in this regression ($F = 1.7269$, $p = 0.17$). Figure 19 shows the results of the final model with the regression line representing the relationship between weight and length of harbour porpoise stranded on the west coast of the UK (data was back transformed to facilitate interpretation). While the relationship between weight and length was the same across the west coast, this graph show that the largest individuals were found in the Southern region.

Residuals from this model were used to assess seasonal and long-term trends in body condition. This showed there was variation in body condition between years and between regions, where condition ranged from poor to good in most years for each region (Figure 20). Exceptions were 1992, 1996, 2007 and 2016 for the Northern region (which includes the Atlantic and North Celtic areas), when all animals were in a poorer body condition than the average. It should however be noted that these years were also characterised by a low number of animals for which these data were available. Body condition of animals in Wales appeared lower at the start of the study period from 1992 to 1996, where the majority of animals were in a poor body condition. From 1997 – 2006 body condition was relatively normally distributed between animals in good, moderate and poor condition. For the latter part of the study period (from 2007 onwards), the majority of the animals showed to be in a good body condition. High between-year variation is apparent for the Southern region. Here, body condition is equally distributed for most years, with the majority of the animals being in a condition better than average. Noteworthy years here are 1997, 2003 and 2009 where all animals were in good body condition (though number of animals for which data were available in these years was low), and 2006 and 2010 where the majority of the animals were observed to be in a poorer body condition.

Assessing seasonal variation in body condition showed that animals of all body conditions are found throughout the year (Figure 21). For the North region, body condition is equally spread around the average from January until April. From May through to September, the majority of the animals are in a body condition lower than the average while animals stranded from October to December are generally in a better body condition. For Wales, the variation in body condition is equal throughout the year, though lower body conditions are observed from May through to September. The South showed the largest variation between months. The majority of the animals for which data were available stranded in January, when body condition was found to be above average for the most animals. Almost all animals that stranded in May were found to have a condition below average, and animals that stranded in June were all above average. However, April through to September were also characterised by a low number of animals for which these data were available.

5.4.1 Summary Body Condition

- There are no spatial differences in the relationship between weight and length of harbour porpoise on the UK West coast
- While there is some variation in body condition between years and between regions, a relatively equal spread of animals in poor to good body condition was found in most years for each region.
- No obvious seasonal or long-term trends in body condition were detected in animals along the UK west coast.

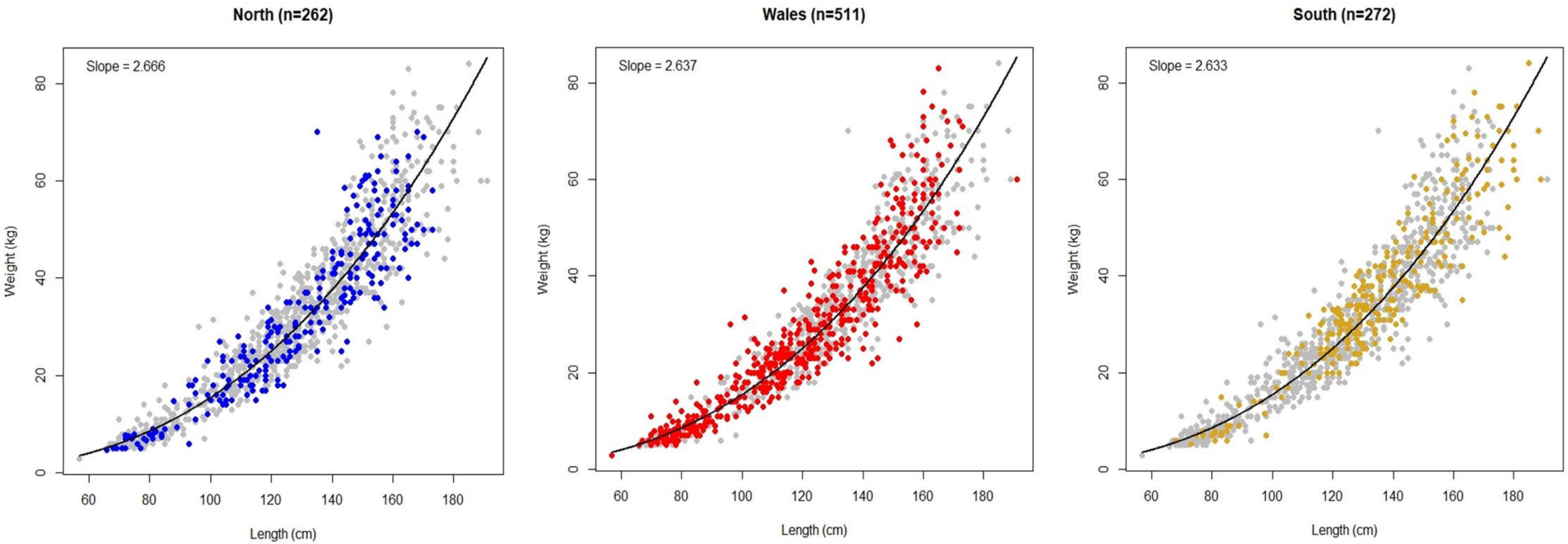

Figure 19: Weight/length relationship of harbour porpoise stranded on West coast UK per region, for which these data were available (n= 1045 in total). The line shows the best fit line of the power regression model using the entire dataset, with cases above this line representing animals in a better nutritional condition and individuals with values below his line being in poorer condition. For each graph, the coloured points represent the individuals from that particular region, the grey points show the remaining cases in the dataset.

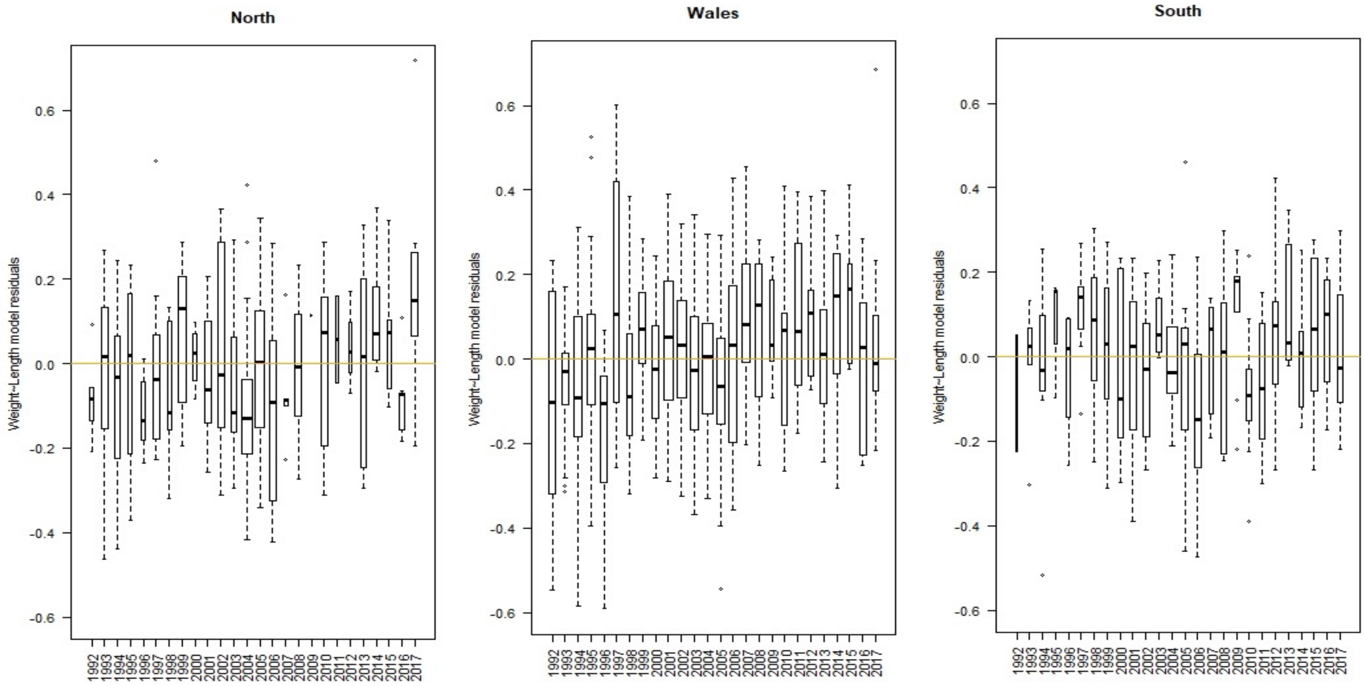

Figure 20: Boxplots showing the spread of residuals of the weight/length relationship regression model per year for each region. The orange line is set at zero- representing the model fit with cases above this line representing animals in a good body condition and individuals with values below the model fit being in poorer condition. Width of the boxplots is proportional to the number of cases available for analysis within that year.

