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Assessing long-term trends in abundance and distribution of cetacean populations in the United Kingdom using citizen science sighting data

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PRIFYSGOL BANGOR UNIVERSITY

sea watch FOUNDATION

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Declaration

This dissertation is the result of my own independent work, except where stated.

This document is being submitted in partial fulfilment of the requirements for the degree of a Master of Science in Marine Biology.

This work has not previously been submitted and is not currently being submitted for any other degree.

All sources are acknowledged in text and in the references section.

In submitting this work I give consent for my dissertation, if accepted, to be made available for photocopying and interlibrary loan, and the title and summary to be made available to external organisations.

Acknowledgements

I would like to thank Dr James Waggitt for his assistance and guidance in conducting this project, and for providing feedback and insight that made this work possible. I would also like to thank Dr Chiara Bertulli for providing the data used in this project and her guidance in processing and organising the final dataset used. I would like to thank Dr Peter Evans for providing additional source materials and guidance when writing and researching for this dissertation.

I would also like to thank the many volunteers of the Sea Watch Foundation and participants of the National Whale and Dolphin Watch over the years who have collected thousands of hours of effort data and recorded sightings.

Finally, I would like to thank my friends and family for their support and generosity during my studies, and without whom I could not have completed this journey.

List of Abbreviations

ANOVA……………………………………..………………………Analysis of variance

ASCOBANS……………………………. Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas

AWSD ……………………………………………………….. Atlantic white-sided dolphin

BND…………………………………………………………………...Bottlenose dolphin

CODA…………………………………..…Cetacean Offshore Distribution and Abundance in the European Atlantic

GLM ……………………………………………………………… General Linear Model

HP…………………………………………………………………….Harbour porpoise

HWDT ……………………………………………….. Hebridean Whale and Dolphin Trust

IPUE……………………………………………...…………Individuals per unit effort

LFPW ……………………………………………………….. Long-finned pilot whale

MPA…………………………………………………………Marine Protected Area

MW…………………..…………………………………………………Minke whale

MWDW ……………………………………………… Manx Whale and Dolphin Watch

NWDW ……………………………………………… National Whale and Dolphin Watch

SBCD ……………………………………………... Short-beaked common dolphin

SCANS …………………. Small Cetacean Abundance in the North Sea [and adjacent waters]

SPUE………………………………………………………..……Sightings per unit effort

SST……………………………………………………………Sea surface temperature

SWF ……………………………………………………………... Sea Watch Foundation

T-NASS……………………………………………..Trans North Atlantic Sightings Survey

WBD …………………………………………………..… White-beaked dolphin

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Abstract

Monitoring populations of whale and dolphin species is essential to conservation efforts. As distributions of both resident and migratory species can change over time in response to both environmental pressures and interspecies competition, regular monitoring is required in order to detect significant trends.

Traditional scientific surveying programs, while covering large areas systematically, are expensive and conducted at intervals of several years. Citizen science projects, which encourage members of the public to participate in watches, have been proposed in several studies as an alternative source of acquiring large amounts of data. The Sea Watch Foundation, a UK cetacean conservation group, has conducted a Whale and Dolphin Watch annually since 2002.

In this study, data collected from several years of the NWDW have been used to conduct a study of long-term trends in cetacean abundance and distribution in the UK. The results obtained were then compared with results from formal scientific surveys such as SCANS. The aim of this project is to compare the effectiveness of citizen science projects in collecting data and detecting trends compared with surveys conducted by formally trained scientists using cetacean monitoring technology.

1. Introduction

1.1 Cetacean species in the North Atlantic and threats faced

A large proportion of the mammal fauna of the UK consists of marine mammals. 28 cetacean species have been recorded in British and Irish coastal waters since the 1960s, of which 13 are commonly sighted (Evans and Hammond 2004). Many of these species are protected under the EU Habitats Directive, and include species from both the Odontocete and Mysticete suborders. The two most commonly recorded species are the harbour porpoise (*Phocoena phocoena*) and bottlenose dolphin (*Tursiops truncatus*). Other common small cetaceans include the short-beaked common dolphin (*Delphinus delphis*), Atlantic white-sided dolphin (*Lagenorhynchus acutus*) and white-beaked dolphin (*L. albirostris*). Whale species that are commonly seen include minke (*Balaenoptera acutorostrata*) and fin (*B. physalus*) whales. Species such as Risso's dolphin (*Grampus griseus*), orca or killer whale (*Orcinus orca*) and humpback whales (*Megaptera novaeangliae*) are also commonly sighted.

Cetacean species occur either as local resident populations or migrate seasonally. Semi-resident populations of bottlenose dolphins occur in Cardigan Bay in Wales and Moray Firth in Scotland; the Moray Firth population is considered the most significant population of this species within the North Sea (Wilson *et al*. 1997). Larger cetaceans such as minke whales tend to migrate from breeding grounds to the North Atlantic in summer months when prey is abundant (Evans 1980). While some species such as harbour porpoise have a wide range, differences in distribution according to habitat preference have been observed; common dolphins, for example, are rarely found beyond 60°N, where *Lagenorhynchus* sp. become more common in shelf waters around north-western Scotland (Weir et al. 2001).

Cetaceans and other large marine mammals are important as ecological indicators, and serve important ecological roles as both predator and prey species. Many species benefit from the hunting activity of both small and large cetaceans; it has long been observed that the concentration of prey towards the surface during whale feeding also provides feeding opportunities for many seabird species (Evans 1982). In addition to their role as predators, cetaceans contribute to nutrient cycling and ocean productivity. Carcasses of large whales represent a significant nutrient source for deep-sea benthic fauna, supporting a diverse range of taxa in successional assemblages from scavengers to bone specialists (Lundsten et al.

2010). Additionally, it has been estimated that pre-whaling populations, in terms of biomass, may have represented as much as $2.5x10^7$ tonnes of carbon storage in global oceans (Pershing et al. 2010). Finally, as highly charismatic and intelligent species, protecting cetacean biodiversity may have the additional benefit of promoting the protection of marine ecosystems as a whole, and whale and dolphin-based wildlife tourism can represent a considerable source of income and employment in rural coastal areas (Parsons et al. 2003).

Many subpopulations of whale and dolphin species worldwide are at risk due to changes in the marine environment, many occurring primarily as a result of human activity. Although common and widely distributed, harbour porpoises are of particular concern to conservation, suffering high mortality rates as a result of fishing bycatch. Bjørge *et al*. (2013) estimated that as many as 6, 900 porpoises are killed as bycatch annually in Norwegian fisheries. Increases in average ocean temperature over the past several decades have impacted cetaceans, primarily through habitat loss and changes in prey availability resulting in changes in distribution for many species (Simmonds and Elliott 2009). Cetaceans are also vulnerable to pollutant-related mortality, particularly heavy metal and microplastic contaminants from ingested prey. Such pollutants are known to affect reproductive success and survival rates; additionally, larger plastic fragments have been found in the stomach contents of many species of stranded cetaceans (Baulch and Perry 2014). Another threat to many cetacean species is the development of offshore structures such as oil and natural gas rigs and wind farms; such constructions can cause disturbance and may produce damaging levels of noise pollution during construction (Goodale and Milman 2016).

1.2 Cetacean monitoring and conservation

Cetacean species in the EU are protected under the EU Habitats Directive, which requires regular monitoring of cetacean species. Data gathered in large-scale cetacean surveys is used to inform marine ecosystem management policy and the designation of marine protected areas (MPAs). Frequent monitoring of whale and dolphin populations is essential to conservation, and allows for accurate population estimates and to determine trends in abundance and distribution. Insufficient data remains a challenge in assessing many species populations, and while large-scale scientific surveys can produce estimates of populations as a whole, changes in local populations are often more difficult to determine using such data.

International scientific surveys such as the SCANS surveys, conducted in 1994, 2005 and 2016 (Hammond et al. 1995; Hammond et al. 2013; Hammond et al. 2017), are one of the most important sources of cetacean abundance data, covering large areas systematically by aerial or vessel-based line-transect surveys and generating reliable abundance estimates. Other examples of such large-scale surveys include T-NASS, which measured the abundance of fin whales in Iceland and the Faroes (Pike et al. 2008), and CODA, which focuses on offshore populations in the western Atlantic beyond the continental shelf (Hammond et al. 2009).

Many scientific surveys incorporate acoustic monitoring (Nuuttila et al. 2017) or mark-recapture techniques when assessing smaller subpopulations. Historically, stranding data has also been used to estimate abundance, and is still used for data-deficient species that are more difficult to detect in surveys (Meager and Sumpton 2016). Combining data from different sources (e.g. Cheney et al. 2013) has the advantage of creating a large sample size and covering larger areas in greater detail than a single survey. However, problems in comparing data in different formats can arise when such datasets are analysed. Data from aerial, vessel-based and land-based surveys require different recording methods, and different organisations may use different techniques.

The cost and resources required to undertake large-scale surveys limits the extent of the data that projects such as SCANS can provide; surveys are conducted once every 10 years, and overall abundance within the North Atlantic is measured, rather than coastal distribution at a small scale. Additionally, significant watch effort is required to generate meaningful data when covering a large area, and the intensity of effort needed limits traditional scientific surveys compared to volunteer projects involving large numbers of people. One method that has been suggested as a lower-cost alternative is the use of commercial ferries as platforms of opportunity, which have the advantage of following fixed routes, effectively allowing line-transect surveys to be taken within an area over time (Brereton et al. 2001).

1.3 Citizen science and the Sea Watch Foundation

Citizen science is being increasingly recognised as a useful tool for gathering data relevant to informing policy, and while it cannot replace formal scientific surveys, it can potentially provide data at a larger scale than most scientific projects (Hyder et al. 2015). Citizen science can be defined as the undertaking of recording and collecting data by members of the public not formally trained as scientists. Citizen science projects can be a relatively inexpensive method of acquiring large amounts of data, and can involve many hundreds of volunteers over a large area. Data collected from citizen science projects can be incorporated into scientific studies, and the process of collecting data can inspire enthusiasm in members of the public, particularly projects relating to conservation of charismatic species or environmental issues such as marine litter. A wide range of biological criteria can be measured using citizen science projects, from species distribution and abundance to migration timing and species interactions within ecosystems (Chandler et al. 2017). In addition to lower costs and large numbers of volunteers, citizen science can offer additional advantages over traditional scientific surveys. For example, volunteer surveys can reveal areas with a high encounter rate on a smaller scale than areas typically covered by scientific surveys (Alessi et al. 2019).

Volunteer surveying programs can be an effective method of collecting data, and can provide useful data from areas that are not regularly monitored. However, some of the limitations of citizen science projects include the requirements of basic training in field methods for volunteers and the need to organise data collected in a format that meets scientific requirements (Thiel et al. 2014). Many recent studies have attempted to assess the validity of using citizen science data as a method of obtaining estimates of species abundance and distribution compared to traditional scientific surveys. The main challenges to increasing the incorporation of citizen science data include concerns over the quality and accuracy of recorded data (Hochachka et al. 2012). Additionally, issues relating to data structure can create challenges in analysis; in recent years general linear models (GLMs) using additional predictive factors such as behaviour and time of day have increased the power to interpret limited datasets, such as presence-only species data (Higby et al. 2012). Other challenges include accounting for variability in observer estimates and autocorrelation when conducting statistical analysis (Bird et al. 2014).

