# **Distribution and relative abundance of harbour porpoise (*Phocoena phocoena*) in the Outer Moray Firth, Scotland**

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*I certify that this dissertation is entirely my own work and no part of it has been submitted for a degree or other qualification in this or another institution and give permission for a copy to be held by my supervisor and distributed at their discretion.*

Harry David Clark – 700056818

<u>Journal Choice:</u> Marine Ecology Progress Series (MEPS)

This thesis focuses on a coastal species within a marine area. I have chosen Marine Ecology Progress Series (MEPS) as the journal of choice for the thesis. MEPS is a leading multidisciplinary journal on topics surrounding marine and coastal ecology. With an impact factor of 2.8, and a broad audience, the journal would be a suitable platform to present this data. This data updates previous estimates on a specific species in an area.

# Abstract

Harbour porpoises (*Phocoena phocoena*) are the smallest and most abundant coastal cetacean species in the UK. Previous large-scale surveys have identified declining trends of harbour porpoises in the northern North Sea over the last three decades. Although previously suggested as an important area for harbour porpoises, the Moray Firth lacks sufficient data to aid in the implementation of conservation measures. A 20-year (2001-2020) cetacean dataset collected by the Cetacean Research & Rescue Unit (CRRU) in NE Scotland were analysed to determine the spatial distribution and relative abundance of harbour porpoises. Recorded throughout the survey area during all survey months (May to October), group sizes ranged from one to 40 individuals. Group sizes were significantly higher during the latter months. Peak abundance was estimated at 0.59 individuals per km. Pooled abundance for all years showed variable changes, with peaks in 2012, 2013 and 2020. Interannual abundance estimates gradually increased from May to October, with peaks later in the survey season. Abundance and group size estimates in this study are higher than others in European waters, indicating the very high importance of the Moray firth for the species. The Moray Firth is a candidate ‘safe area’ for harbour porpoises which may be important for future protective measures.

# Introduction

The harbour porpoise (*Phocoena phocoena*) is the smallest and most abundant coastal cetacean species in UK waters (Booth *et al*. 2013; Calderan and Leaper 2019; Sarnocinska *et al*. 2020). Growing to a maximum of 1.9m, causing minimal surface disturbance and a small triangular dorsal fin; this species is difficult to spot (Hammond *et al*. 2002; Booth *et al*. 2013). Harbour porpoises typically inhabit murky waters, living in bays and estuaries (Bjørge 2003; Booth *et al*. 2013; Braulik *et al*. 2020; Waggitt *et al*. 2020). Found throughout the North Sea, this species is typically recorded inshore and along continental shelves (Reijnders 1992). Further, these small cetaceans are often found in close proximity to minke whales (Balaenoptera acutorostrata), due to similar prey species and habitat requirements (Clark 2005; Robinson *et al*. 2007). Harbour porpoises diet consists primarily of lesser sandeels (*Ammodytes* marinus), which are burrowed in sandy composites (Wright *et al*. 2000; Santos *et al*. 2003; Clark 2005; Pierce *et al*. 2007).

Harbour porpoises are exposed to a number of threats in UK waters: by-catch, intra-guild predation, over-fishing, entanglement, climate change, marine debris, pollutants, and noise pollution (Spitz *et al*. 2006; Parsons *et al*. 2010; Hammond *et al*. 2013; Peltier *et al*. 2016; Calderan and Leaper 2019; Evans and Waggitt 2020). Currently, they are classified as “least concern” by the International Union for Conservation of Nature Red List of Threatened Species (Braulik *et al*. 2020). As a signatory member state of many European and international agreements, the UK is dedicated to the protection of cetaceans (Goodwin and Speedie 2008). Harbour porpoises are protected under the Wildlife and Countryside Act 1981, CITES Appendix II, Annex II of the Habitats Directive and Conservation Regulations 1996

(Evans and Wang 2008). Annex II of the Habitats Directive lists species which justify the designation of Special Areas of Conservation (SAC; Embling *et al.* 2010; Hammond *et al*. 2013; Laran *et al*. 2017; European Commission 2021). Creating an SAC or similar area of protection for marine mammals can be difficult due to the lack of apparent geological boundaries for a population (Pinn 2009). An SAC for harbour porpoises is identifiable if *'it is possible to identify areas representing crucial factors for the life cycle of this species'* on the basis of one or more factors (Pinn 2009):

*1) The continuous or regular presence of the species (subject to seasonal variation).*

*2) Good population density (in relation to neighbouring areas).*

*3) A high ratio of young to adults during certain periods of the year.*

Within the Moray Firth, two areas of protection are designated; the Inner Moray Firth Special Area of Conservation and the Southern Trench Marine Protected Area (Weir *et al*. 2008; Arso *et al*. 2019; Gov.Scot 2021; Robinson *et al*. 2021). Designated in 2005, the Inner Moray Firth SAC is for the conservation of bottlenose dolphins (*Tursiops truncatus;* Weir *et al*. 2008). The Southern Trench MPA, although recent in its implementation in 2020, was designated for the protection and conservation of minke whales (Gov.Scot 2021). Although neither protected area is specifically designed for the conservation of harbour porpoises, the ongoing conservation efforts will provide an aspect safety for the species. The Moray Firth has been already been suggested as a 'safe area' for harbour porpoises on previous studies, however the current lack of long-term data is one of the primary reasons of the apparent complacency by the UK government to implement conservation measures (Whaley

2004; Whaley and Robinson 2004). The nesseacity for a better understanding of harbour porpoises in the Moray Firth is vital for the conservation of the species.