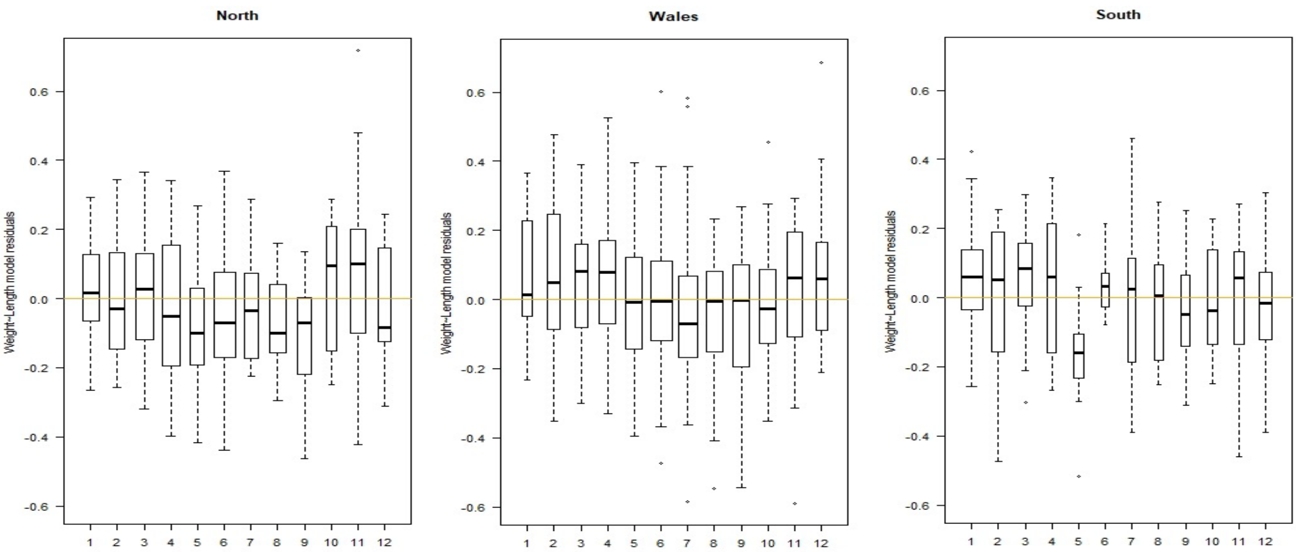

Figure 21: Boxplots showing the spread of residuals of the weight/length relationship regression model per month for each region. The orange line is set at zero- representing the model fit with cases above this line representing animals in a good body condition and individuals with values below the model fit being in poorer condition. Width of the boxplots is proportional to the number of cases available for analysis within that year.

6. Discussion

This study utilised harbour porpoise strandings data to investigate spatial and temporal patterns of occurrence on the west coast of the UK. This is the first time data from the UK stranding networks has been analysed at this scale, and doing so has provided useful insight into the population of harbour porpoise throughout the UK's western seaboard. A total number of 4329 harbour porpoises strandings were recorded from 1992 – 2017. Annual stranding frequencies varied over the study period, with a general increasing trend observed for all regions. The highest density of strandings was reported on the Welsh coastline, accounting for 46% of the total number of harbour porpoise strandings.

6.1 Seasonality in stranding frequencies

The modelling approach used here has previously shown to be a robust method of identifying significant deviations from expected stranding numbers (ten Doeschate *et al*., 2017). By fitting and assessing models per region, the approach permits for any change in the incidence of strandings to be detected at a regional scale, providing a framework that can be used for monitoring periods of unusual mortality. Nevertheless, interpretation of the potentially detected unusual variation in stranding frequencies should be done with caution. Where a significantly different observation could indicate a change in mortality or abundance, it may be a function of unusual variation in physical oceanographic conditions resulting in more carcases making landfall, or observer efforts which are unquantified.

There was a persistent but complex seasonality in strandings incidence, which is a function of variation in abundance, distribution and mortality of animals. This seasonality is also influenced by the non-biological components of the stranding process including oceanographic and effort factors. Investigation of these influences, whilst important, was beyond the scope of this report. Quantifying baseline seasonal variation is a necessary first step in assessing the potential drivers for mortality and identifying seasonality in metrics of population health and status (ten Doeschate *et al.,* 2017).

In the Atlantic region, the seasonal signal was not very strong, with high between - and within year variation, and no strandings were recorded for a number of months particularly in the first few years. Assessing strandings per age class showed that although adults are relatively equally spread throughout the year, the highest density of juvenile individuals was observed in March and April. Lockyer (2003) reported maternal dependency of calves with a total length of <115 cm, and presumable age of up to ten months for harbour porpoises. With calving mainly occurring from May to September, juvenile harbour porpoise become independent between February and April. Mortality at this life stage is the highest in many mammal species (e.g. Barlow & Boveng 1991), and this additionally coincides with the period at which sea surface temperatures are at their lowest around the UK's west coast (Hughes *et al*., 2017). In species such as the harbour porpoise with large surface to body volume ratio and high energetic requirements (Kastelein *et al*. 1997; Lockyer 2007), insufficient prey intake and low sea temperatures can rapidly lead to high nutritional and associated physiological stress.

Interestingly, this spring juvenile mortality did not seem obvious for the remaining regions; the North Celtic and Welsh regions in particular showed generally lower stranding numbers in these months. This could simply indicate a lower presence of juvenile animals in these regions, however an interesting alternative hypothesis would be the pressures affecting juvenile mortality are lower in these areas compared to the Atlantic region. This could suggest that these two areas exhibit better quality habitat, higher prey abundance, less disturbance or more benign environmental conditions than the Atlantic region, resulting in a higher chance of survival for recently weaned juveniles.

The seasonal pattern for both the North Celtic and Welsh region is much more consistent. Both areas show a peak in stranding numbers throughout the summer months from May through to October with a significant component of neonatal strandings in the Welsh area, indicating calving occurs in these regions. Secondly, the highest density of adult strandings in both areas occurs between June to October, possibly indicating mortality following reproductive stress. From these findings it can be hypothesised that the Welsh area, and to a lesser extent the North Celtic region, are possibly important areas for porpoise reproduction on the west coast of the UK. This pattern fits with the predicted persistent high density of harbour porpoise around the Welsh coastline during summer months (Heinänen and Skov, 2015). However a persistent year-round high density was also predicted for the Cardigan Bay area which suggests that the observed seasonal pattern in stranding incidence is less plausibly explained simply by seasonal variation in abundance and distribution.

The seasonal pattern observed in the Southern area differs from all the other regions. Here the majority of the strandings are found in the winter months, between December and March and peaking in January, after which numbers slowly decline to a more constant low during summer and autumn months. Very few neonates are found in this region, and while a higher proportion of the stranded animals are adult, there is a relatively equal spread of adults and juveniles throughout the year suggesting there is no specific age or life-stage mortality. Heinänen and Skov (2015) identified low abundance in summer but persistently high densities of porpoises throughout the winter months in the Bristol Channel, which largely falls within the Southern region. There is a high inshore gillnet fishing effort in this region (Calderan and Leaper, 2019), and concern over a high bycatch rate has previously been flagged in this area (Northridge *et al.*, 2014). Findings here support this, with the highest levels of anthropogenic (bycatch representing 98.5%) causes of death along the UK west coast being observed in the Southern region. This is further emphasised when assessing seasonality in causes of death, which showed that the largest proportion (range 40% up to 75% in January) of strandings sent for necropsy in the winter months died as a result of being bycaught in fishing gear. Incorporating the cause of death with strandings prevalence data suggests the observed seasonal pattern is most likely driven by a combination of increased density and fisheries interaction. Analyses incorporating external data sources on spatiotemporal variation in fishing effort would allow further investigation of this and would provide useful further insight in the potential drivers for seasonality in this region.

6.2 Body condition

Body condition has been demonstrated to be a good predictor of fitness for marine mammals, as it affects both direct survival and can influence demographic processes (Pettis *et al*., 2004). Understanding spatiotemporal variation in body condition among individuals within a population is therefore a useful indicator important for predicting population health and resilience to external stressors (Kershaw *et al.,* 2017). Despite its importance, little is known about the body condition of many cetacean species, and currently, no consensus has been reached about the best morphometric condition index. Body condition is known to vary on a number of variables and an unbalanced dataset could confound these types of analyses. The body condition index used here has been suggested to be a good metric able to differentiate between individuals with different cause of death (chronic versus acute), age classes, and life-history stages of small cetaceans (Kershaw *et al.,* 2017). It was therefore considered the most appropriate index for an initial exploration of spatiotemporal variation in nutritional condition on the UK's west coast.