The Sea Watch Foundation (www.seawatchfoundation.org) is a volunteer conservation organisation that conducts regular monitoring of cetaceans and encourages education and engagement with the public. Sea Watch has conducted a National Whale and Dolphin Watch annually in late July and early August since 2002. Hundreds of volunteers along the UK coast record thousands of hours of watch effort annually, including land and vessel-based data, and large amounts of sightings records have been collected. Sightings from whale-watching and marine mammal conservation groups such as the Hebridean Whale and Dolphin Trust are also included in sightings databases. Data obtained by Sea Watch has been included in several cetacean distribution studies (e.g., Marubini et al. 2009) and research conducted by Sea Watch volunteer members has contributed to a number of key marine protection policies, including the EU Habitats Directive and the UK Biodiversity Action Plan for Cetaceans.

1.4 Hypotheses and Objectives

The primary aim of this project is to compare the findings of the Sea Watch Foundation with results from large-scale scientific surveys such as SCANS in order to determine the ability of volunteer-gathered data to accurately detect trends in cetacean abundance and distribution.

The main hypothesis of this project is that surveys carried out in citizen science programmes are as effective as formal scientific surveys in detecting cetaceans and that a similar estimate of abundance can be generated for a given species. The project also aims to determine if there is a significant relationship between hours of watch effort invested by a volunteer and successful sightings/number of cetaceans sighted, and to determine the amount of watch effort required to detect cetaceans within the study area.

The aims of this project are:

To determine changes in distribution and abundance of cetacean species in different regions between years.

To analyse the relationship between watch effort and cetacean sightings

To compare sighting rates of each species across each year and between regions.

To identify areas that may be of interest to conservation where shifts in species distribution have occurred.

To compare average sighting rate with sighting rates from formal scientific surveys such as SCANS, and from published studies of populations in the same regions.

2. Methods

2.1 Temporal extent of study and survey area

The study area consisted of continental shelf waters around the British Isles, between latitudes 48° and 61°N, including as far north as Shetland and as far south as Guernsey and northern France. The total survey area covered between all years from ferries, small mobile boats and land watches includes up to approximately 145,000km^2 and 11,000km of coastline.

Effort and sightings were categorised into six coastal regions, based on groupings of existing SWF designations;

1. the North-East Atlantic including the Hebrides, Orkney and Shetland;

2. the North Sea extending from the Moray Firth to North Yorkshire;

3. the North Sea from Flamborough Head to Margate;

4. the Channel, from Kent to South Devon and including the Channel Islands;

5. the Celtic Sea/Western Approach extending from Cornwall to Aberystwyth;

6. the Irish Sea, extending from North Wales to the Firth of Clyde and including Northern Island and the Isle of Man.

In order to compare citizen survey effectiveness with established long-term scientific survey programs, such as SCANS, a temporal comparison of accumulated SWF data was made at 3-year intervals from 2009 to 2018. Data from 2018, 2015, 2012 and 2009 were cleaned and organised, then compiled and integrated into a single database, allowing for analysis and comparison.

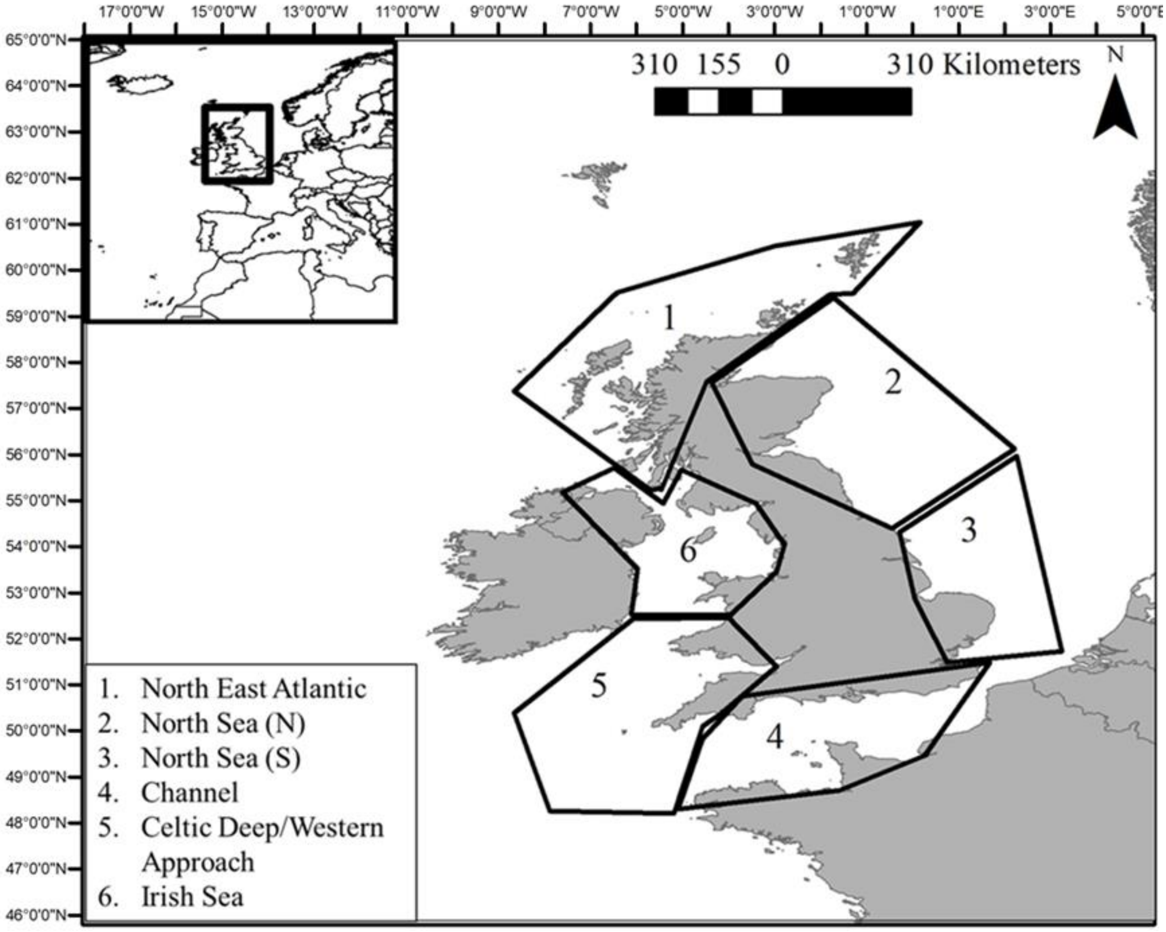


Figure 1. Map of sea regions (created in ArcGIS (ESRI 2018)).

2.2 Survey methods

Across the four years of data covered in this study, the majority of dedicated watches were carried out from land, with a smaller subset conducted from wildlife tour boats, commercial ferries or small motorboats. Sea Watch volunteers followed similar methods for recording effort and sighting data in land or vessel-based surveys. Basic information such as location, date and time were recorded, along with GPS location, sea state, swell height and relevant additional information such as weather conditions and presence of boats in the area. All surveys were conducted in conditions of up to sea state/Beaufort scale 5, with the majority of watches conducted between sea state 2-3.

Conditions were recorded every 15 minutes regardless of presence of animals, and in vessel-based surveys GPS position was logged every 15 minutes. When cetaceans were sighted, species, group estimate and presence of calves/juveniles was recorded, along with bearing, distance, behaviour and any additional relevant information. A dedicated watch is considered by the Sea Watch foundation to be at least 30 minutes, and most watches consisted of 1 or 2 hour periods. Sea state, visibility and swell height were the only consistently recorded environmental variables; wind speed and direction, boat speed, precipitation type and intensity were most commonly not recorded. Only sea state and visibility were included in analysis.

Table 1. Watch effort by year, platform type and region. *Includes all vessel-based platforms; ferry, motorboat, sailboat, etc.

	Region					
	1		**2**		**3**	
Platform	Land	Vessel*	Land	Vessel*	Land	Vessel*
Year						
2018	42:30	199:35	206:00	14:40	91:35	02:15
2015	36:00	113:45	263:15	82:10	67:25	39:05
2012	24:15	0	81:00	27:00	44:40	0
2009	02:00	0	22:00	16:15	03:00	0
Total	104:45	313:20	572:15	140:05	206:40	41:20

	Region					
	4		**5**		**6**	
Platform	Land	Vessel*	Land	Vessel*	Land	Vessel*
Year						
2018	28:30	21:35	91:30	119:40	57:45	22:30
2015	24:15	14:00	268:05	42:55	73:20	65:50
2012	56:40	0	93:05	13:05	101:30	06:00
2009	07:30	0	14:45	0	0	0
Total	116:55	35:35	467:25	175:40	232:35	94:20

2.3 Data cleaning and processing

Data was obtained and collated from four years of NWDW sighting records. Data was formatted and checked for errors and missing data. Data was visualised using Microsoft Excel and R, using the package plotrix, and sites of encounters were mapped using ArcGIS (ESRI 2018).

For the purposes of the study, only effort-related data were considered. As the durations of watch times between observers varied considerably, a measure of watch effort termed “Units of effort" was calculated by dividing watch times into 15-minute sections, with a unit of effort 1 being defined as 15 minutes, 2 units as 30 minutes, *etc*. Observations that were not part of a continuous series and were less than 15 minutes were considered "casual" sightings and were filtered from the database.

A total of thirteen species were recorded across all years. However, many sightings lacked a definite identification, and were marked as UNCE (unknown cetacean), UNLW (unknown large whale) or UNDO (unknown dolphin). For the purposes of analysis all sightings were included; however for the purpose of visualising trends in abundance only the five most commonly recorded identified species were used; harbour porpoise (HP), bottlenose dolphin (BND), minke whale (MW), short-beaked common dolphin (SBCD), and white-beaked dolphin (WBD).

2,4 Data Analysis

Statistical analysis was conducted using R (R Core Team 2018). In order to determine the relationship between amount of watch effort and sightings rate, a table was created from the raw dataset, totalling the amount of watch effort and number of sightings for each combination of observer, date, and location. A linear regression was then conducted on watch effort in minutes and number of animals seen per observation. To further investigate the significance of additional factors such as sea state and platform type, effort data was separated by year, and a number of general linear models (GLMs) were run with the following variables tested as random factors; platform type, date, sea state, region and visibility.

Total counts for each of the five species of interest was used to estimate individuals per unit effort. An ANOVA was run for each species to determine if abundance differed significantly between years and between regions. Abundance estimates obtained were compared with estimates from several years of surveys such as SCANS, allowing for differences in methods of estimating abundance and total area covered.

3. Results

3.1 Effort intensity and sightings by year

A total of 2501 hours and 5,740 animals across four years were included in the final analysis. A summary of the watch hours, units of effort and sightings for each year are outlined in Table 2. As only five species were analysed in detail, a list of all species and numbers seen is given in Appendix 1.

Table 2. Summary of data by year. *Includes categories of 'unknown cetacean'.

Year	Survey dates	Sightings	Animals recorded	Total effort (in watch hours)	Units of effort	Number of species seen*
2018	28/7 - 5/8	851	3498	898:05:00	3592.8	13
2015	25/7 – 2/8	418	1489	1090:05:00	4421.4	13
2012	27/7- 5/8	146	583	447:15:00	1788	6
2009	18/7- 26/7	21	170	65:30:00	262	2

Table 3. Summary of watch effort and total animals seen by year and region.