Within European waters and the North Sea, large-scale and localised studies on the distribution and abundance of harbour porpoises have been carried out. This is likely influenced by the possibility of anthropogenic disturbance through fishing activities, shipping and hydrocarbon exploration (Hammond *et al*. 1995; Hammond *et al*. 2002; Hammond *et al*. 2006; Scheidat *et al*. 2008; Geelhoed *et al*. 2013; Peschko *et al*. 2016; Hammond *et al*. 2017; Laran *et al*. 2017; Geelhoed and Scheidat 2018; Gil *et al.* 2019; Gilles *et al*. 2019; Bouveroux *et al*. 2020; Leonard and Oien 2020).

Studies on harbour porpoises in the North Sea have described the movements and population patterns for this species in recent decades (Hammond *et al.* 1995; Hammond *et al*. 2006; Hammond *et al.* 2017). The current favourable status estimates of harbour porpoise abundance in UK waters are from three decadal surveys carried out by the Small Cetaceans in the European Atlantic and North Sea (SCANS) team (Hammond *et al.* 1995; Hammond *et al*. 2006; Hammond *et al.* 2017; Risch *et al.* 2019). SCANS started in 1994, with two more large-scale surveys following in 2005 and 2016, using aerial and vessel-based platforms to record and assess the current populations of cetaceans in UK waters.

SCANS surveys created a crude abundance estimate displaying a snapshot of time to highlight areas for further study, possible trends for populations and potential areas of importance (Hammond *et al*. 1995; Hammond *et al*. 2002; Reid *et al*. 2003; Hammond *et al*. 2006; Hammond *et al*. 2013; Hammond *et al*. 2017). Although SCANS-I (1994), SCANS-II (2005) and SCANS-III (2016) covered the same overall area, section extents varied. A section comparable to the Moray Firth region presented estimates indicating a declining population trend over the three surveys (0.36, 0.27 and 0.15 individuals per kilometre (individuals/km) respectively; Supplementary Table 1). Leonard and Oien (2020) presented similar conclusions during two large-scale surveys in the Northeast Atlantic from the northern North Sea to the Arctic circle, supporting the suggestions made by the SCANS team that harbour porpoise populations are in decline. Abundance estimates reduced from their first survey (2002-2007) to their second (2008-2013), showing an overall decrease of 0.063 to 0.011 individuals/km. Within an area comparable to the Moray Firth, abundance estimates and sightings decreased drastically between the two surveys, with no individuals sighted in the Moray Firth during the second survey.

Several studies have indicated that harbour porpoises are migrating out of the eastern North Sea in the latter months of summer. Geelhoed *et al.* (2013) and Geelhoed and Scheidat (2018) conducted aerial surveys along the Dutch Continental Shelf (DCS). Their data indicated significant movement of porpoises out of the survey area during July, with abundance estimates three times lower than in March. Gilles *et al*. (2011) also found a decrease in harbour porpoise abundance from Spring to Autumn in the German exclusive economic zone (EEZ), inferring harbour porpoises were migrating out of the eastern North Sea region. This evidence suggests that harbour porpoises may migrate from the eastern North Sea to the western North Sea over the summer months. An influx of harbour porpoises with calves to both the western North Sea and Scottish waters during the latter months of the year has also been demonstrated (Northridge *et al.* 1995; Lockyer and Kinze 2003; Learmonth *et al.* 2014), indicating the western North Sea and Scottish waters may be a refuge for pods with young calves.

Further studies in European and UK waters have identified hotspot areas and seasonal movements. In Iceland and the Faroe Islands, abundance estimates peaked at 0.46 individuals/km (Gilles *et al*. 2019). In the Bay of Biscay (BoB) and English Channel (EC), harbour porpoises were recorded to be in higher abundance in summer compared to winter (BoB summer = 0.021 individuals/km, BoB winter = 0.004, EC summer = 0.089, EC winter = 0.086; Laran *et al*. 2017).

Harbour porpoises are typically recorded as lone individuals or in small groups (Reid *et al.* 2003). Within the North Sea, average group size of harbour porpoises rarely exceeds 2 individuals. Throughout SCANS-I, II and III, harbour porpoise group size rarely surpassed 2 individuals, with averages typically under 1.5 (Hammond *et al*. 1995; Hammond *et al*. 2006; Hammond *et al*. 2017). The large-scale surveys carried out in the North Atlantic by Leonard and Oien (2020) further supported the comments that harbour porpoises are recorded in small groups or lone individuals, with averages no greater than 1.61 individuals. Geelhoed and Scheidat (2018) recorded a maximum group size of 8 individuals along the DCS, with an average group size of 1.21. Their group size estimates increased from Spring to Summer/Autumn. Gilles *et al*. (2019) recorded a maximum group size of 4, with an average of 1.46 in Iceland and 1.8 in the Faroe Islands. Within all the studies presented, harbour porpoises are typically recorded in small groups.

The estimates and conclusions presented by the previous studies in the northern North Sea and Moray Firth indicate that although the area is of importance to the species, the population is facing pressures and declining trends have been recognised. Aside from data analysed from sectioned segments of large-scale studies in the North Sea, long-term reliable data on harbour porpoise distribution and abundance lack comprehensive detail. Understanding the distribution and abundance of a species is vital for the implementation of effective conservation measures by facilitating the assessment of potential impacts from harmful anthropogenic activities (Canadas and Hammond 2008; Barlow 2010). This study will aim to identify the current distribution, potential areas of importance, and annual and interannual variation in abundance and group size for harbour porpoises in the Moray Firth, Scotland.