The initial data exploration done here has shown that there are no spatial differences in the relationship between weight and length of harbour porpoise on the UK West coast, and, while there is some variation between years and between regions, a relatively equal spread of animals in poor to good body condition was found in most years for each region. The Southern area showed the largest seasonal variation where the majority of the animals for which data were available stranded in January, when body condition was found to be above average. This is unsurprising given that a high proportion of animals for which these data are available in this region die from acute trauma (bycatch), and therefore there are proportionally more healthy animals in this cohort.

No obvious seasonal or long term trends in body condition were detected in animals along the UK west coast, suggesting population fitness has been stable throughout the last 26 years. However, given the high metabolic rate of harbour porpoise, and the concomitant requirement for regular food intake, good body condition in itself is not necessarily a predictor of an individual's robustness or resilience to disturbance. Investigation into the prevalence of acute starvation and chronic emaciation in these cases would be a worthwhile next stage.

6.3 Strandings in Wales

There is a consistently high density of strandings in the Cardigan Bay area - to the extent that the approximately 200km of coastline from Cardigan north to Bardsey Island accounts for 56% of Welsh, and over 25% of all harbour porpoise strandings on the entire western coastline of the United Kingdom. While this cluster of strandings could reflect a number of biological, oceanographic and effort factors, the magnitude of this cluster suggests that the Welsh coastline in general, and the Cardigan Bay region in particular, are important areas for harbour porpoise. This combined with the indication that the Welsh coastline is an important area for calving and reproduction, and the high density of occurrence as identified by Heinänen and Skov (2015), highly supports the designation of the West Wales Marine / Gorllewin Cymru Forol Special Area of Conservation. In light of this, further investigation into this observed cluster of mortality is recommended, in specific a more detailed analysis of mortality factors would be welcome.

6.4 Variation in data collection and quality

The collection of strandings data relies on opportunistic discovery and reporting, and the quality and resolution at which data are collected is highly dependent on public awareness, as well as the mechanisms in place to maximise the amount of data obtained for each individual case. Both SMASS and the CWTMSN make use of a volunteer network to augment the information received from members of the public. This enables the detail and quality of data of each case to be maximised and effective triage of cases for necropsy or sampling. For cases that are not collected for necropsy, volunteers are specifically trained to record detailed information including sex determination and taking accurate measurements that can be used as an indicator of age class. In the rest of England and Wales, unless carcases are collected for further examination, the CSIP rely on deriving these data from untrained members of the public. Personal communications with the strandings coordinators for the different CSIP consortiums indicated that there may be some discrepancy in the way data are recorded in the central CSIP database. Data on total length was measured for some cases and estimated by reporters for others. While some consortiums used a database specific indicator of uncertainty (a recording of "length uncertain") to specify an estimate over a measurement; this was not consistently done by all organisations. Additionally, for some regions the approach of data recording was uncertain for earlier years, with a change of staff members and associated loss of institutional memory. This means that the available data for length of cases that had not been sent for necropsy most likely consist largely of estimates rather than true measurements in all areas, with the exception of data collected by the CWTMSN and data from Scotland since 2014 (when the volunteer network was initiated and data recording method utilising the certainty indicator was adopted). Capturing this uncertainty is important, particularly when undertaking analyses aiming to assess age structure of harbour porpoises. It should be acknowledged that the challenges and logistics of carcase reporting, triage and recovery differ across consortiums, yet exploring mechanisms for increasing the quality of data derived from each stranded case across the entire UK coastline would be recommended.

Confidence in diagnosis of cause of death is a function of carcase condition, pathological experience and completion of the appropriate ancillary tests. Some causes of death are more straightforward to diagnose than others, and this can introduce a complex bias. For example, blunt force trauma cases, such as attack by bottlenose dolphins, causes a reasonably unambiguous lesion pattern (Ross and Wilson, 1996), which can often be reliably ascertained from photographs of the stranding and confirmed by gross necropsy. Bycatch, in contrast, requires both detailed gross necropsy and in some cases histopathology to confidently attribute a cause of death. While no pathognomonic lesions are recognised, signs of acute external entanglement, bulging or reddened eyes, recently ingested gastric contents, pulmonary changes, and decompression-associated gas bubbles have been identified in the condition of 'per-acute underwater entrapment' in bycaught animals (de Quirós *et al.*, 2018). Causes of death such as infectious disease and starvation require an even higher level of diagnostic rigour to establish the ultimate cause of death. Wild animals may carry a number of infectious agents, whose interaction and synergies define the degree and rate of morbidity, and eventual mortality. Furthermore, these infectious processes can be exacerbated by stress, environmental factors such as noise or high contaminant burdens (eg Grattarola *et al*. 2019) and nutrition. Diagnosis of starvation, defined as negative energy balance severe enough to cause death, is particularly challenging. This is in many cases a diagnosis of exclusion, having effectively ruled out the role of significant infectious or metabolic processes. Acute starvation is identified in harbour porpoise where an animal with apparently adequate lipid reserves can nonetheless suffer from an acute metabolic energy deficit severe enough to lead to its death (Wisniewska *et al*. 2016).

In addition to the challenges highlighted above, diagnosis can be further compromised by the degree of carcase decomposition, post mortem scavenger damage and freeze-thaw damage present in any carcase frozen prior to necropsy (Read and Murray 2000). All these processes introduce artefacts which can both mimic or mask ante-mortem pathological processes. It was noted that a high proportion of cases (46.7%) were stored frozen pending necropsy in the Welsh region, in contrast to 16.5% in the Atlantic region, 24% in the North Celtic region, and only 6% in the Southern region. It is important that these confounding factors are taken into account when using necropsy data to infer about local pressures and threats. It is very plausible that cases displaying subtle pathology indicative of bycatch may not have been picked up on. As such, the analysis on direct anthropogenic causes of death here should be interpreted as representing a minimum estimate of anthropogenic mortality.

6.5 Challenges of strandings surveillance

There are multiple biases associated with the strandings process, which are inter-linked through a complex relationship and are all individually associated with a degree of uncertainty, making estimating at sea mortality challenging. Strandings are a function of biological, physical and social processes that influence stranding rates, where the biological signal that is of interest from a monitoring point of view is confounded by physical and social factors which influence the incidence of beach cast and reported strandings (ten Doeschate *et al.,* 2017).

Strandings are recorded opportunistically and reporting effort has likely improved over time with increasing public awareness, technological developments which facilitate submission of stranding reports, and interest in marine animal conservation. This is unquantified for all consortiums of the CSIP and could therefore not be accounted for in any of the analyses done as part of this report. There is however no evidence that suggests that this expected increase in reporting effort has been significantly different between the individual regions, and it was therefore assumed homogenous across areas with data comparable for the purposes of this report. Nevertheless, it can be expected that public awareness increases following outreach activities (such as local volunteer training courses and post mortem demonstrations), and public surveillance of the coastline will vary throughout the year depending on a number of variables including weather and holiday periods. Secondly it should be acknowledged that not all areas of the coastline receive an equal level of surveillance. This is result of heterogeneity in human population density as well as accessibility to the coastline. Flat sandy beaches near larger towns will have more visitors and thereby the chances of a carcases being found and reported is higher than on a remote part of the coastline. The development of methods to quantify effort would provide a welcome contribution to our understanding of observer bias and its effect on opportunistic surveillance.

The biological signal arising from strandings is additionally confounded by physical oceanographic factors influencing carcase drift, which determine whether and where an animal ends up on the coastline after dying at sea (e.g. Authier *et al*., 2014). Wind intensity and direction are the most commonly named influential factors on carcase drift, and variation in these is likely to introduce noise to the observed stranding rate (Peltier *et al*., 2013). Nevertheless, the probability of a carcass stranding on the coastline is dependent on a wide variety of physical and biological factors. These include but are not limited to coastal topography, wind and current regimes, atmospheric pressures, oceanographic influences, as well as the distance to shore at time of death, level of scavenging, causes of mortality and buoyancy of the dead individual (e.g. Evans *et al*. 2005; Brabyn and McLean, 1992). Due to the large geographical and temporal differences in these parameters, it can be expected that the variability in stranding rates is significant on both a spatial and a temporal scale. The west coast of the UK has a complex topography, and previous work on the development of a carcase drift model for the West coast of Scotland concluded that classic models incorporating drift alone do not accurately represent strandings and mortality in complex coastal areas (Bedington, 2015). This suggests that a more parameterised model would be required for this area. Further work on this would be recommended to develop strategies for environmental monitoring addressing two major requirements; first to pinpoint areas of high mortality (generally or following an unusual mortality event), and second to guide targeted surveillance selecting beaches where carcases are likely to end up if impacted by known anthropogenic activity such as offshore developments.