2018				
Regions	Animals	Hours	Units of effort	Sighting rate
1	865	242:20:00	969.3	0.892397
2	505	220:40:00	882.6	0.572173
3	183	93:50:00	375.3	0.48761
4	34	50:05:00	201.3	0.168902
5	1680	211:10:00	844.3	1.989814
6	231	80:00:00	320	0.721875
Total	3498	898:05:00	3592.8	0.973614
2015				

Regions	Animals	Hours	Units of effort	Sighting rate
1	358	149:45:00	598.1	0.598562
2	425	345:25:00	1379.5	0.30808
3	20	106:30:00	453.4	0.044111
4	9	38:15:00	152.9	0.058862
5	585	311:00:00	1259.6	0.464433
6	92	139:10:00	577.9	0.159197
Total	1489	1090:05:00	4421.4	0.336771

2012

Regions	Animals	Hours	Units of effort	Sighting rate
1	26	24:15:00	97	0.268041
2	359	112:20:00	448	0.801339
3	21	40:40:00	162.6	0.129151
4	29	56:40:00	226.3	0.128148
5	111	106:10:00	424.4	0.261546
6	37	107:30:00	429.7	0.086107
Total	583	447:15:00	1788	0.326063

2009

Regions	Animals	Hours	Units of effort	Sighting rate
1	7	2:00:00	8	0.875
2	159	38:30:00	154	1.032468
3	2	3:00:00	12	0.166667
4		7:30:00	30	0
5	2	14:45:00	59	0.033898
Total	170	65:45:00	263	0.646388

3.2 Species abundance

Harbour porpoise

Across all years, harbour porpoise was the most commonly recorded species with a total of 2,350 individuals recorded across all years, and were recorded in all regions. The highest rate of occurrence was in 2018, with 313 animals sighted in region 1 (mean group size=2.285, SD=1.715) and 594 animals sighted in region 5 (mean group size= 4, SD= 4.1658).

Table 4. Harbour porpoise abundance in individuals per unit effort (IPUE) for each region and year.

		Region					
Year	**N total**	1	2	3	4	5	6
2018	1422	0.322913	0.134829	0.474287	0.084451	0.703541	0.628125
2015	736	0.436382	0.149329	0.044111	0.039241	0.13417	0.12805
2012	180	0.247423	0.125	0.129151	0.026513	0.094251	0.076798
2009	12	0.875	0.006494	0.166667	0	0.033898	0

Bottlenose dolphin

Bottlenose dolphins were most commonly recorded in regions 2 and 5, with no sightings recorded in region 3. A total of 1,218 individuals were recorded across all years, with the highest rates of occurrence in region 2. 298 animals were recorded in region 2 in 2018 (mean group size=5.5185, SD=4.2058). Bottlenose dolphins were only recorded in region 2 in 2009, but were recorded in larger group size estimates than in later years (N=158, mean group size= 11.286, SD=11.118).

Table 5. Bottlenose dolphin abundance in individuals per unit effort (IPUE) for each region and year.

		Region					
Year	**N total**	1	2	3	4	5	6
2018	527	0.051584	0.337639	0	0.014903	0.195428	0.034375
2015	185	0	0.070315	0	0	0.065894	0.008652
2012	348	0	0.558036	0	0.101635	0.167295	0.009309
2009	158	0	1.025974	0	0	0	0

Minke whale

Due to low average group size, minke whale numbers were low but were recorded across all regions except region 4. A total of 112 minke whales were sighted across four years, with the highest rate of occurrence in region 1 in 2018 (N=45, mean group size=1.046, SD=0.305).

Table 6. Minke whale abundance in individuals per unit effort (IPUE) for each region and year.

		Region					
Year	**N total**	1	2	3	4	5	6
2018	84	0.046425	0.038523	0.005329	0	0.001184	0.00625
2015	22	0.018392	0.005074	0	0	0.001588	0.003461
2012	6	0.010309	0.011161	0	0	0	0

Short-beaked common dolphin

A total of 1,598 common dolphins were sighted in 2015 and 2018; the highest sighting rate occurred in region 5 in 2018 (N=895, mean group size= 10.056, SD= 10.36).

Table 7. Common dolphin abundance in individuals per unit effort (IPUE) for each region and year.

		Region					
Year	**N total**	1	2	3	4	5	6
2018	1223	0.316723	0.007931	0	0	1.06005	0.04375
2015	375	0.030095	0.028996	0	0	0.249285	0.005191

White-beaked dolphin

White-beaked dolphins were only sighted in regions 1 and 2, with the highest abundance recorded in region 2; however, 59 white-beaked dolphins were also sighted in region 1 in 2018 (mean group size= 11.8, SD=16.07).

Table 8. White-beaked dolphin abundance in individuals per unit effort (IPUE) for each region and year.

		Region					
Year	**N total**	1	2	3	4	5	6
2018	95	0.060869	0.040789	0	0	0	0
2015	52	0	0.037695	0	0	0	0
2012	44	0	0.098214	0	0	0	0

3.3 Changes in species distribution between years

Figure 2 (a-d) shows the changes in spatial distribution of sighting across years. Overall, there was an increase in number of sightings and species diversity between 2009 and 2018, as watch effort and number of watch locations increased.

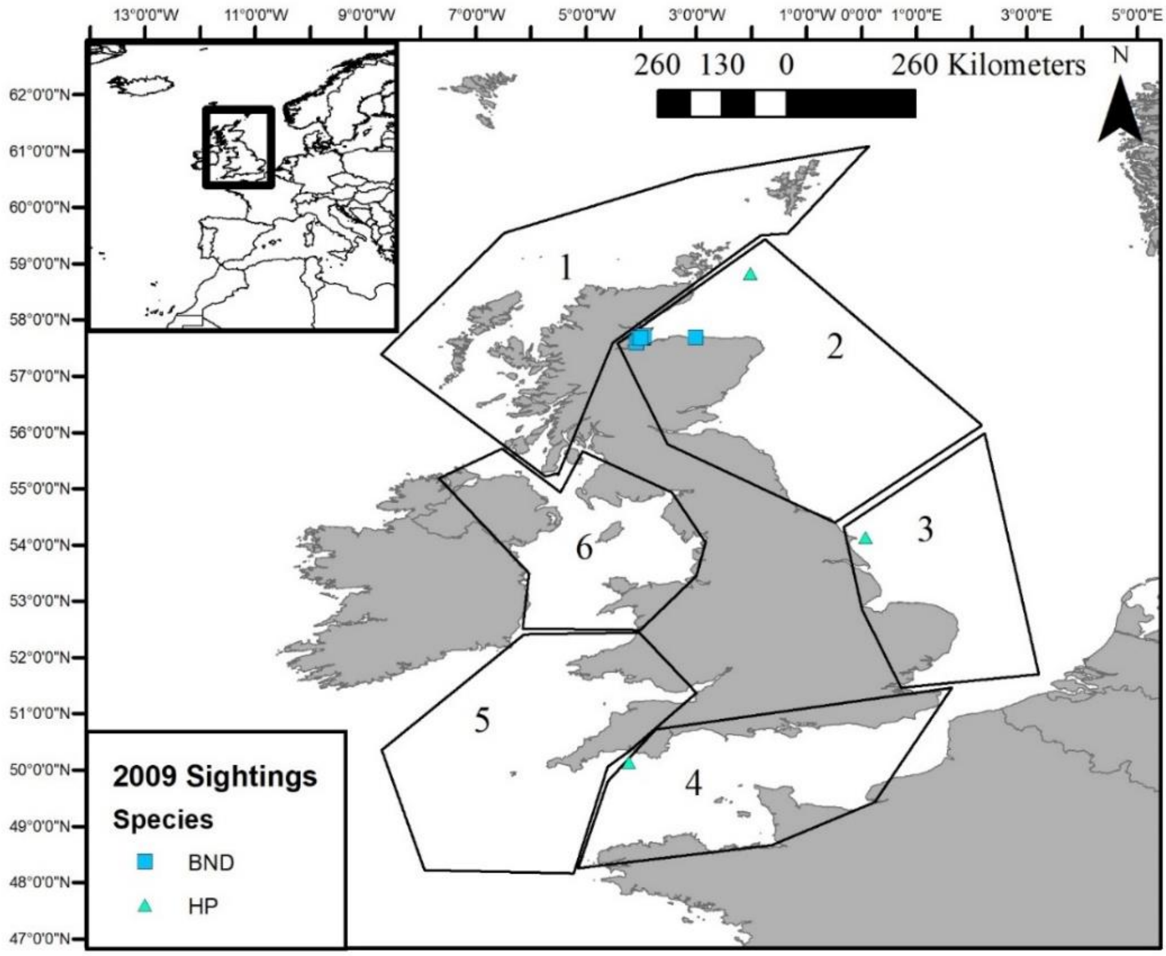


Figure 2. (a) Distribution of effort-related sightings in 2009.

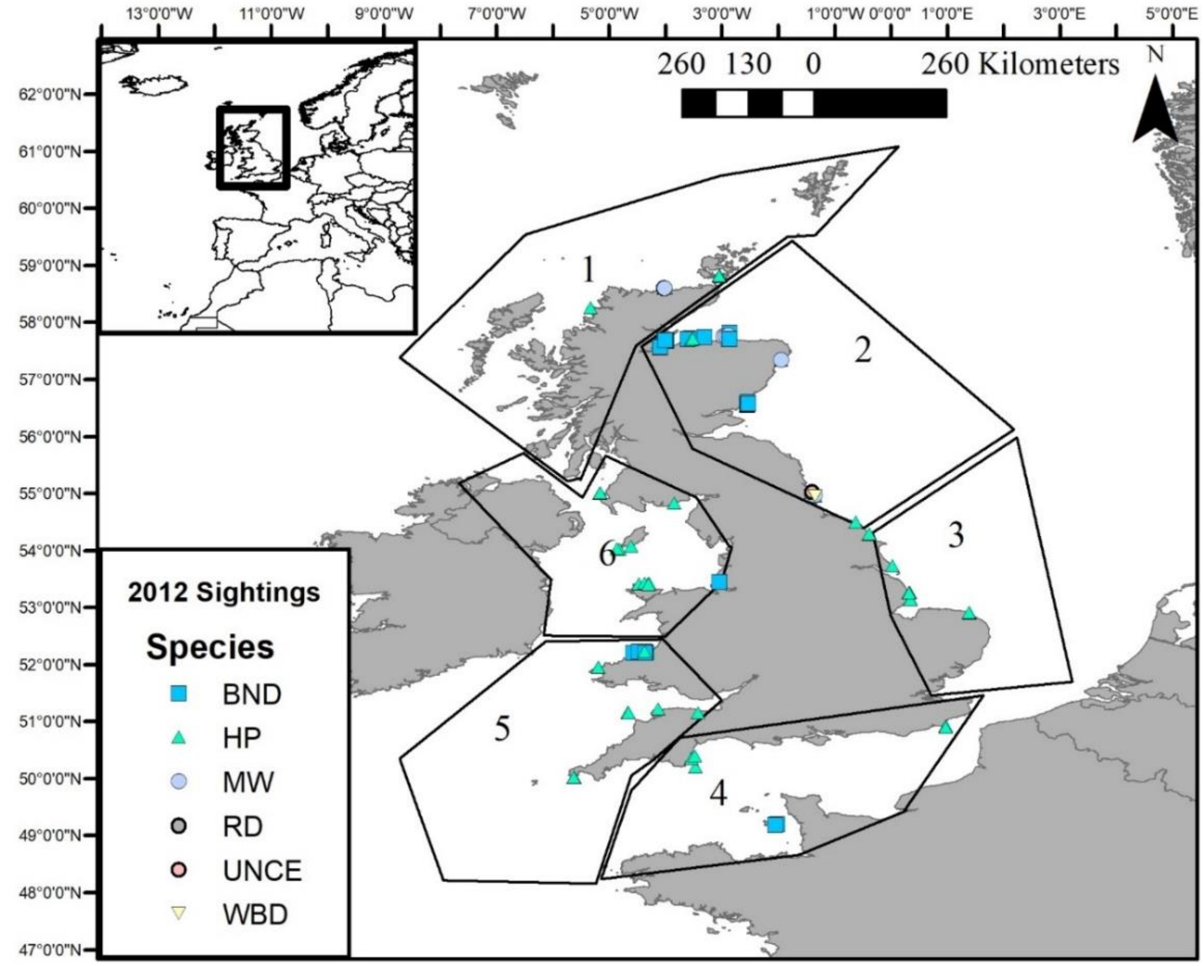


Figure 2. (b) Distribution of effort-related sightings in 2012.