# Methods

## Study Area

Located in the north east of Scotland and covering approximately 5230km$^2$, the Moray Firth is the largest embayment in Britain. The Moray Firth is divided in to two sections, the Inner Firth and the Outer Firth. Data were collected during dedicated boat surveys along the southern coastline of the Outer Moray Firth in NE Scotland between May and October, 2001 to 2020 (Figure 1). The survey area, laying between the ports of Burghead (57°41′59N, 3°29’21W) to the west and Fraserburgh (57°41’35N, 1°59’50W) to the east, covered approximately 2300km$^2$.

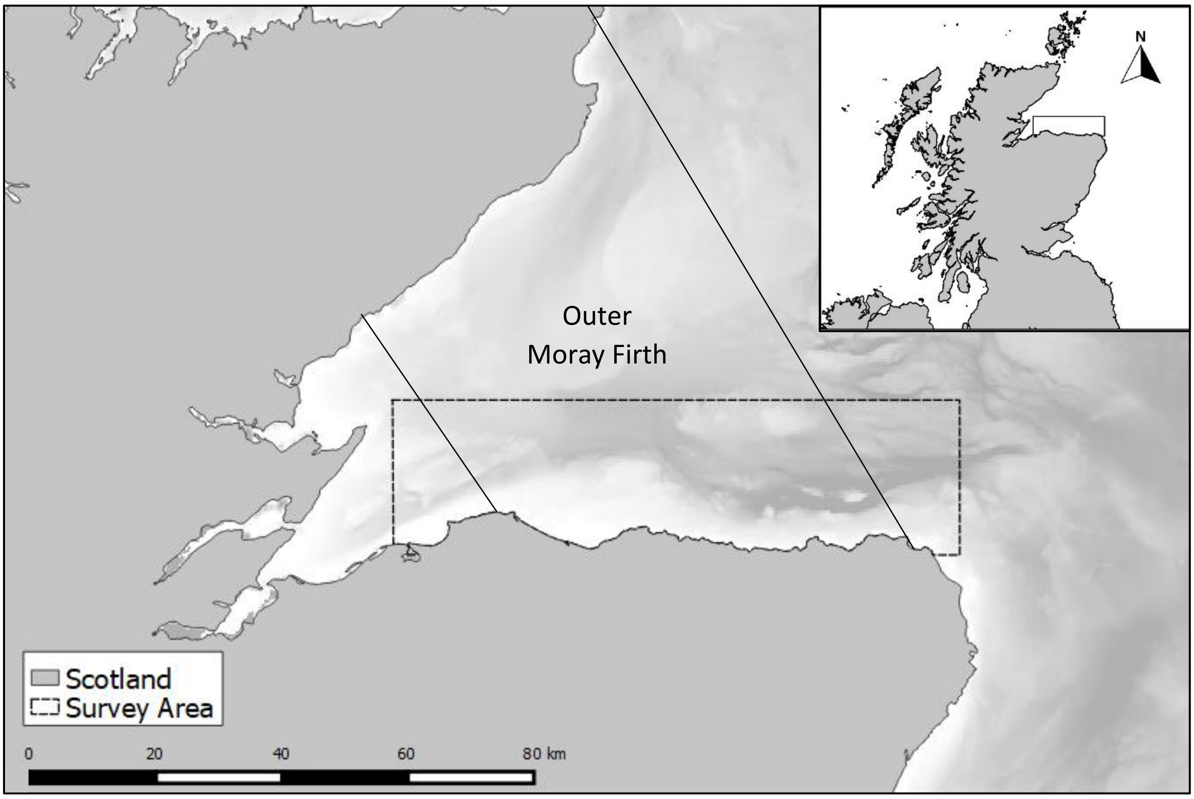


*Figure 1. Showing the study area and southern coastline of the Outer Moray Firth, Scotland. The solid black line indicates the boundaries of the Outer Moray Firth. Greyscale layer indicates bathymetry (dark patch centre right of study area = the southern trench).*

## Data Collection

All data within the study were previously collected between 2001 and 2020 and provided by the Cetacean Research & Rescue Unit (CRRU). Boat surveys were carried out using Rigid Inflatable Boats (RIB) with survey routes being determined by daily weather forecasts. Observer height was approximately 2m. Average speed was ~7 to 9knots. Visual surveying was carried out using a continuous scanning method (after Mann. 1999) using 8 x 50 binoculars. All surveys were carried out in Beaufort Sea States ≤3 (Robinson *et al*. 2009). During surveys, both RIB positioning (Global

Positioning System) and respective environmental data (date, time, survey effort 'positive/negative', Beaufort Sea State, swell, Sea Surface Temperature and depth) were recorded. During cetacean encounters, species, group size and behavioural data was recorded. For further information on survey design and methods, see Robinson *et al*. (2009).

## Statistical Analysis

In the present study, statistical analyses were carried out using R Studio software (RStudio, Boston, USA). During analysis of data, a one-way ANOVA was carried out, with further post hoc tests for any differences between groups if significance was identified. Data from 2001 to 2020 was used in the subsequent analysis of spatial distribution, group size, sediment usage, distance from shore and water depth ranges (herein after referred to as the 'main dataset'). Spatial distribution overlapped with sediment data were analysed to identify habitat preferences for potential use in later studies.

A refined version of the main dataset (hereinafter referred to as the 'refined dataset') with available survey effort data was created. Survey effort was available from 2009 to 2020. Since porpoise detectability decreases significantly with increasing Beaufort Sea State (Northridge *et al*. 1995; Baines *et al*. 1997, Palka 1995; Evans and Hammond 2004; Leonard and Oien 2020), the refined dataset was further filtered for data collected only in favourable sea states of Beaufort Sea States ≤1. This dataset was subsequently used in the analysis of abundance estimates and for presence/absence modelling using QGIS (version 2.8.3; QGIS 2021).