While these challenges exist, long term surveillance schemes like the CSIP allow analysis of historical and baseline trends and patterns. Nevertheless the limitations should be taken into consideration when making population level inferences based on stranded specimens, and a better understanding of the effect of these factors on observed mortality would improve both the qualitative and quantitative potential, ecological relevance, and the applicability of stranding data on the general status of cetacean populations at sea.

6.6 Policy and Management Considerations

Investigation into the physiological and nutritional resilience of harbour porpoise populations is worthwhile for informing mitigation strategies for anthropogenic disturbance. It is essential that consideration is given to spatiotemporal variation in population resilience and vulnerable population groups, especially in particular areas and time periods, to minimise disturbance and negative impacts on populations when consenting proposed anthropogenic activities. For example, consent for impulsive noise activities, potentially likely to impair or constrain feeding, could be restricted to periods of the year when populations exhibited greatest resilience and energy reserves.

The analyses done here have provided a first insight into spatiotemporal patterns of occurrence and mortality of harbour porpoise around the west coast of the UK. The information derived from strandings usually cannot be gathered by other means, thus tools to improve and expand the utility of these data will be of significant benefit to conservationists and policy makers and can deliver real conservation gains in increasing our knowledge of the conservation status, distribution and pressures faced by cetacean species.

7. Recommendations and future work

The analyses done here have provided a first insight into spatiotemporal patterns of mortality of harbour porpoise around the west coast of the UK. This has been an essential first step in assessing population structure, from which further hypotheses about the processes that generated these data can be specified. Secondly the report highlighted some of the issues with strandings surveillance, and areas where improvements can be made to further enhance the use of strandings data for population level inferences.

This report has generated a number of hypotheses that are worthy of further analysis, and has highlighted improvements that can be made to maximise the quality of data obtained through strandings surveillance. The main recommended research directions and methodological improvements are listed below.

7.1 Suggested further research:

- **Develop better statistical approaches to reduce the biases associated with the non-biological factors of the strandings process.**

  Determining causal trends in observed mortality is challenging without properly accounting for biases in these non-biological stranding factors. At present there is no framework that is able to quantify variation due to these factors. The development of novel statistical approaches to reduce the biases associated with the strandings process is therefore considered a critical next step to reduce scientific uncertainty around the use of information on stranded individuals for population level inferences. This includes the development of area specific drift models able to account for the complex coastal topography of the UK's west coast.

- **Align strandings datasets with wider external data sources to better characterise the impact of fishing effort**

  The high levels of anthropogenic mortality in the Southern area is suggested to be due to increased interactions with inshore fisheries. This can either be due to increased abundance of animals, or increased fishing effort in winter months. To assess this association for the Southern area, as well as the remaining west coast, would merit closer analysis for which available information on region specific fishing effort would need to be obtained.

- **Detailed investigation of areas of coastline with high incidence of strandings.**

  Harbour porpoise demographics are driven by ecological and environmental processes, which are largely independent of the national borders or management units, yet for impact assessment and conservation purposes it is useful to divide the UK west coast into smaller units. In this analysis this has been done by dividing the western coastline into four large sections, largely partitioned by latitude and administrative region. However given the strong heterogeneity in strandings density, there would be benefit from partitioning the coastline into more sections of equivalent length, as this would afford a higher level of granularity to the analysis and reduce any within region variability. This may allow for the identification of stranding hotspots, which has the potential to direct targeted surveillance strategies.

7.2 Suggested methodological improvements

- **Investigate methods for improving data derived from those strandings not sent for necropsy.**

  To increase general data quality and accuracy and the amount of information obtained per individual case, it is recommended to explore options for the involvement of other organisations monitoring coastal environments, or citizen science strategies. This will increase data accuracy and thereby reduce uncertainty regarding data from which relevant inferences on population structure could be made. SMASS and CWTMSN already have made improvements through the development of a trained volunteer network, and exploring options to deploy similar strategies to assist with basic data collection is recommended CSIP wide.

  In July 2019, SMASS released a mobile phone app (www.beachtrack.org) which invites members of the public to survey the Scottish coastline, submit findings, quantify survey effort and reports on beach cleanliness, which encourages data submission and may help to target and address effort related issues. If successful, there may be scope to further expand this in England and Wales.

- **Review logistical and operational processes to improve the accuracy of diagnosis of causes of death at necropsy.**

  Decomposition and the freeze-thaw process can both mimic or mask pathological processes. There is a high proportion of cases frozen prior to necropsy in the Welsh region compared to elsewhere, and it would be advisable wherever possible to consider alternatives to freezing, such as use of courier services, to improve data quality in future. Similarly, it is recommended to develop a system which captures the level of examination done, and adds a confidence metric to particular diagnoses.

- **Expand the range of ancillary tests undertaken as routine to improve accuracy in both establishing cause of death and metrics of overall health**

- It is suggested that the range and detail undertaken on samples recovered from stranded animals is further improved, particularly with regard to screening for pathogen carriage, contaminant burden and physiological indicators of stress. This would develop strandings investigation beyond the derivation of an individual cause of death towards using these apex species as sentinels and sensors of the marine environment. For example, peak adult mortality coincides with the known calving period of harbour porpoise, which may indicate an effect of reproductive stress associated with the breeding season. Investigation of potential causal links however requires a comprehensive assessment of the physiological and health parameters of reported cases.

The data that form the basis of this report covers the best part of the last three decades of continuous cetacean stranding surveillance in the UK. Over this time, the policy and scientific drivers for the scheme have evolved. Originally instigated largely to identify and quantify acute anthropogenic impacts on cetacean populations, nowadays the data derived from strandings investigation forms an increasing part of wider marine ecological monitoring. The data can be used to assess metrics of population health and resilience, identify presence and magnitude of pollution and disturbance and inform on appropriate and proportional policy, management and consenting decisions. Since the requirements for the data have changed, it is suggested that the current operating strategies for the CSIP are reviewed in order to optimise the value of future data from the scheme whilst maintaining the continuity offered from these long term datasets.

8. References

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9. Appendix 1

9.1 Stranding numbers

Table 4: Summary table of number of harbour porpoise strandings per region per year. Both the absolute number of strandings (N) are given as well as the percentage of the annual total (% AT)

Year	N (Atlantic)	% AT (Atlantic)	N (North Celtic)	% AT (North Celtic)	N (Wales)	% AT (Wales)	N (South)	% AT (South)	TOTAL
1992	5	10.9%	4	8.7%	32	69.6%	5	10.9%	46
1993	12	16.4%	10	13.7%	44	60.3%	7	9.6%	73
1994	15	17.6%	7	8.2%	49	57.6%	14	16.5%	85
1995	10	15.4%	8	12.3%	41	63.1%	6	9.2%	65
1996	18	21.2%	15	17.6%	37	43.5%	15	17.6%	85
1997	19	19.2%	11	11.1%	49	49.5%	20	20.2%	99
1998	17	15.9%	8	7.5%	58	54.2%	24	22.4%	107
1999	27	23.1%	4	3.4%	72	61.5%	14	12.0%	117
2000	11	8.9%	9	7.3%	75	61.0%	28	22.8%	123
2001	21	12.0%	24	13.7%	94	53.7%	36	20.6%	175
2002	27	11.0%	18	7.3%	119	48.4%	82	33.3%	246
2003	20	9.9%	17	8.4%	112	55.4%	53	26.2%	202
2004	40	11.3%	53	15.0%	126	35.6%	135	38.1%	354
2005	44	17.9%	44	17.9%	109	44.3%	49	19.9%	246
2006	39	16.5%	34	14.3%	109	46.0%	55	23.2%	237
2007	9	5.8%	24	15.4%	86	55.1%	37	23.7%	156
2008	19	11.9%	22	13.8%	77	48.1%	42	26.3%	160
2009	9	6.4%	27	19.3%	62	44.3%	42	30.0%	140
2010	17	11.6%	35	23.8%	61	41.5%	34	23.1%	147
2011	12	6.8%	24	13.6%	89	50.3%	52	29.4%	177
2012	6	3.8%	23	14.4%	64	40.0%	67	41.9%	160
2013	32	16.3%	22	11.2%	88	44.9%	54	27.6%	196
2014	41	21.9%	26	13.9%	89	47.6%	31	16.6%	187
2015	34	18.6%	30	16.4%	64	35.0%	55	30.1%	183
2016	50	19.8%	45	17.8%	72	28.5%	86	34.0%	253
2017	63	20.3%	69	22.3%	112	36.1%	66	21.3%	310
TOTAL	**617**	n/a	**613**	n/a	**1990**	n/a	**1109**	n/a	**4329**