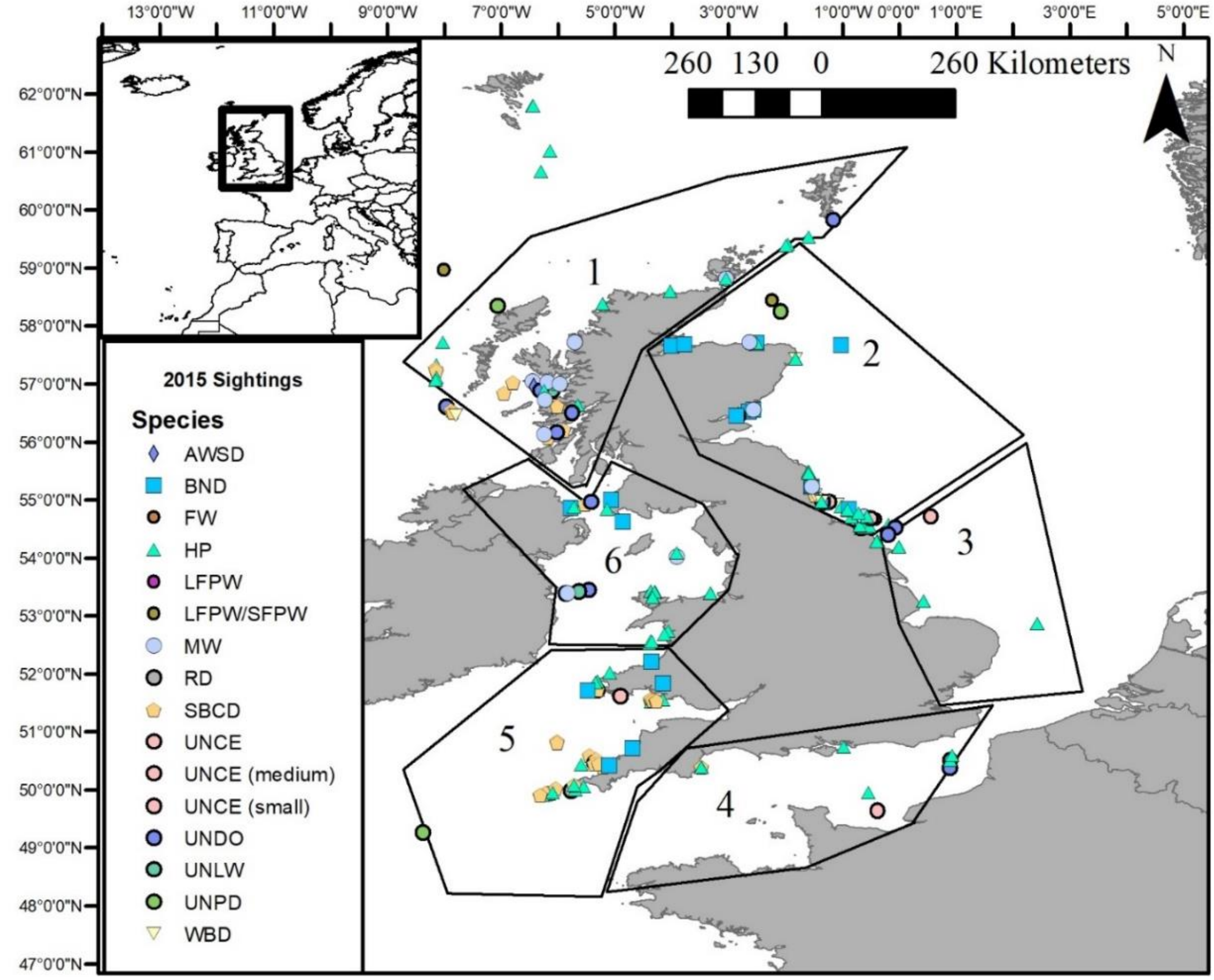


Figure 2. (c) Distribution of effort-related sightings in 2015.

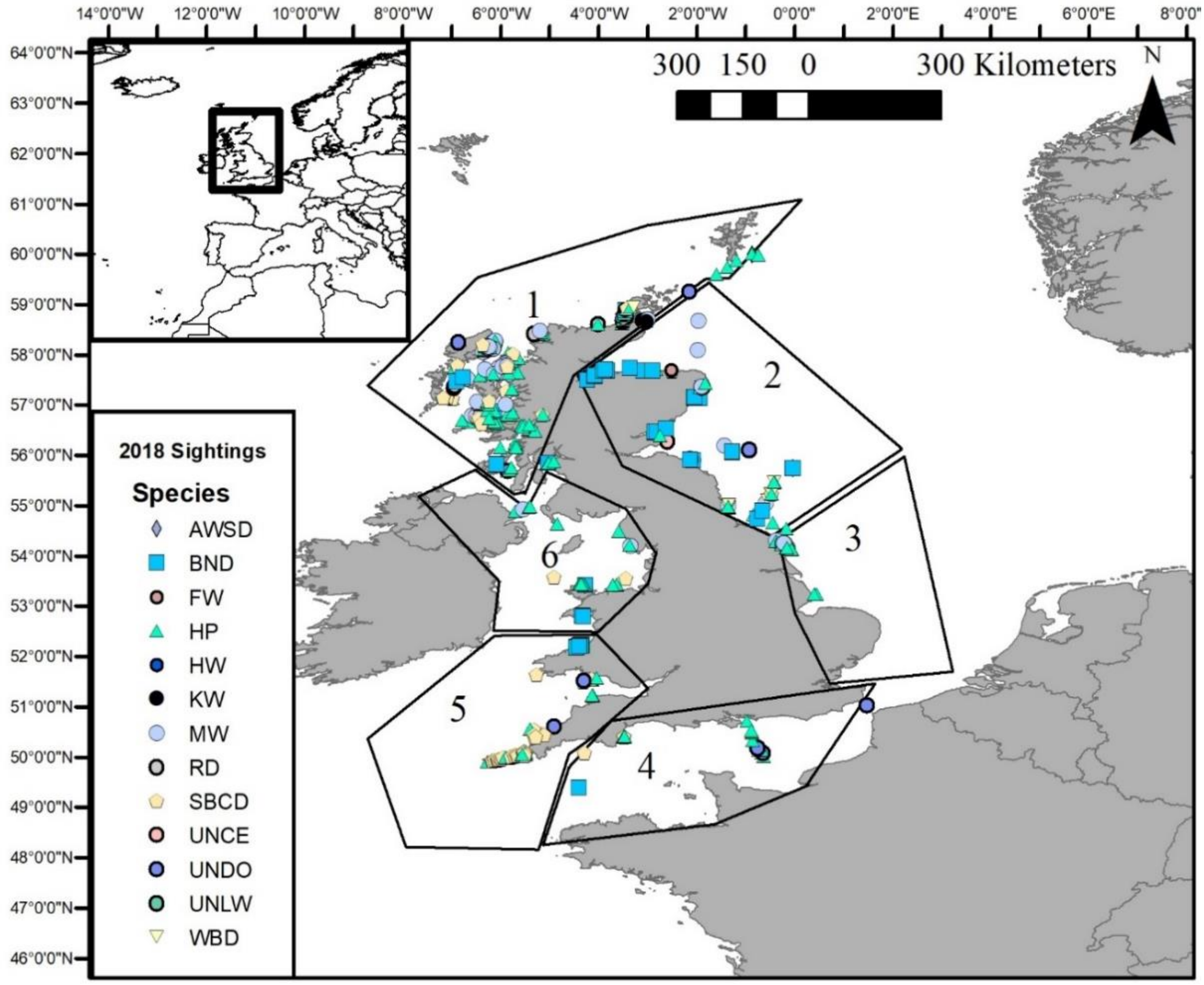


Figure 2. (d) Distribution of effort-related sightings in 2018.

In general, the areas of highest abundance for all species were regions 1, 2, and 5 (Hebrides/North East Atlantic, North Sea and Celtic Sea). Common dolphins and minke whales, in particular, were concentrated in the southwestern Celtic Sea and North Sea respectively.

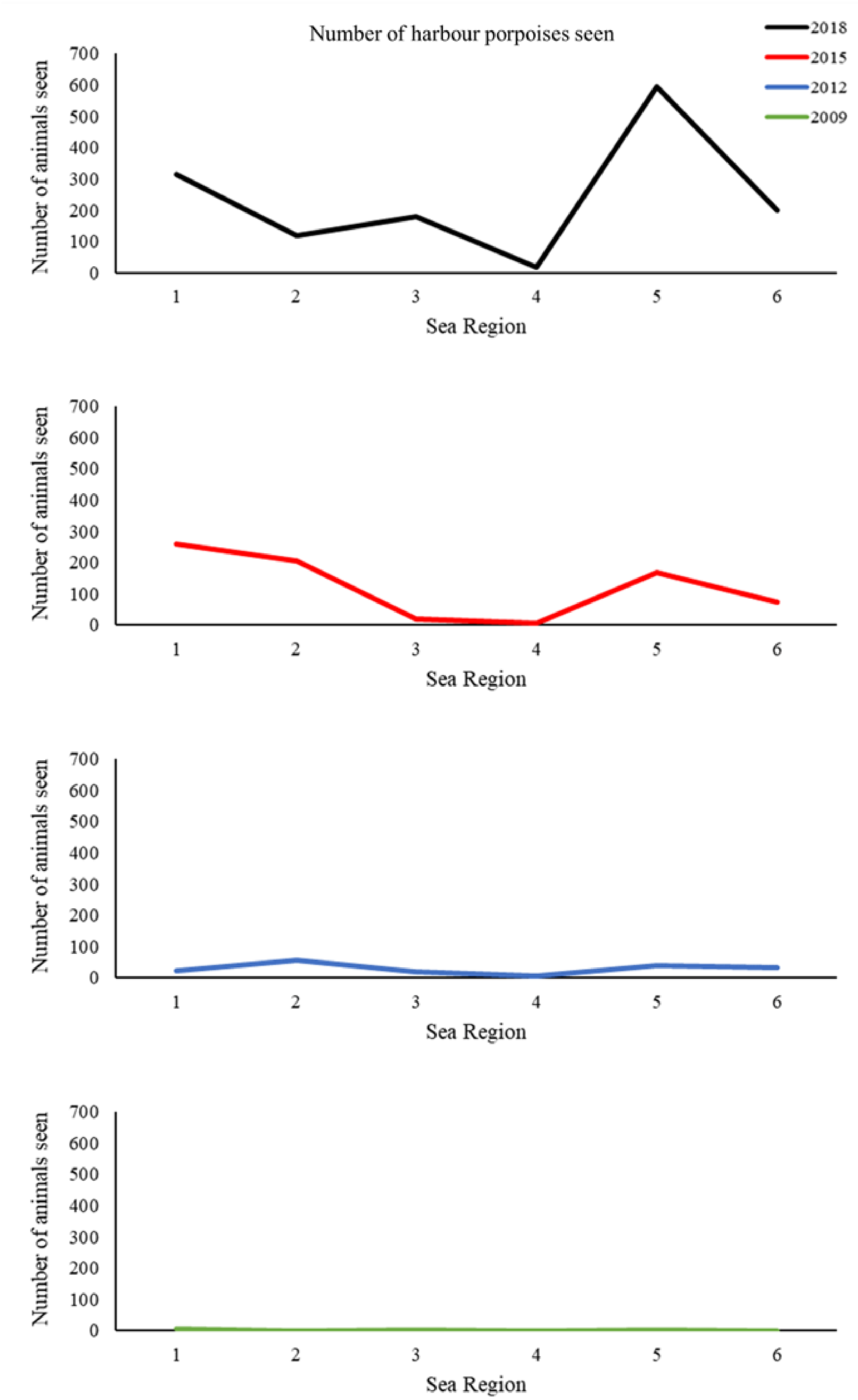


Figure 3. Abundance of harbour porpoise (*Phocoena phocoena*) in each region by year.