# Visual Analysis

A Geographical Information System of the dataset was created in QGIS. Outputs were created using the rasterize function and hexagonal grid creation. A Mercator WGS1984 projection was used as the central meridian for these outputs. To show distribution of harbour porpoises, a mix raster generation of trackline presence/porpoise presence was created for the spatial distribution of porpoise sightings. A raster grid was created with a grid cell sizes of $0.2km^2$. Hexagonal grid displays for with a cell size of $1km^2$ were created for density estimates. Larger cell sizes were defined due to sighting ability in bft0 and bft1 and the observer platform height of ~2m, allowing a 500m search effort based either side of the survey trackline (based upon detectability estimates by Shucksmith *et al*. 2009).

# Results

Harbour porpoises were sighted throughout the entire study area during all survey months and all survey years (Figure 2a). Sightings rates showed considerable intra and interannual variation. Between 2001 and 2020 a total of 634 sightings, accounting for a total 1916 individuals, were recorded by the CRRU research team. From the available survey effort, a total of 10,300km of dedicated boat-based effort was conducted between May and October 2009 to 2020 (Figure 2b). From this, a total of 6,150km (59.7% of all surveys) was carried out in favourable sea states of Beaufort Sea States ≤1.

Considerable survey effort was carried out in the central portion of the study area (Figure 2c). Annual survey effort was highest in 2009 with 47 surveys, and lowest in 2020, with 9 (limited surveys due to the Covid-19 pandemic). August had the largest monthly effort with a total of 65 surveys, whilst October had the lowest effort with 10 surveys. Mix raster generation of tracklines and porpoise sightings in $200m^2$ cell grids presents presence/absence (1 or 0) of harbour porpoises in relation to survey effort (Figure 2d). Mix raster generation presents visual data indicating porpoises were not equally distributed along the coastline and areas of preference have been identified.

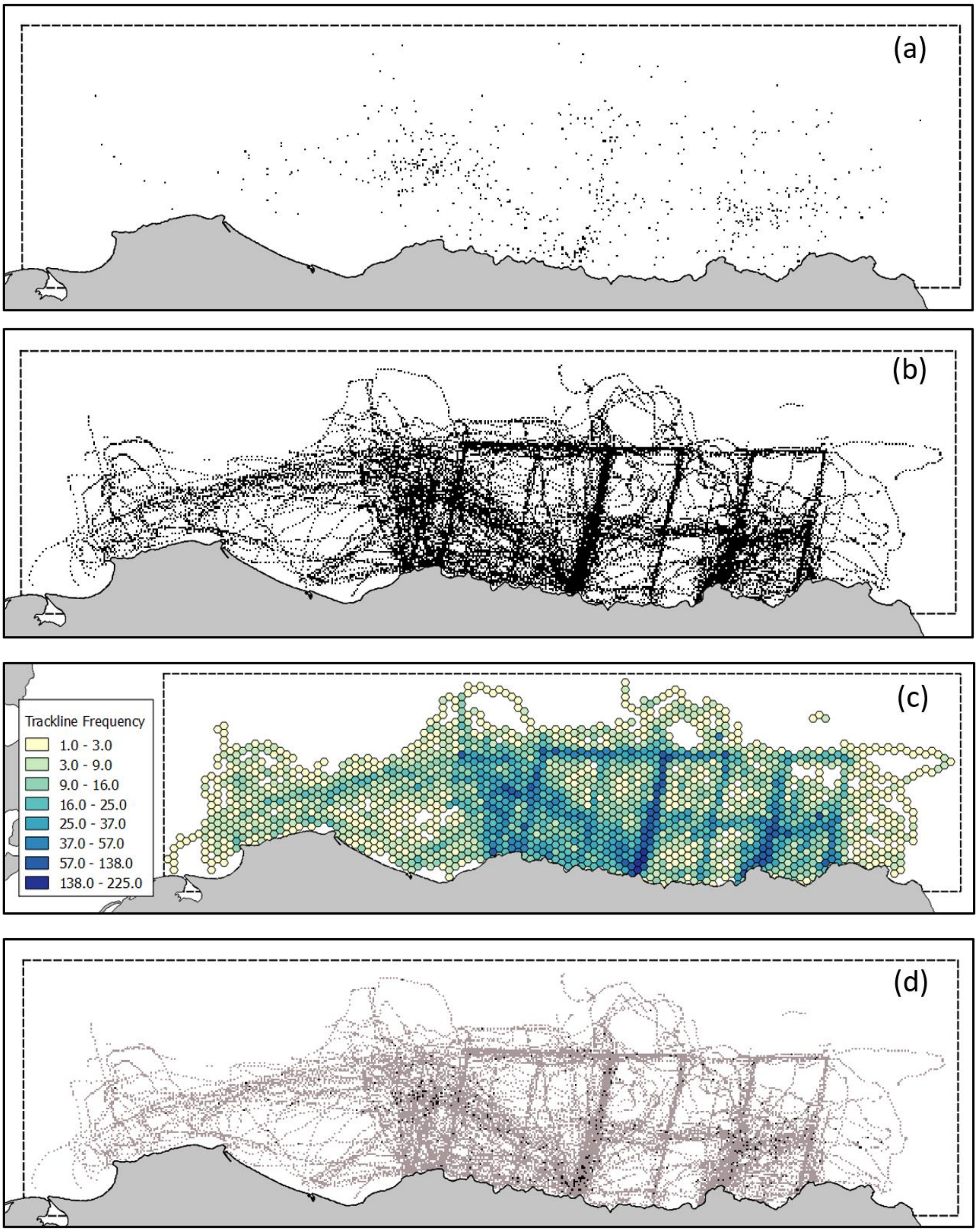


*Figure 2. (a) Spatial distribution of harbour porpoise sightings in the southern outer Moray Firth between May and October 2001 to 2020 (n=634) (b) Survey effort from 2009 to 2020 (c) Frequency of survey effort per cell (1km$^2$) from 2009 to 2020 (d) Survey Tracks (grey) from 2009 to 2020 and locations of porpoises (black) within 100m of survey path.*