10. Appendix 2

10.1 Trends in other main causes of death of Harbour porpoises on the UK's West coast.

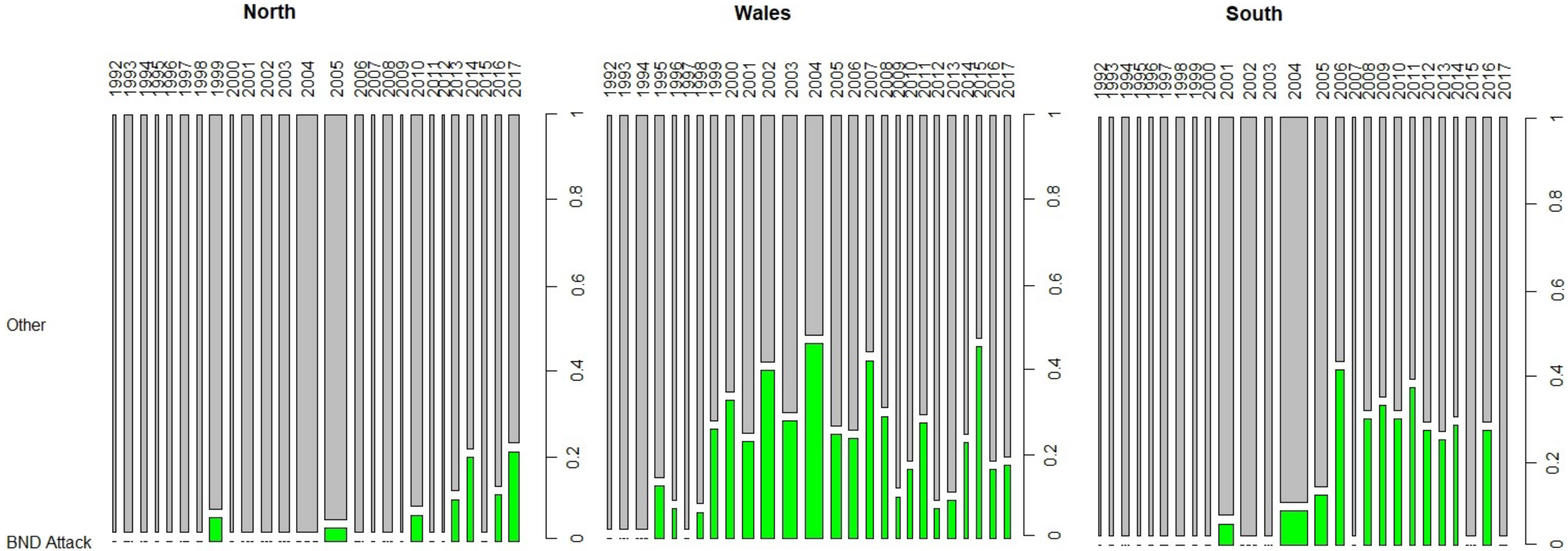

Figure 22: Overview of cause of death due to Bottlenose dolphin attack (green) vs all other causes of death per year for each region. The width of the bars reflects the total number of porpoises in the individual years proportional to the region's total number of animals sent for necropsy.

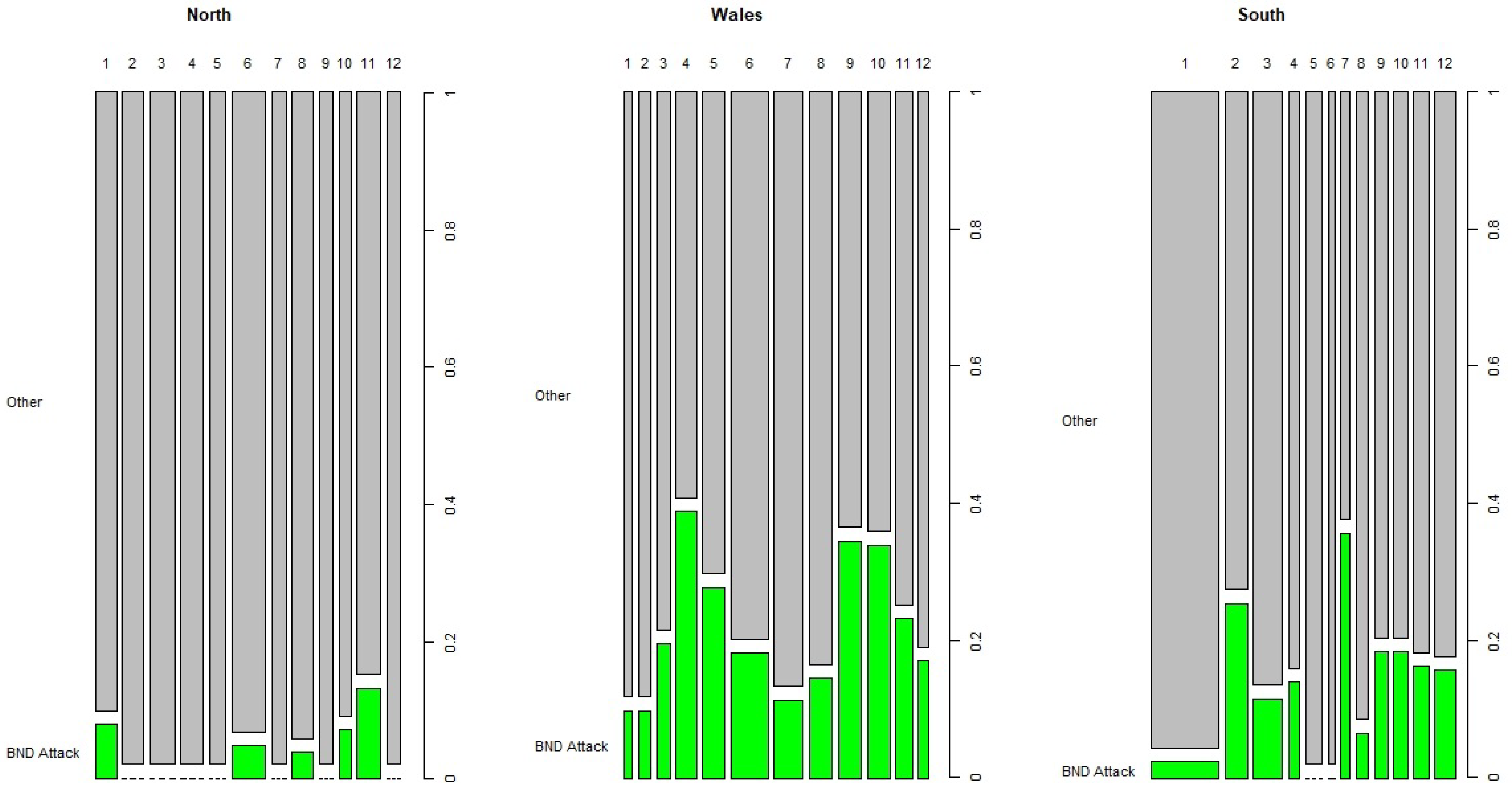

Figure 23: Overview of cause of death due to Bottlenose dolphin attack (green) vs other causes of death per month for each region. The width of the bars reflects the total number of porpoises in the individual years proportional to the region's total number of animals sent for necropsy