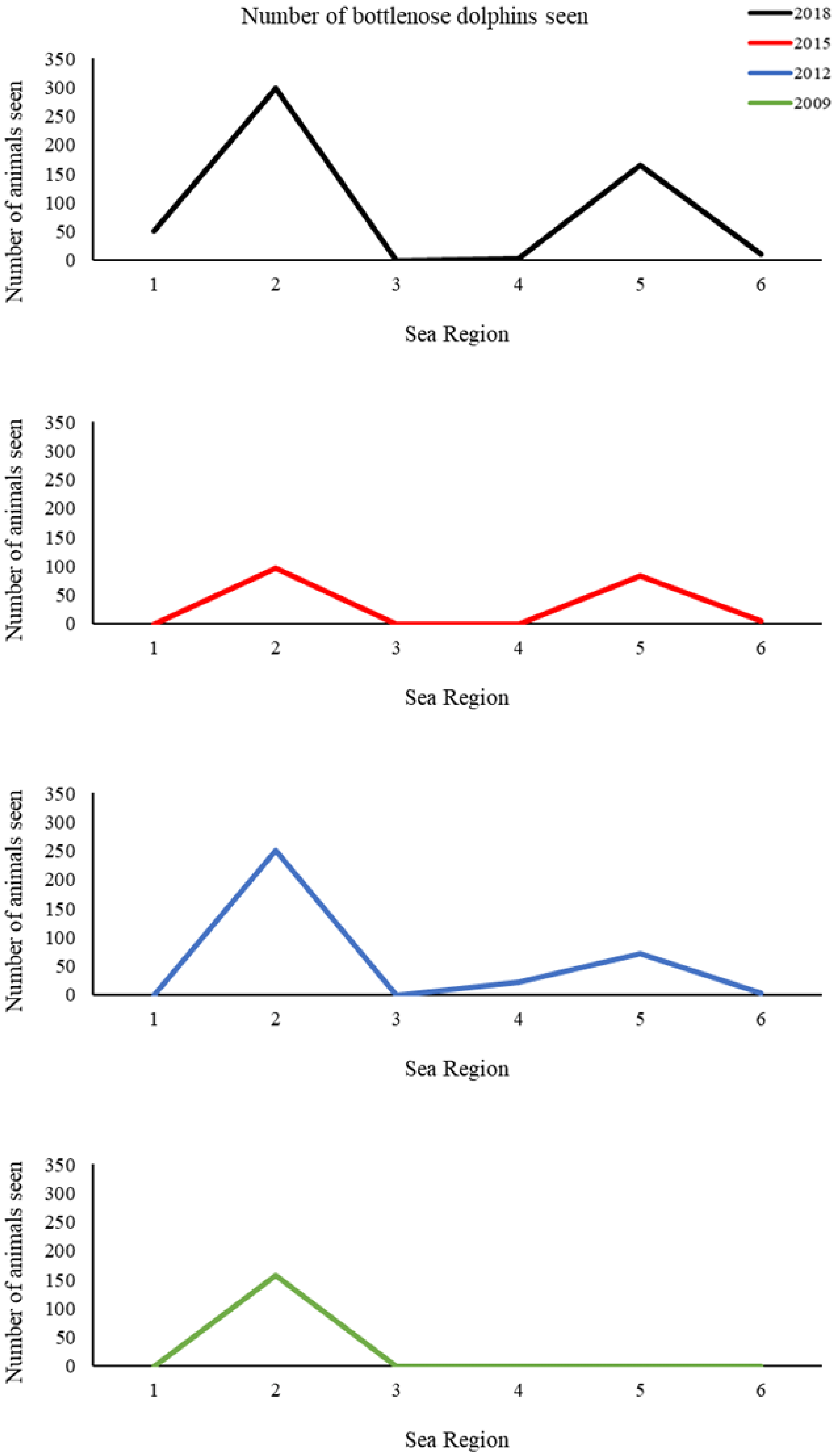


Figure 4. Abundance of bottlenose dolphin (*Tursiops truncatus*) in each region by year.

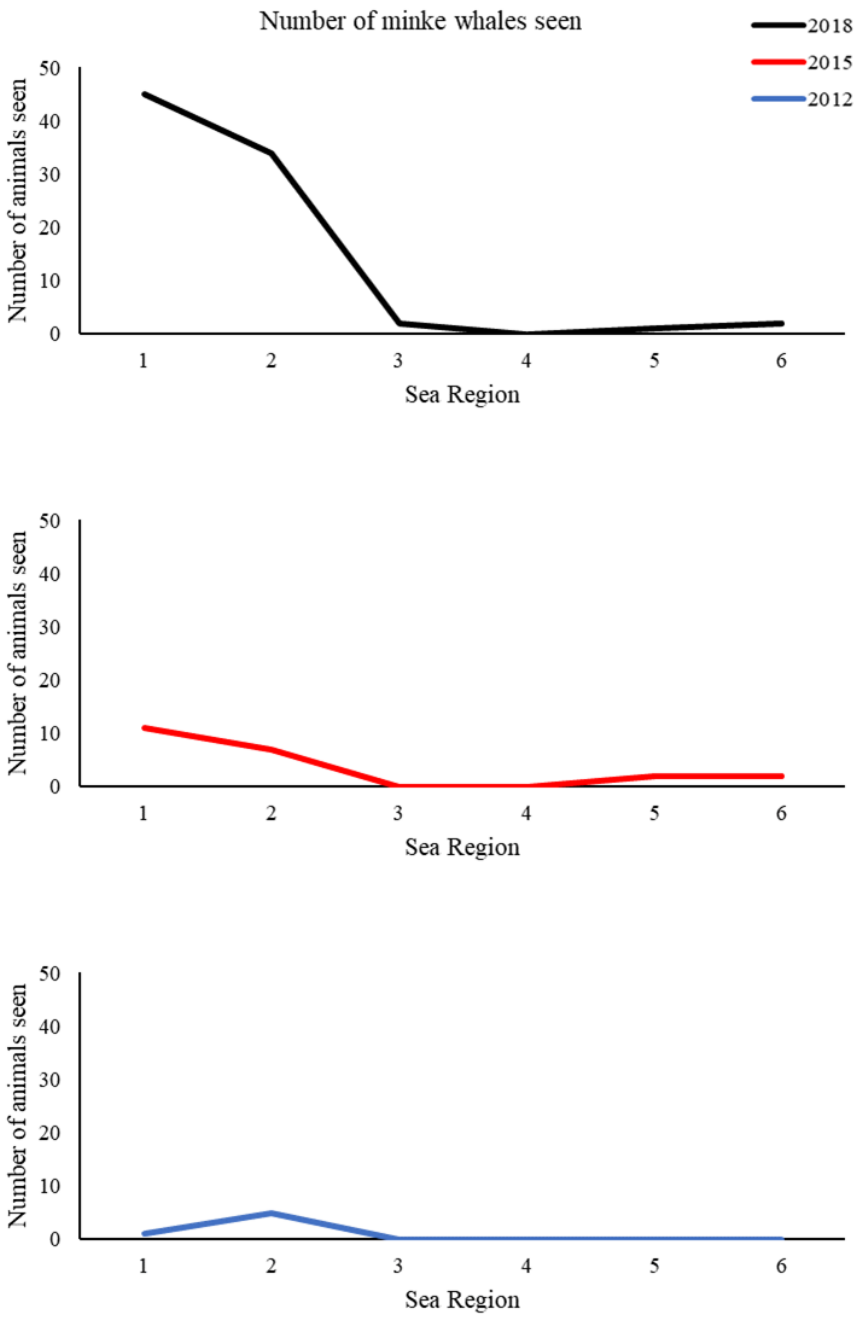


Figure 5. Abundance of minke whale (*Balaenoptera acutorostrata*) in each region by year.

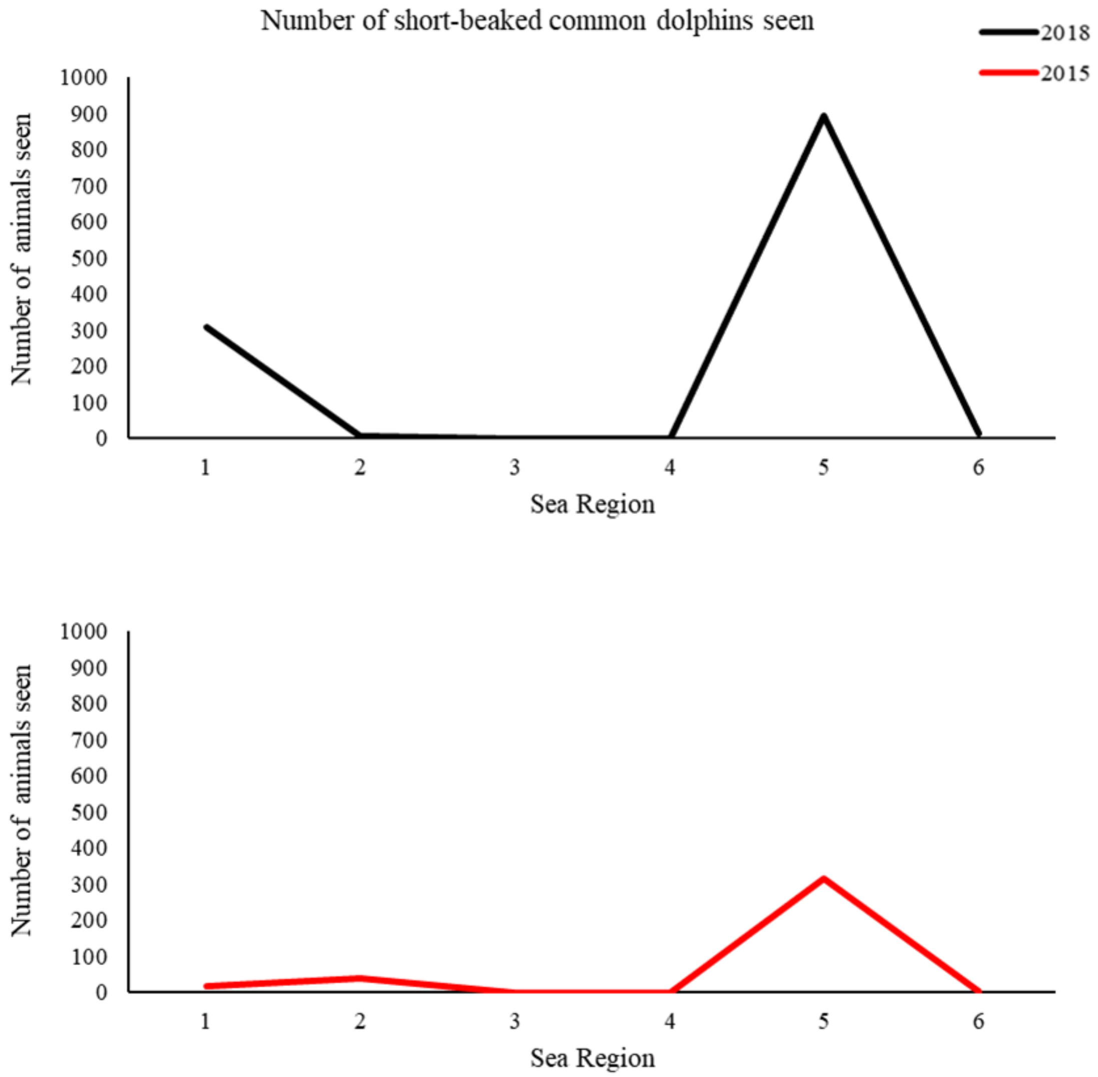


Figure 6. Abundance of short-beaked common dolphin (*Delphinus delphis*) in each region by year.