## Abundance

Harbour porpoise abundance estimates were based on confident sightings. Along the coastline of the Outer Moray Firth, peak abundance was estimated at 0.59 individuals/km. Overall abundance for the Moray Firth was estimated at 0.28 individuals/km, with variable annual and interannual estimates (Figure 3a-b). Monthly abundance estimates showed an increasing trend throughout all months, ranging from 0.046 individuals/km in May to 0.372 individuals/km in September. No significant statistical variation was identified in analysis of monthly abundance estimates ($F_{(5,52)} = 2.377$, $p = 0.051$). Further, no significant variation was identified within annual estimates ($F_{(11,46)} = 1.402$, $p = 0.204$).

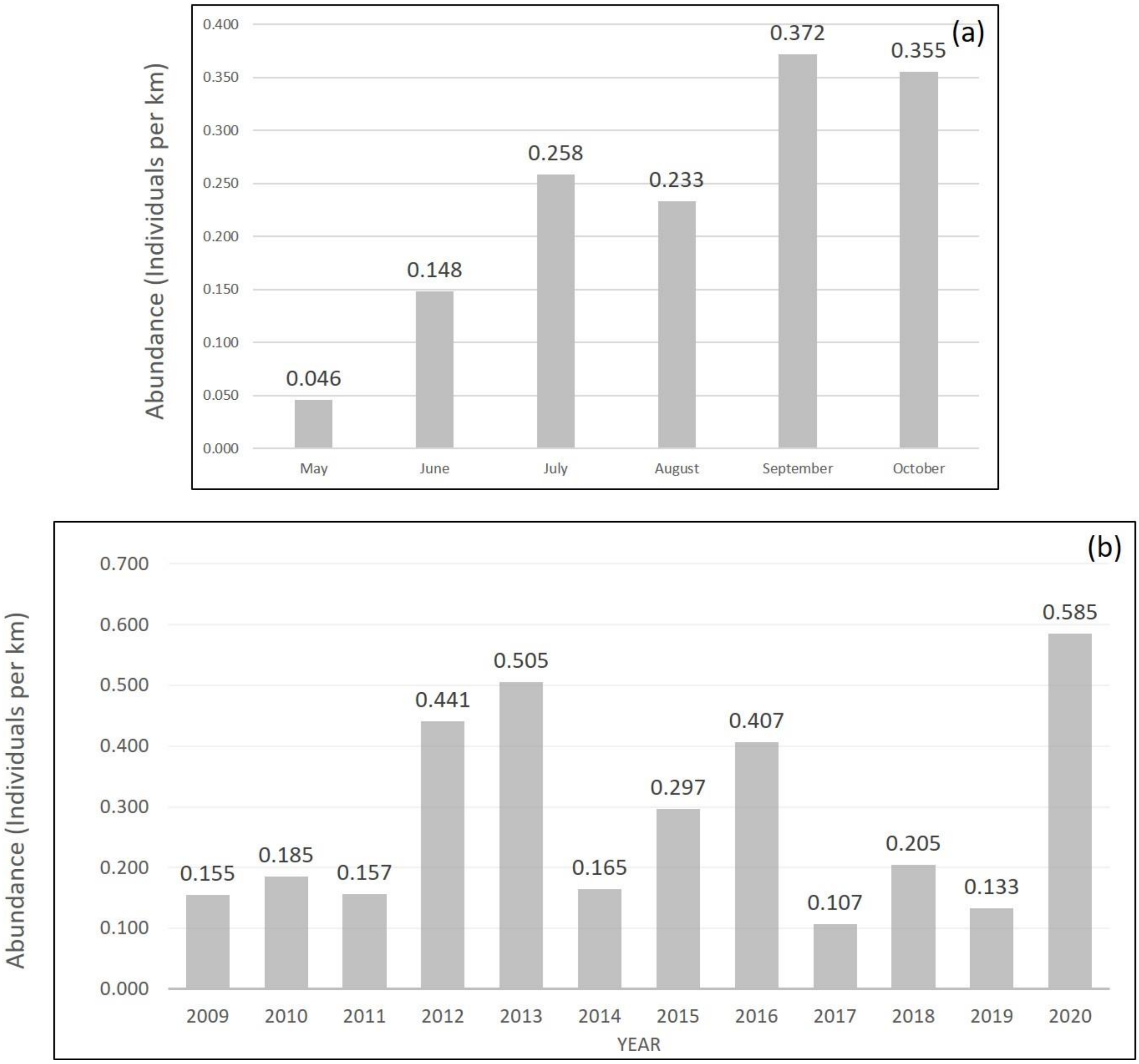


*Figure 3. Abundance estimates of harbour porpoises in the Moray Firth from 2009 to 2020, with values stated (a) monthly estimates (b) annual estimates.*

# Distribution

Two areas of interest have been identified within the study area, suggesting an area of importance for the species (Figure 4a). The study area was divided into 3529 grid cells, with 425 having at least one harbour porpoise sighting recorded. Not every cell grid was surveyed in due to survey effort. Harbour porpoise sighting frequency ranged from 1 to 7 encounters per grid cell. Cells containing the highest number of recorded harbour porpoises were located in the central and eastern sector of the study area. Sightings recorded from June through to September indicated overlapping areas of sightings, indicating the two areas of importance (Figure 4c-f).