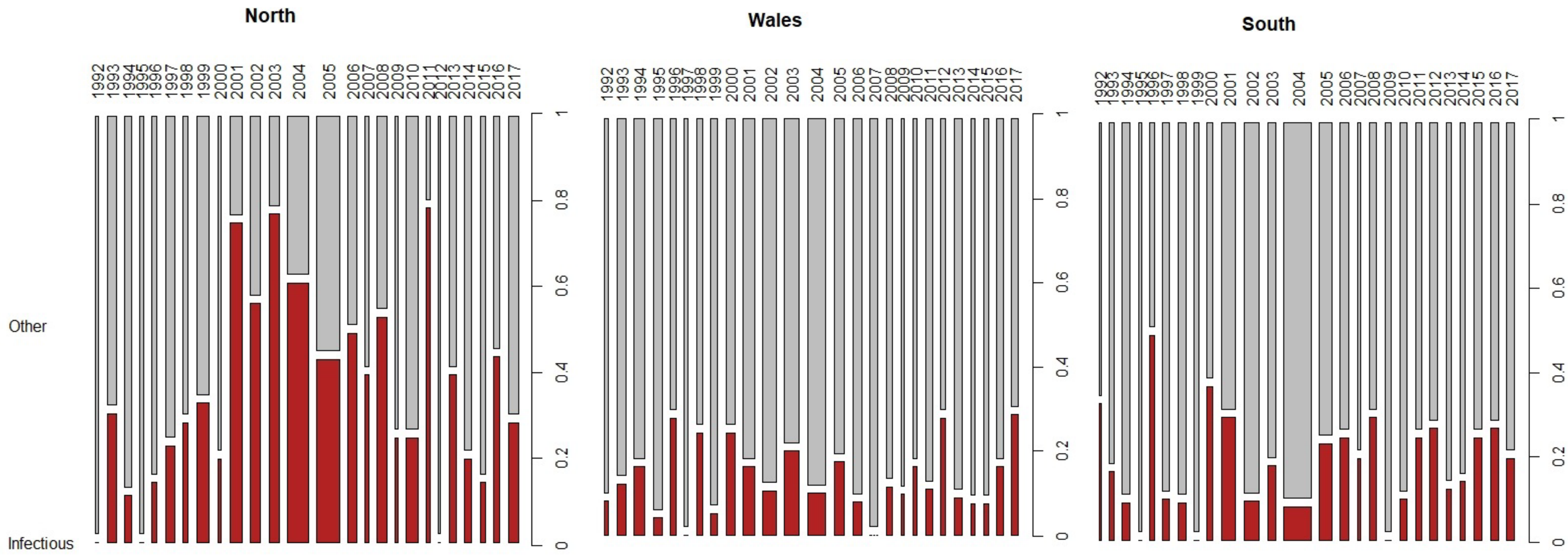

Figure 24: Overview of cause of death due to infectious disease (red) vs all other causes of death per year for each region. The width of the bars reflects the total number of porpoises in the individual years proportional to the region's total number of animals sent for necropsy.

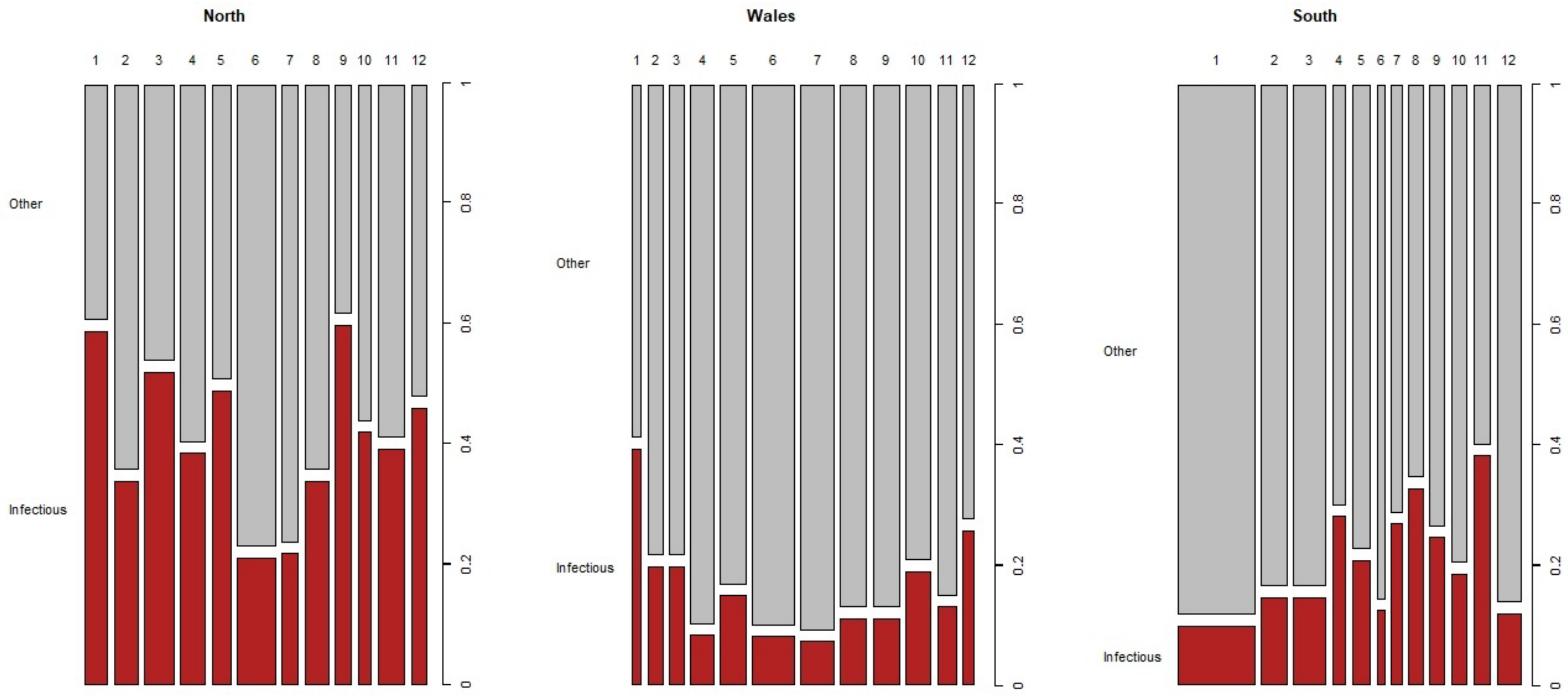

Figure 25: Overview of cause of death due to infectious disease (red) vs other causes of death per month for each region. The width of the bars reflects the total number of porpoises in the individual years proportional to the region's total number of animals sent for necropsy

11. Appendix 3

Residual variation regional spatiotemporal models.

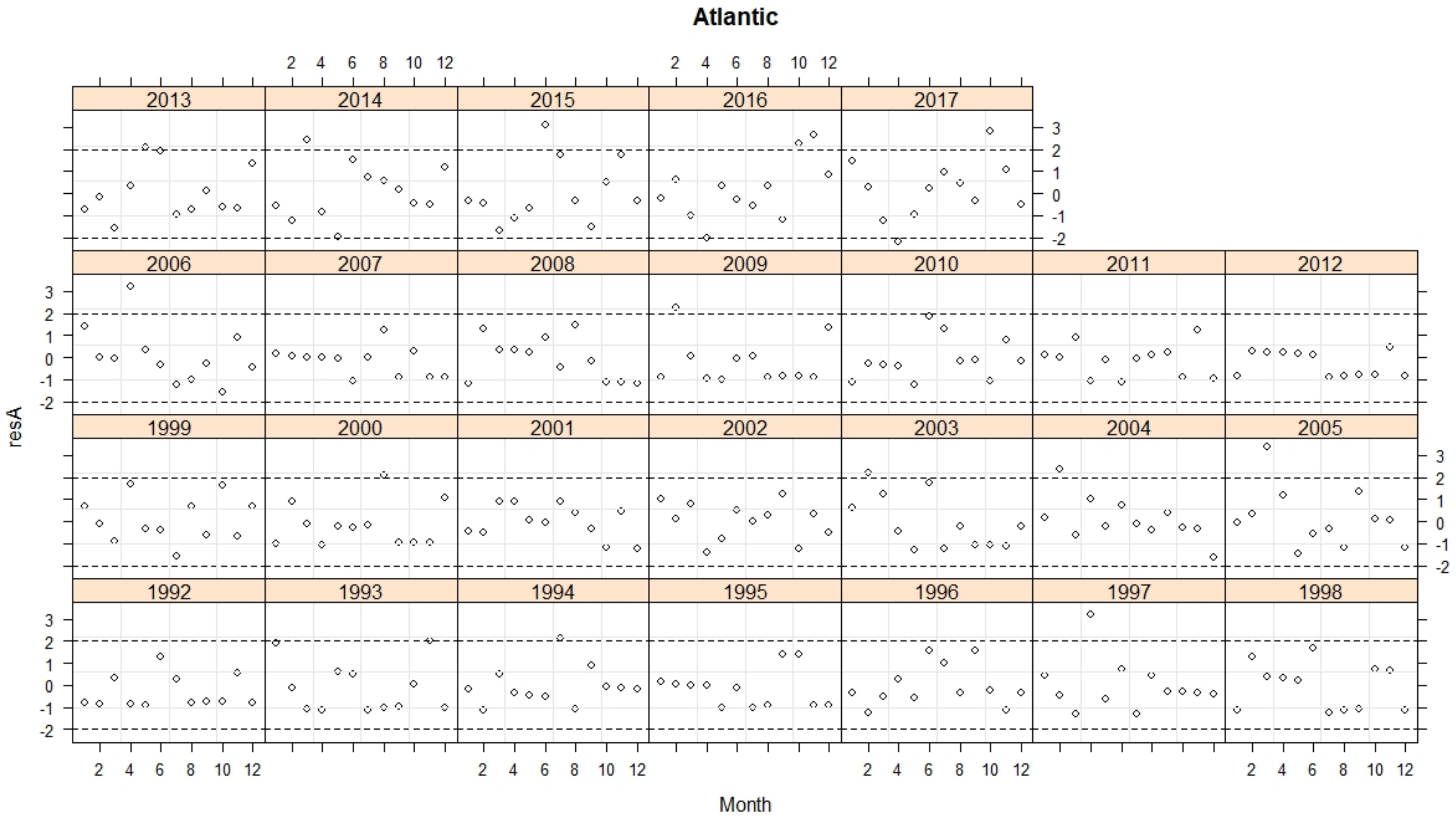

Figure 26: Pearson residuals extracted from the GAMM for the Atlantic region, showing residuals per month for each year. The months are displayed on the x axis, with residual variation indicated on the y axis. For each window (year), points should be centred around zero, with values outside the -2 and 2 confidence bands being considered lower or higher variation than expected by the model.