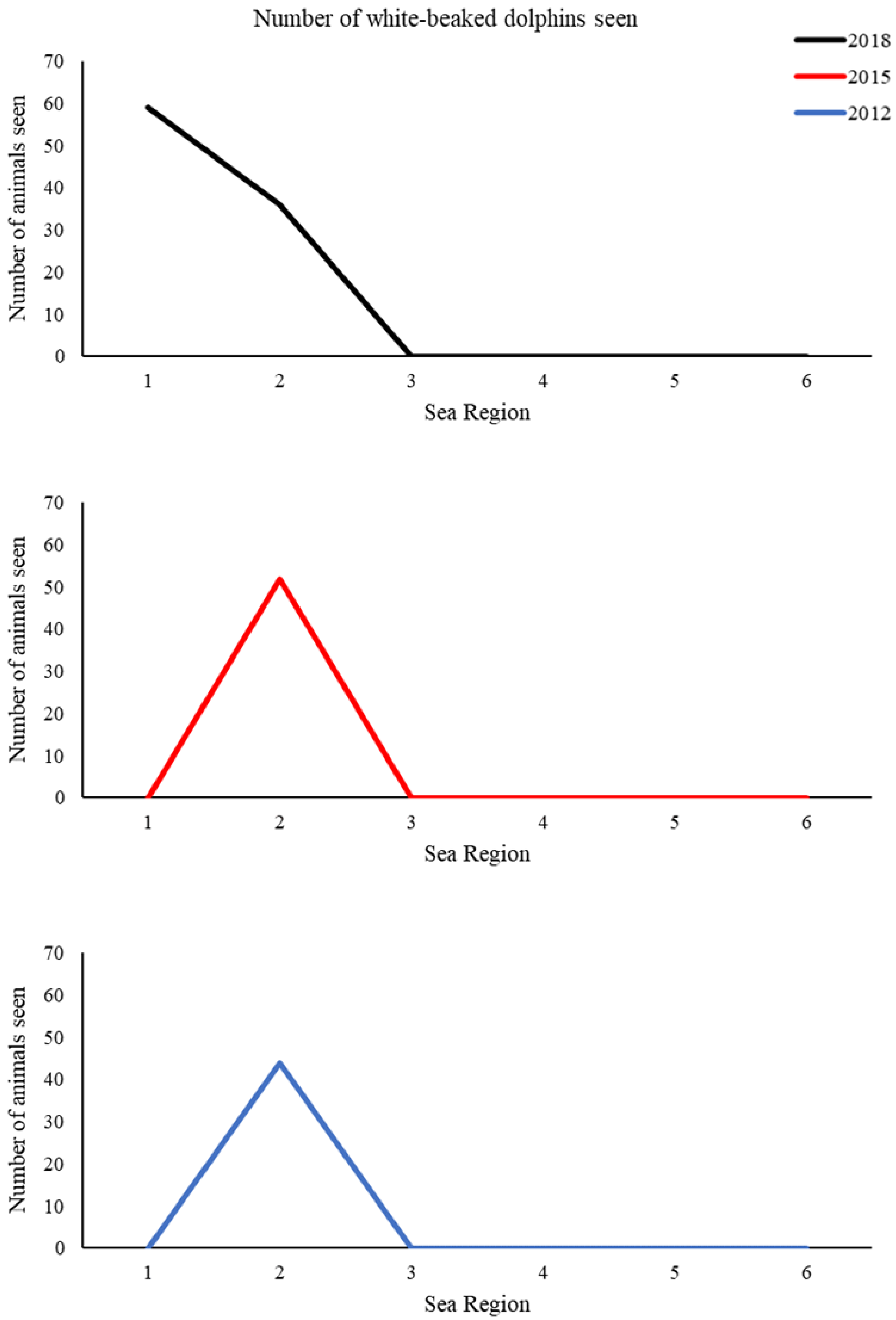
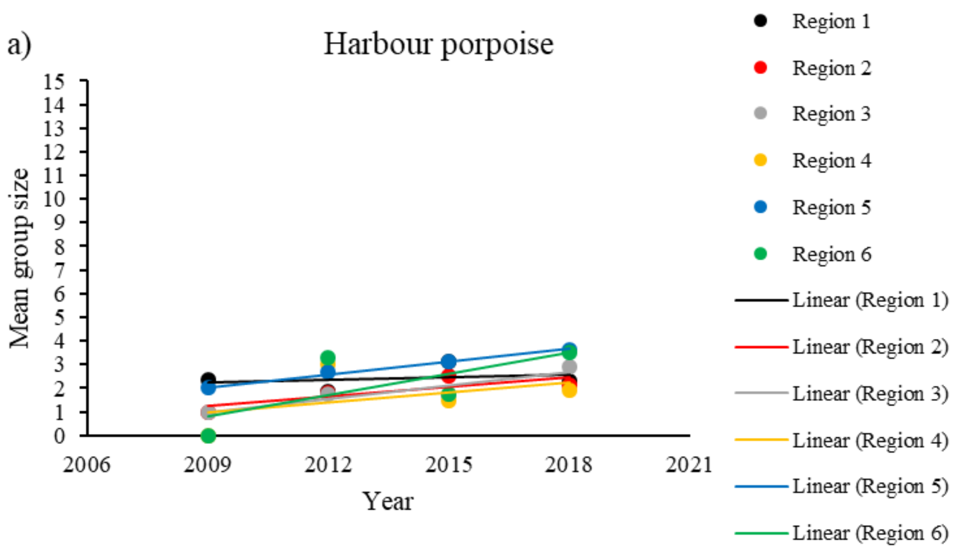
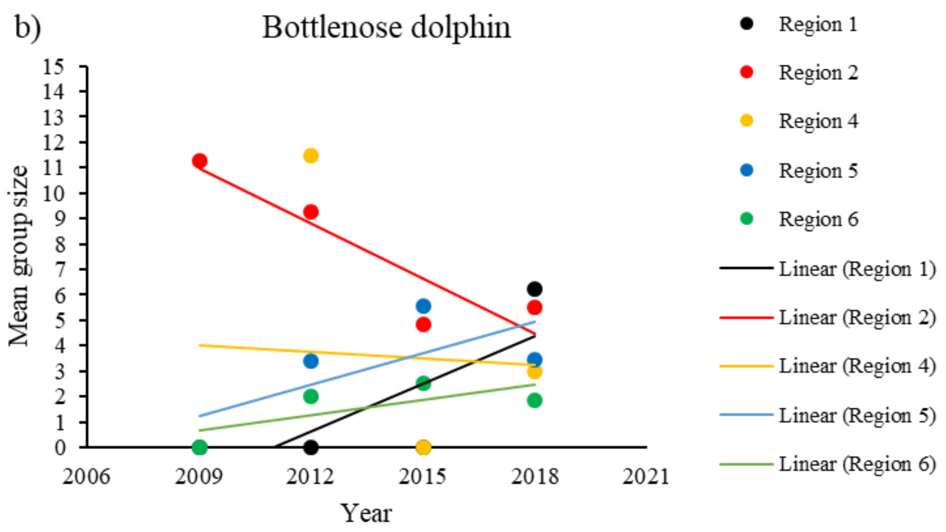
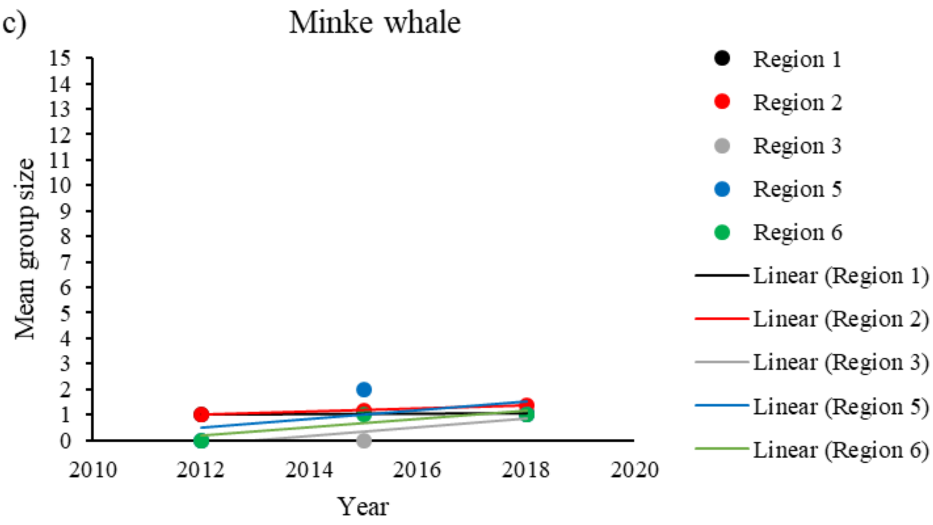


Figure 7. Abundance of white-beaked dolphin (*Lagenorhynchus albirostris*) in each region by year.