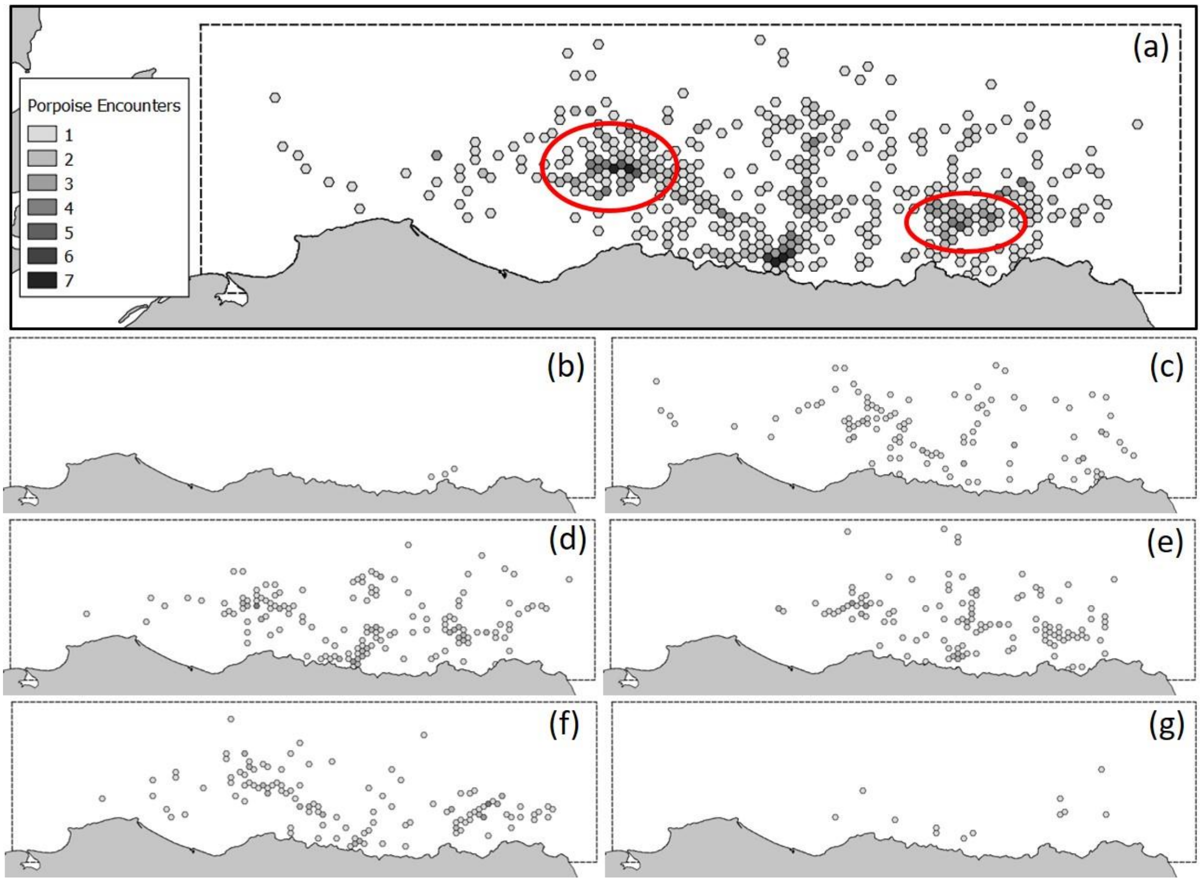


*Figure 4. Frequency of harbour porpoise sightings per 1km$^2$ grid cell for (a) all months, (b) May, (c) June, (d) July, (e) August, (f) September and (g) October within the survey area. Red rings indicated areas of high encounter frequency.*

# Group Size

The average group size recorded for porpoise encounters was 3 individuals (SE = 0.14, 95% CI 2.73 - 3.3). The highest group size recorded was 40 individuals in September 2003, although single individuals were most commonly sighted in the study area, 38% of all sightings. The average group size varied by month but showed a general increase throughout the summer months with a peak in October (Table 1). Average group size was highest in September and October (4.55 and 5.9 respectively), whereas the start of the survey season had the lowest ranges. IQR range for May 2-3.5, June 1-2, July 1-3, August 1-4, September 2-5 and October 2-6.5. Although group sizes varied, many large group sizes (10< individuals) were recorded.

*Table 1. Mean and standard deviation of group size of harbour porpoises in the Outer Moray Firth May to October, 2001 – 2020.*

| | May | June | July | August | September | October |
|---|---|---|---|---|---|---|
| **Av. Group size** | 2.7 ±1.528 | 2.1 ±2.008 | 2.3 ±2.780 | 2.9 ±2.608 | 4.6 ± 4.667 | 5.9 ± 6.431 |

Group size of harbour porpoises varied significantly between months ($F_{(5,629)}$ =13.469, p= <0.001), being the smallest in June (2.07 ± 2.01) and highest in October (5.9 ± 6.43). Significant differences were also identified when comparing yearly estimates for group size sizes ($F_{(11,623)}$ = 4.309, p= <0.001).