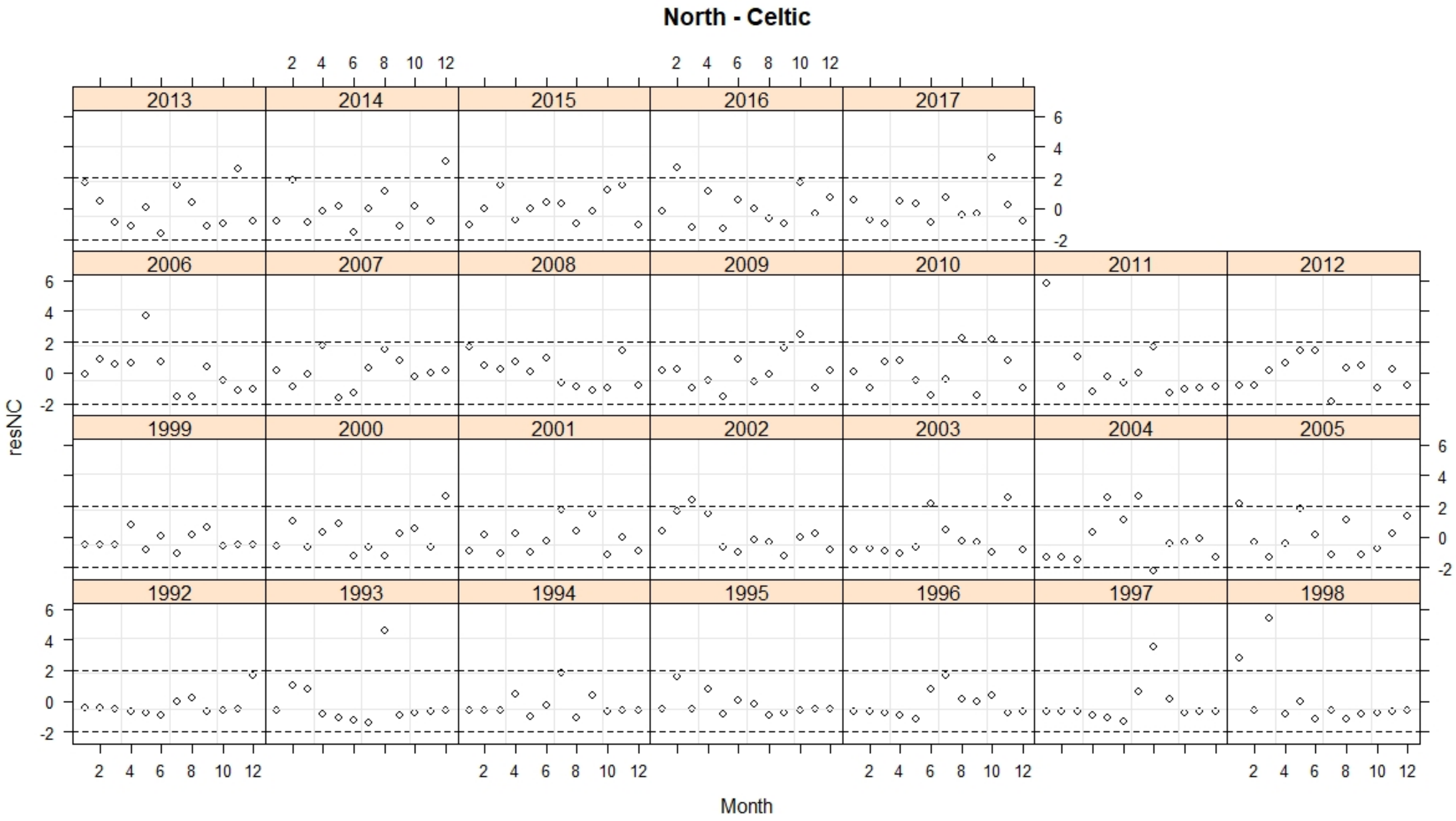

Figure 27: Pearson residuals extracted from the GAMM for the North-Celtic region, showing residuals per month for each year. The months are displayed on the x axis, with residual variation indicated on the y axis. For each window (year), points should be centred around zero, with values outside the -2 and 2 confidence bands being considered lower or higher variation than expected by the model.

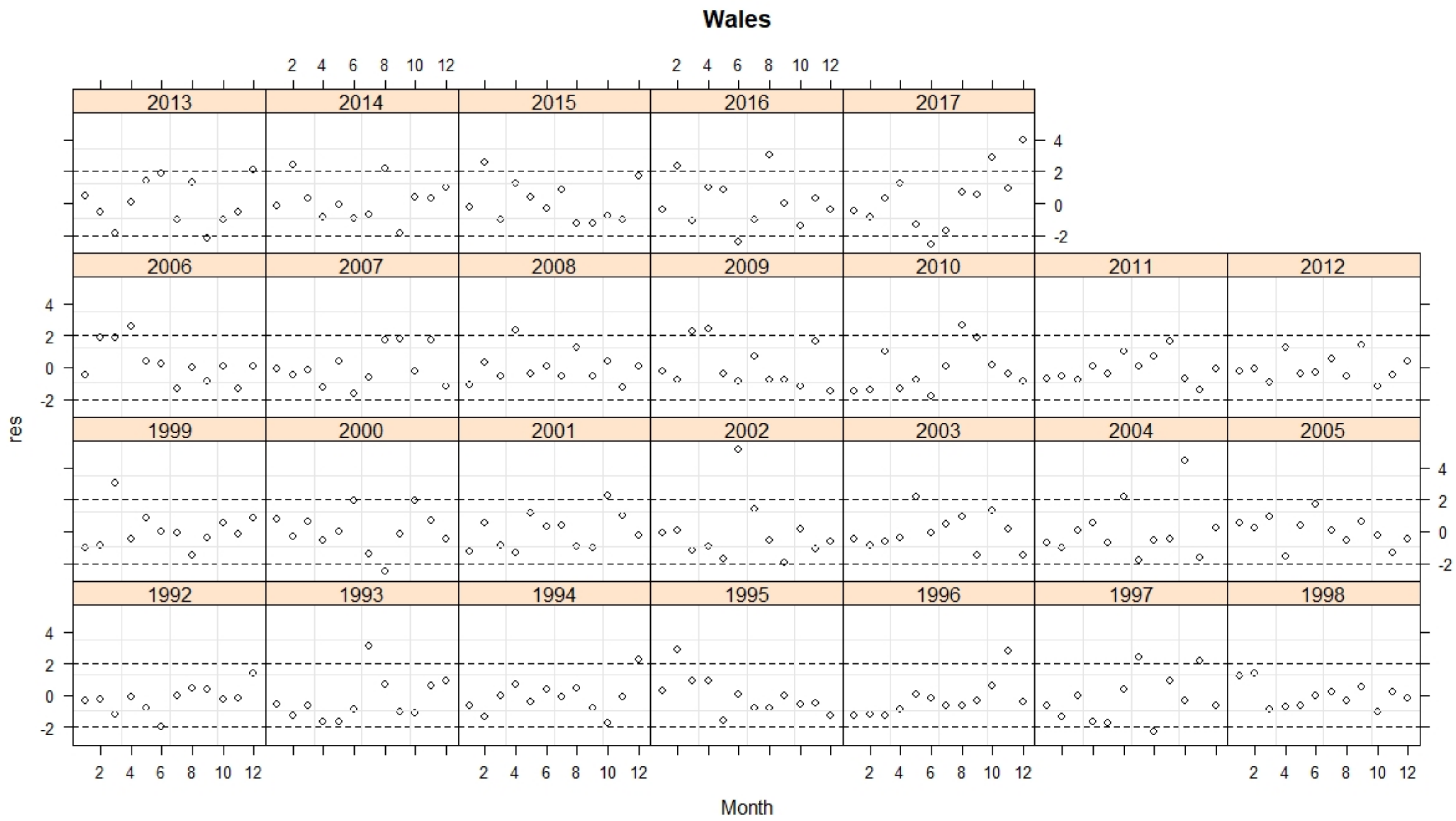

Figure 28: Pearson residuals extracted from the GAMM for the Welsh region, showing residuals per month for each year. The months are displayed on the x axis, with residual variation indicated on the y axis. For each window (year), points should be centred around zero, with values outside the -2 and 2 confidence bands being considered lower or higher variation than expected by the model.