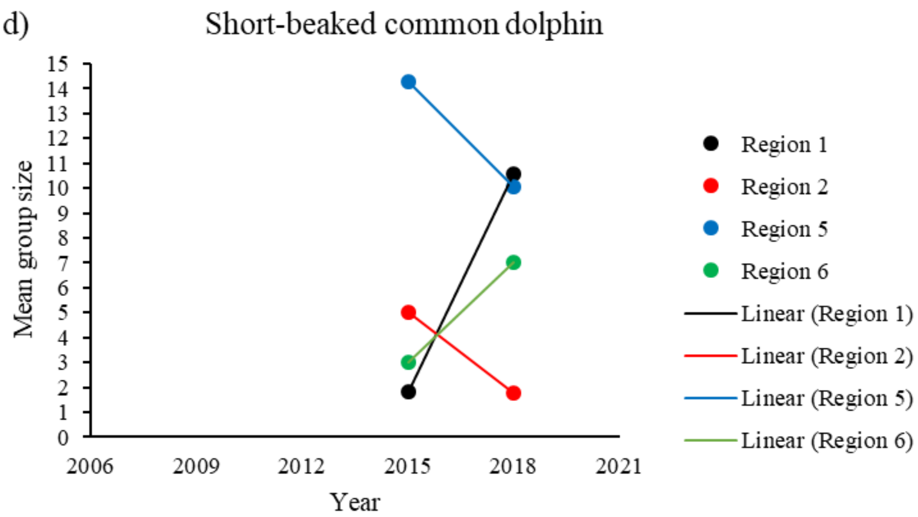

a)
Harbour porpoise
Mean group size
Year
Region 1
Region 2
Region 3
Region 4
Region 5
Region 6
Linear (Region 1)
Linear (Region 2)
Linear (Region 3)
Linear (Region 4)
Linear (Region 5)
Linear (Region 6)


b)
Bottlenose dolphin
Mean group size
Year
Region 1
Region 2
Region 4
Region 5
Region 6
Linear (Region 1)
Linear (Region 2)
Linear (Region 4)
Linear (Region 5)
Linear (Region 6)

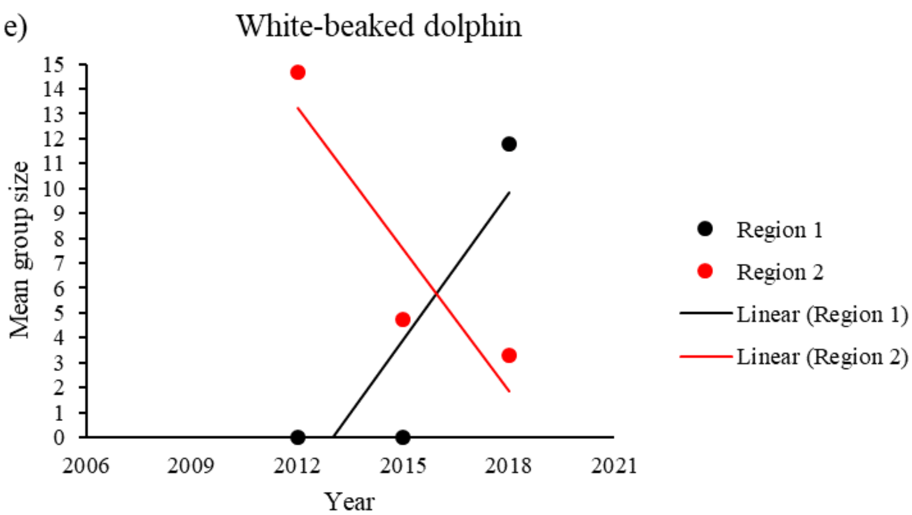
c)


Minke whale
Mean group size
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
2010
2012
2014
2016
2018
2020
Year
Region 1
Region 2
Region 3
Region 5
Region 6
Linear (Region 1)
Linear (Region 2)
Linear (Region 3)
Linear (Region 5)
Linear (Region 6)

d)


Short-beaked common dolphin
Mean group size
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
2006
2009
2012
2015
2018
2021
Year
Region 1
Region 2
Region 5
Region 6
Linear (Region 1)
Linear (Region 2)
Linear (Region 5)
Linear (Region 6)

e)


White-beaked dolphin
Mean group size
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
2006
2009
2012
2015
2018
2021
Year
Region 1
Region 2
Linear (Region 1)
Linear (Region 2)

f)

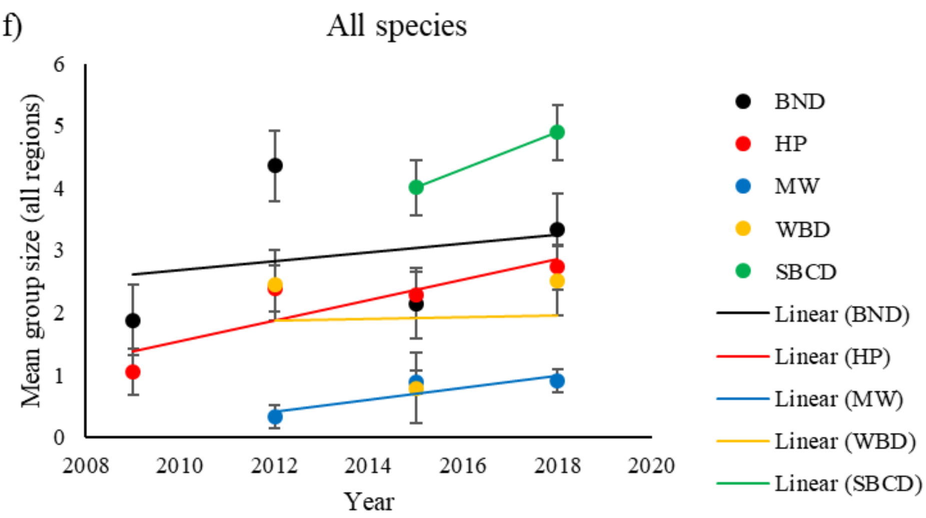


Figure 8. Mean group size per sighting for a) harbour porpoise; b) bottlenose dolphin; c) minke whale; d) short-beaked common dolphin; e) white-beaked dolphin; f) all species and regions combined.

ANOVA results indicated that there was no significant difference between individuals seen per sighting across either year (F (3, 16)= 1.241, *p*=0.328) or region (F(5,24)=0.943, *p*=0.471). There was also found to be no significant difference in mean group size between years (F (3, 92)=0.633, *p*=0.595), but there was a significant difference in mean group size between regions (F (5,90)=3.34, *p*=0.00819).

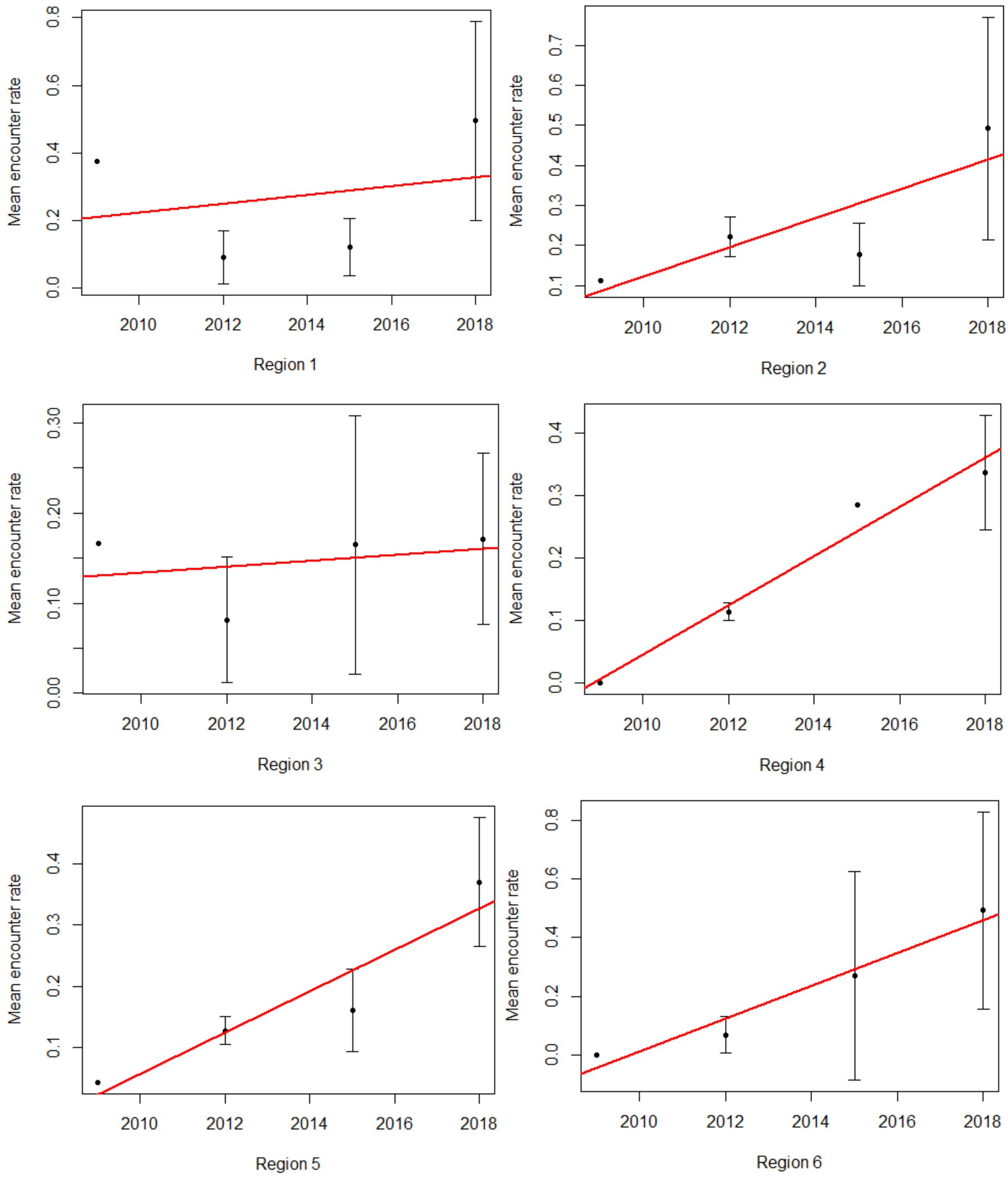


Figure 9. Confidence intervals (SD) of mean encounter rates (SPUE) for each year by region, including trendlines.

3.4 Relationship between watch effort and sightings

There was found to be a significant relationship between watch effort and number of animals detected (adj. R^2= 0.0501, $F(1,840)$= 45.36, p=<0.0001); large group size estimates of some species such as common and white-beaked dolphins resulted in several extreme outliers (Figure 10). Watch effort and sightings rate varied between years, and factors with the highest explanatory power also varied between years. Due to the low sample size and sightings rate of 2009, no significant relationships were found between watch effort, sightings rate and any of the variables tested. For sightings in 2012, sea state was found to have the greatest effect (residual deviance 166.62, df=104, p= 0.0193), with sea state 2 having a significant negative effect (coefficient estimate= -0.17802, p= 0.0175). Region was found to be the most significant factor affecting encounter rate in 2015, with region 5 having a highly significant effect (coefficient estimate= -1.573, p= <0.0001). For 2018, platform type was found to be significant (residual deviance 1306, df=357, p= 0.0076), with land watch having the greatest overall effect (coefficient estimate= 4.672, p= <0.001).