Within the survey area, multiple sediment types occur, from sand and gravel variants to muddy composites (Figure 5a). The most common sediment classes over which harbour porpoises were recorded were sand (n=183), muddy sand (n=163) and sandy gravel (n=162), and the least common sediment class was slightly gravelly sand (n=11) and Gravel (n=13; Figure 5a). Distance of porpoise sightings from shore varied from 10m to 15,000m+ (Figure 5b). Only 28% of sightings were recorded within 5000m of the shore, with a large proportion (45%) being recorded between 5,000 and 10,000m. Harbour porpoises were recorded in depths between 4.9m and 219m, with an average of 64.8m (Figure 5c). Recorded Sea Surface Temperature ranged from 7.6 to 19.6 within the survey area with an average temperature of 14.4 (IQR 13.3-15.3).

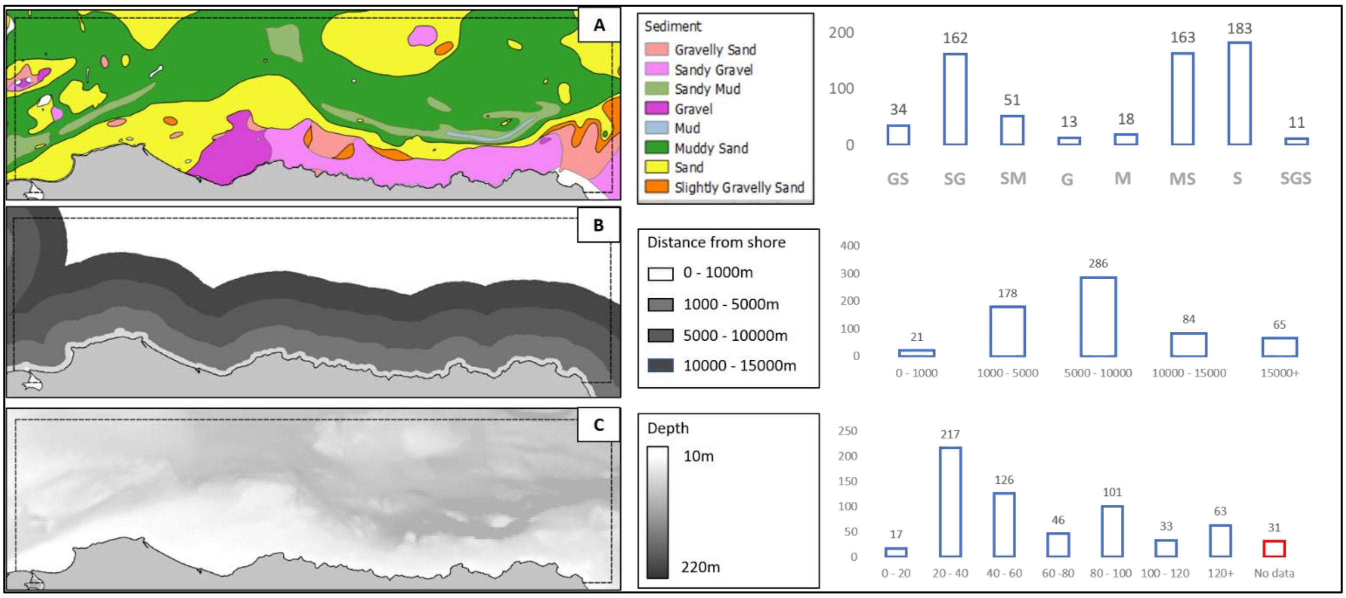


*Figure 5. QGIS maps of the study area showing (A) sediment type (B) distance from shore (C) depth. The porpoise encounter frequencies are shown for each respective variable in the histogram plots to the right.*

# Discussion

This research highlights the importance of a localised study to identify the estimates of a population of interest within an area of interest. The data presented contradicts previous studies' suggestions, with higher-than-expected abundance estimates of harbour porpoises in the Moray Firth. Our current understanding of harbour porpoise abundance estimates in this region are likely understated, as demonstrated by these data. Additionally, we believe that these estimates would increase further after accounting for (1) missed individuals on the trackline (2) submerged individuals on the trackline (3) harbour porpoise avoidance of vessels. These estimates are therefore to be recognised as an absolute minimum for the current abundance in the study area. This study identifies the Moray Firth as an important area for harbour porpoises throughout the summer period due to consistent sightings, high group sizes and high abundance estimates compared to other areas. Harbour porpoises were consistently recorded throughout the entire survey period (May to October, 2001 – 2020), from single individuals to groups of up to 40.

Our estimates show peak abundance for harbour porpoises in the Moray Firth at 0.59 individuals/km. This estimate is higher than previously suggested, with the last two SCANS surveys finding 0.27 individuals/km and 0.152 individuals/km respectively (Hammond *et al*. 2006; Hammond *et al*. 2017). This estimate is also higher than those presented in all but one of the 38 sections surveyed from the North Sea to the Arctic circle (Leonard and Oien 2020). Furthermore, our peak abundance estimate is higher than several other areas including Iceland (0.46 individuals/km), Faroe Islands (0.25 individuals/km), Bay of Biscay (0.021 individuals/km) and the

English Channel (0.089 individuals/km), which further highlights the importance of the Moray Firth for harbour porpoises (Laran *et al.* 2017; Gilles *et al.* 2019).

This study contradicts the suggestions made by SCANS and Leonard and Oien (2020) that harbour porpoises are in decline in the Moray Firth region; between 2009 and 2020, no significant variation or trends were observed. The estimates did however indicate consistently high abundance within the Moray Firth compared to other studies' estimates.