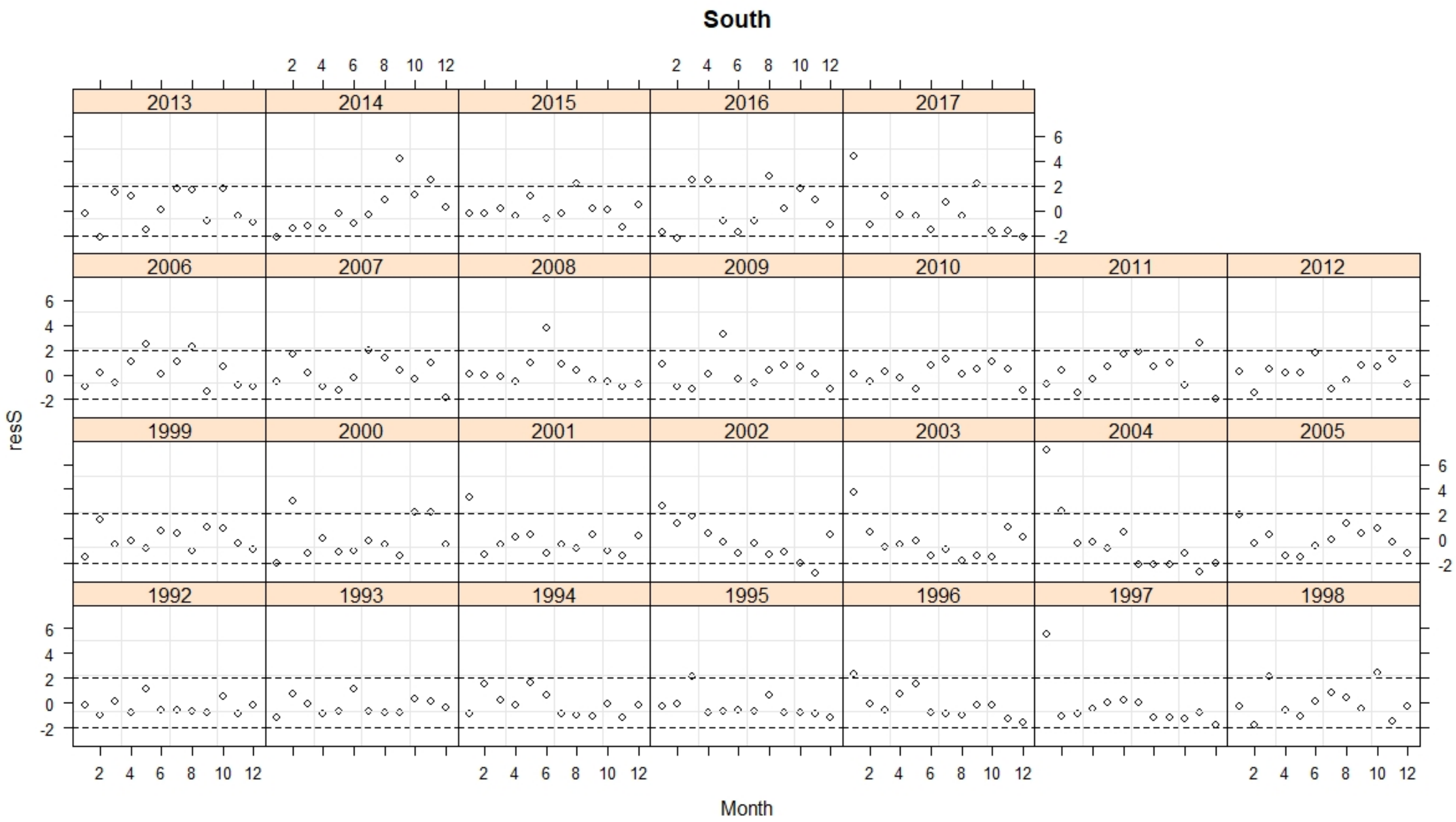

Figure 29: Pearson residuals extracted from the GAMM for the Southern region, showing residuals per month for each year. The months are displayed on the x axis, with residual variation indicated on the y axis. For each window (year), points should be centred around zero, with values outside the -2 and 2 confidence bands being considered lower or higher variation than expected by the model.

12. Appendix 4

12.1 Kernel density maps fresh cases only

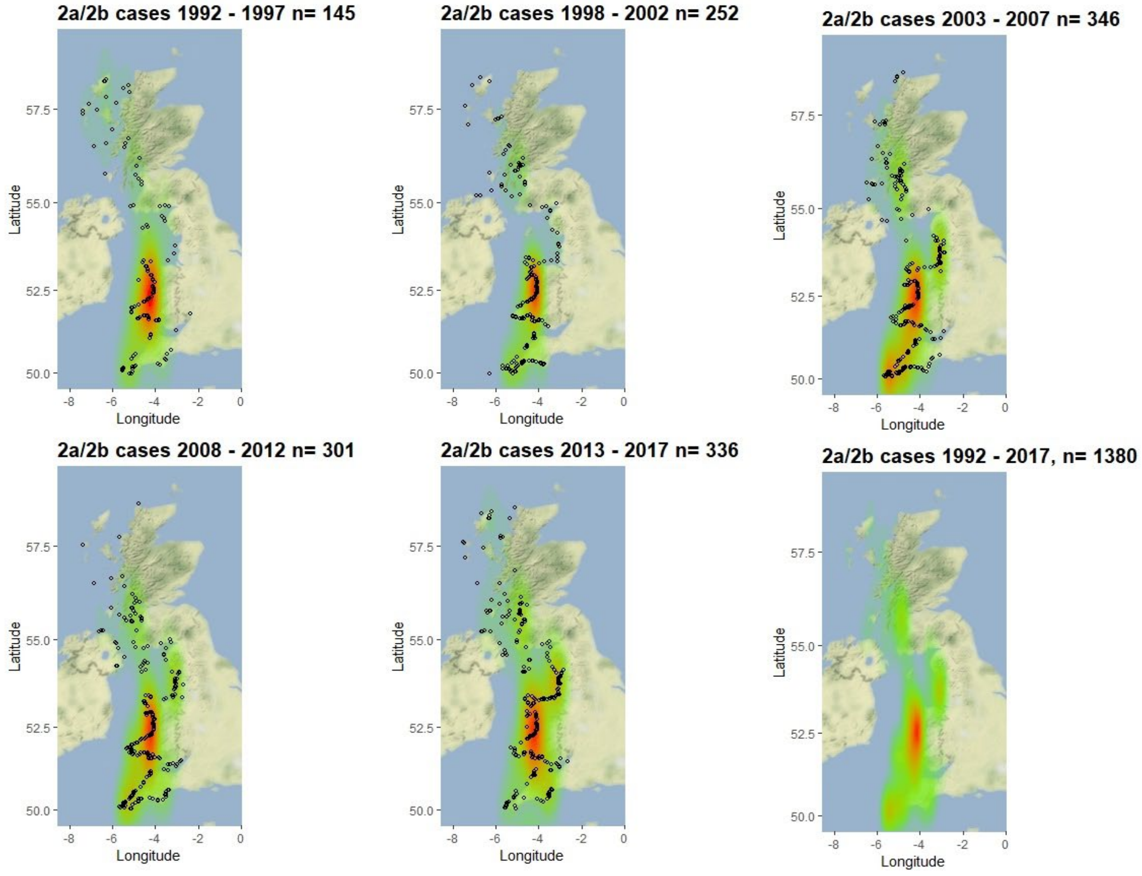

Figure 30: Study area showing the distribution density of freshly dead/slightly decomposed harbour porpoise strandings (2a/2b cases) over five time periods (1992 – 1997, 1998 – 2002, 2003 – 2007, 2008 – 2012, and 2013 – 2017) as well as a map taking into account the entire study period 1992 – 2017. Red areas represent the highest density of strandings per time frame, the black points show individual strandings

No data outputs are held by NRW. Strandings data is held by the UK Cetacean Stranding's Investigation Programme (CSIP).

Information about Strandings data and the central CSIP UK database is accessible via the UK CSIP website

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