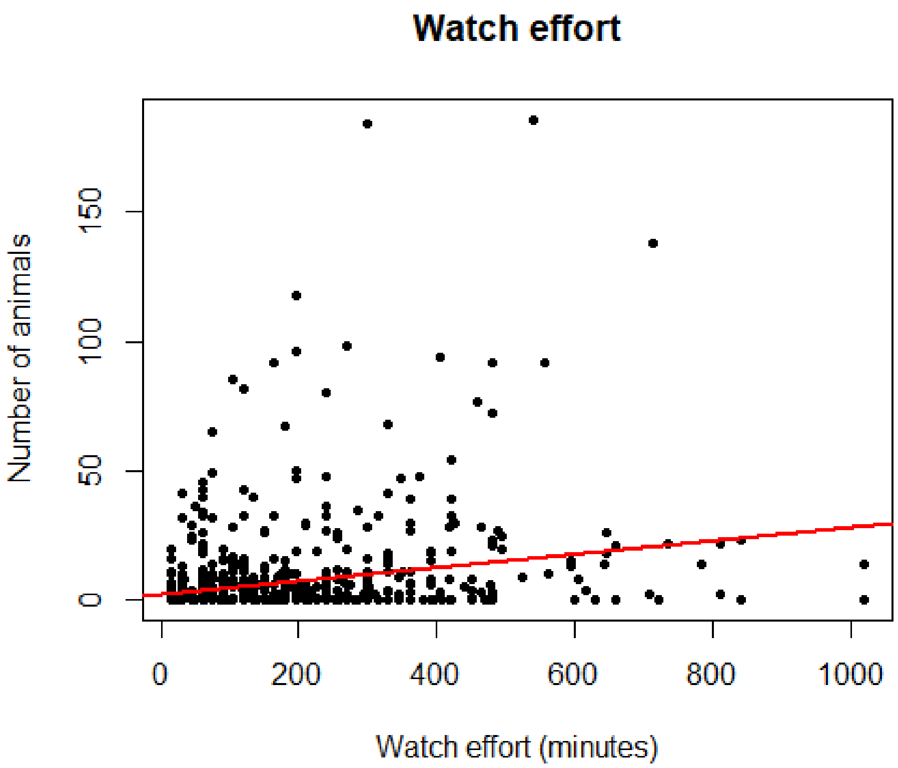


Figure 10. Number of animals seen in relation to amount of watch effort per observer, date and location.

4. Discussion

4.1 General trends in abundance and distribution

Overall, an increase in abundance was observed for 5 species of cetacean between 2009 and 2018, with all species increasing in abundance between 2015 and 2018 (Table 9).

Table 9. Average IPUE as an indicator of general trends in abundance between 2009 and 2018, with (-/+) indicating increase or decline relative to the previous year.

Species	2009	2012	2015	2018	Sig.
HP	0.18	0.116 (-)	0.155 **(+)**	0.391 **(+)**	NS
BND	0.171	0.139 (-)	0.024 (-)	0.106 **(+)**	NS
MW	0	0.003 **(+)**	0.005 **(+)**	0.016 **(+)**	NS
SBCD	0	0	0.052 **(+)**	0.238 **(+)**	NS
WBD	0	0.049 **(+)**	0.019 (-)	0.051 **(+)**	NS

Abundance was generally higher for all species within the North Sea and Western Approach/southern Celtic Sea than in the Channel or southern North Sea (Table 10).

Table 10. Average IPUE as an indicator of general trends in abundance between regions, with (-/+) indicating increase or decrease relative to the adjacent region.

Species	1. Hebrides	2. North Sea (N)	3. North Sea (S)	Sig.
HP	0.47	0.104 (-)	0.204 **(+)**	NS
BND	0.013	0.498 **(+)**	0 (-)	NS
MW	0.025	0.018 (-)	0.002 (-)	NS
SBCD	0.173	0.018 (-)	0 (-)	NS
WBD	0.02	0.059 **(+)**	0 (-)	NS
Species	**4. Channel**	**5. Western Approach**	**6. Irish Sea**	**Sig.**
HP	0.038 (-)	0.241 (+)	0.208 (-)	NS
BND	0.029 **(+)**	0.107 **(+)**	0.013 (-)	NS
MW	0 (-)	0.0092 **(+)**	0.003 **(-)**	NS
SBCD	0	0.655 **(+)**	0.0245 **(-)**	NS
WBD	0	0	0	NS

4.2 Comparison of trends and abundance estimates with existing studies

A pattern of increasing abundance can be seen in all five species studied between 2009 and 2018. Although total abundance obtained cannot be compared directly with SCANS surveys due to differences in survey methods, similar increase over time can be seen in abundance estimates obtained by SCANS between 1995 and 2016 (Figure 11).

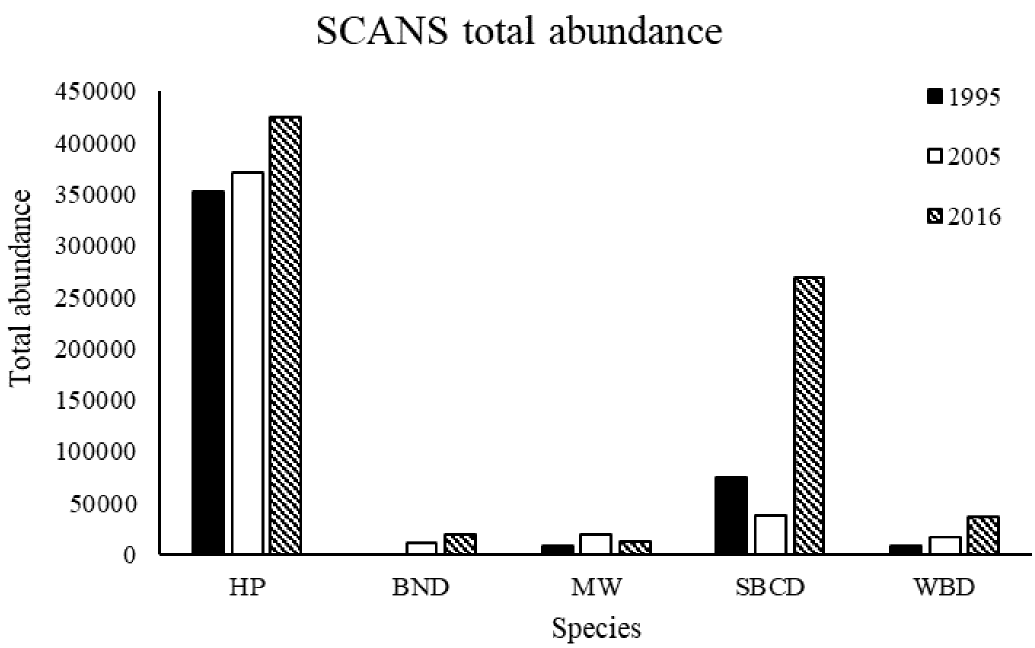


Figure 11. Total species abundance from SCANS, SCANS II and SCANS III (estimates obtained from Hammond *et al*. 1995, Hammond et al. 2013, and Hammond et al. 2017).

The number of each species recorded for each year in this study follow a similar pattern to the trend illustrated in Figure 11, with the exception of minke whales, where a slight decline in abundance appears to be observed from the 2016 SCANS III survey. Although overall numbers recorded in this survey were low, the number of minke whales nonetheless increased annually, from 6 whales recorded in 2012 to 84 in 2018. An apparent decline in common dolphin abundance in 2005 may explain the absence of common dolphins prior to 2015 observed in this study.

While only a limited amount of data could be recovered for 2009, a large number of bottlenose dolphins (N=158) were observed in that year relative to watch effort. The majority of these individuals were sighted within the inner Moray Firth (Figure 2a). This suggests an abundance comparable with the estimated Moray Firth population range of 162-252 in

Cheney et al (2013). In addition, a relatively high sightings rate for harbour porpoise in region 1 (0.875) was found compared to a study of harbour porpoises in the Hebrides from 2003-2010 (Booth et al. 2013), which gives a detection rate of 0.04 for 2009 (11,292km^2, 443 individuals); however as detection rate is measured in area of effort rather than time, it is difficult to scale the relative amount of effort invested.

White-beaked dolphins were found only in the North Sea and Hebrides in this study. Although only SWF data from July and August were used in this study, a study of the Aberdeen region by Weir et al. (2007) indicated that white-beaked dolphin occurrence within the area was seasonal, as they were found only from June to August (average IPUE 1.886). Minke whales were mentioned but not formally quantified in the same study; however based upon the regional distribution of minke whales found in this study, it is likely that a similar seasonal pattern of minke whales in the North Sea is occurring. An increase of both minke whales and white-beaked dolphins in the Hebrides was observed in 2018 (Table 6; Table 8; Figure 5; Figure 7); this may be related to changes in environmental suitability or prey availability, however as environmental parameters were not examined this may also simply be attributed to increased watch effort in the Hebrides relative to other years.

The amount of effort invested by observers varied considerably between location, date and individual observers; this is likely to be related to the sightings rate of different locations. While the large number of unique locations meant that it could not be used as a factor in analysis, watch effort was higher and sustained over several days per year in certain locations, such as New Quay, Cardigan Bay, or Berry Head in Cornwall. Embling et al. (2015) found that sighting rate for a given location affected the amount of effort required to detect meaningful trends, and that watch effort required to detect trends varied even within the Moray Firth, from 3 watches per day in Spey Bay to around 5 per day in North Kessock. In contrast to the increase in bottlenose dolphins observed in Embling et al. (2015) between 2005 and 2013, bottlenose dolphin sightings in this study were found to decline between 2009 and 2012, with an increase occurring in 2018 (Table 9); however, abundance was highest overall in Region 2, corresponding to the North Sea and including the Moray Firth (Table 10).

The distribution of common dolphins and white-dolphins reflects the trend observed in Weir et al (2001); common dolphins were most commonly sighted in the southern Irish Sea and

Celtic Deep, while white-beaked dolphins were found exclusively in the Hebrides and North Sea (Figure 2 (b-d); Figure 6; Figure 7). The differences in species distribution, particularly for these species, is likely to be related to sea surface temperature (SST) and other environmental factors such as seafloor topography and local tidal patterns. As tidal conditions were not recorded for any watches and additional environmental data such as SST could not be obtained for the study area within the correct time range, species habitat models could not be created to determine if environmental factors affected the distribution of any of the species examined in this study.

4.3 Issues and limitations

One of the main challenges in conducting the study was the limited amount of data available for 2009 compared to 2012, 2015 and 2018. As only 65 hours of watch effort and 21 effort-related sightings could be obtained, inclusion of 2009 data in trend analysis presented difficulties when comparing effectively with the larger sample sizes of 2018 and 2015. The accuracy of group size estimates also varied between years; group size estimates for bottlenose dolphins in 2009 tended to be higher than in later years.

Differences in method become apparent in comparisons of abundance estimates with traditional scientific surveys. The surveys measured in this study were primarily taken from static watch points on land, with survey effort measured in time; most scientific surveys are aerial or ship-based line transects measured in total area covered. Additionally, comparison of findings with large-scale scientific studies was limited primarily to SCANS; as only a few fin whales were recorded (Appendix 1), comparisons could not be made with T-NASS, and the study area did not extend to the offshore areas covered by CODA.

4.4 Conclusions

Despite the limitations of the data used in this study, positive trends in cetacean abundance between 2009 and 2018 were observed, and spatial trends were observed which reflect the findings of existing studies. This suggests that data collected through citizen science, if collected with sufficient consistency, can produce findings comparable to large-scale offshore scientific surveys. Additionally, the study revealed potential shifts in the distribution of certain species which could be examined in future studies.

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Appendix 1. List of all species and number of animals recorded between 2009 and 2018 by the Sea Watch Foundation.

Species name	**Common name**	**Total number of animals recorded**
Lagenorhynchus acutus	Atlantic white-sided dolphin	9
Tursiops truncatus	Bottlenose dolphin	1218
Balaenoptera physalus	Fin whale	4
Phocoena phocoena	Harbour porpoise	2350
Megaptera novaeangliae	Humpback whale	3
Orcinus orca	Killer whale	36
Globicephala melas	Long-finned pilot whale	37
Balaenoptera acutorostrata	Minke whale	112
Grampus griseus	Risso’s dolphin	20
Delphinus delphis	Short-beaked common dolphin	1598
-	Unidentified cetacean	17
-	Unidentified dolphin	110
-	Unidentified large whale	7
-	Unidentified porpoise/dolphin	28
Lagenorhynchus albirostris	White-beaked dolphin	191