The positive correlation between month (May to October) and abundance estimates in this study, although not significant, may be related to the negative correlation of estimates in the eastern North Sea. Harbour porpoise sightings in the eastern North Sea increased in Spring and early Summer (June & July), then drastically decreased at the end of summer (August) into Autumn (Delefosse *et al*. 2018). This opposes our results which found an increase in abundance estimates in the end of summer. This may indicate a migration of harbour porpoises in the North Sea from east to west over the summer period.

The migration into the Moray Firth may be related to prey abundance and minke whale behaviour; harbour porpoises are known to co-occur with minke whales, with the two species feeding on similar prey and inhabiting the same habitats (Clark 2005; Robinson *et al*. 2007). Diets overlap until late summer when minke whales transition to herring (*Clupea harengus*; Macleod *et al*. 2004; Clark 2005; Robinson *et al*. 2007). The shift in minke whale diet creates an increased availability in sandeels, leading to suggestions that harbour porpoises become more co-operative in their foraging tactics, enabling larger group sizes (Clark 2005).

Harbour porpoises were predominately recorded within inshore waters; two hotspot areas were delineated. Hotspot areas were selected based on repeated sightings within 1km$^2$ grid cells. Sighting's data revealed the presence of the species was recorded up to seven times within a single grid cell. The distribution of the species on a monthly basis did not show any significant changes or trends. The inshore presence of harbour porpoises may be caused by prey, predator avoidance, mating and anthropogenic avoidance. This study supports the categorisation of harbour porpoises being coastal cetaceans, GIS visualisation found that 76% of sightings were recorded within 10km of the shoreline and 56% of sightings shallower than 60m.

Cetacean distribution is affected by the presence of prey (Clark 2005). Sandeels, the main prey of harbour porpoises, inhabit sandy compositions (Clark 2005). Harbour porpoises displayed strong oceanographic preference (80% of all sightings) to three sediment types comprised of sandy variants: sandy gravel (SG), muddy sand (MS) and sand (S). Sandeels burrow until May, then slowly emerge to feed within water columns (Clark 2005). This emergence of the prey species coincides with the increase in harbour porpoise abundance and group size within the study area as sandeels become more prominent within the waters. The correlation of harbour porpoise distribution over these sediments is likely heavily influenced by the presence of sandeels. The abundance of prey to harbour porpoises is vital; if prey abundance reduces then harbour porpoises will become scarcer.

Furthermore, harbour porpoise distribution is affected by the presence of predators; habitat and prey preferences overlap with bottlenose dolphins. Conspecific competition between harbour porpoises and bottlenose dolphins has previously been observed with violent interactions perpetrated by the latter species, resulting in behavioural and distributional changes in harbour porpoises (Ross and Wilson 1996). Bottlenose dolphins in the Moray Firth have been extensively studied, and distributional studies show bottlenose dolphins are predominately focused to inshore waters no deeper than 25m (Culloch and Robinson, 2008).

While average group size for this study was 3 individuals and recorded sizes were higher than the rest of the North Sea, 38% of all sightings were single individuals. With a maximum of 40, average group size was shown to increase significantly from 2.67 in May to 5.9 in October.

The group sizes recorded in this study are very high compared to other studies on harbour porpoises in UK and European waters. Average recorded group sizes in previous studies in the North Sea rarely exceeded 2 individuals: SCANS (1.5), North Atlantic (1.61; Leonard and Oien 2020), DCS (1.21; Geelhoed and Scheidat 2018), BoB and English (between 1-2 individuals per sighting; Laran *et al.* 2017) and Iceland and Faroe Islands (1.46 and 1.8; Gilles *et al.* 2019). The increasing group sizes throughout the season suggests harbour porpoises moving to the to the Moray Firth during summer months; the increase of harbour porpoises towards the end of the survey season may be a response to the increase in abundance of prey. The increase in group sizes could relate to breeding, aggregating in larger numbers for safety from predators and an increased breeding success. Further, group sizes are affected by many factors including prey availability, predators, environmental conditions and anthropogenic disturbance. In-line with other studies displaying an increase in group size into Summer months, the data presented here indicates a large influx of individuals to the study area.

Harbour porpoise detectability can be directly affected by a number of factors relating to the survey design; from vessel specifications to the variation in an observer's ability to detect individuals (Bravington *et al*. 1999; Bravington *et al*. 2014). On average observers on vessel platforms underestimate mean group sizes by up to 25.8% when compared to aerial photos of the same cetacean group (Gerrodette *et al*. 2002; Barlow 2002; Barlow 2006). Furthermore, unlike some species which indulge in bow-riding behaviour, harbour porpoises tend to shy away from fast vessels (Bravington *et al*. 1999). This avoidance behaviour is partially due to the size, speed and acoustic noise of the vessel (Bravington *et al*. 1999; Dawson *et al*. 2008; Bravington *et al*. 2014). An observer height of 10m resulted in approximately 23% of harbour porpoise individuals going unnoticed and when decreased to 2.5m, this can be up to 50% (Shucksmith *et al*. 2009). Based on the conclusions from these studies a 'favourable survey design' for harbour porpoise detectability would be a slow-moving vessel (<7knots) with a high observer platform (5m<), paired with an experienced marine mammal observation team. The survey design for the data collected in this study was not favourable for harbour porpoises; fast vessel with low observer height (0.5m deck level + observer height). The suggested limitations on underestimating group size by Gerrodette *et al*. (2002), Barlow (2002) and Barlow (2006) are applicable to this study due to the non-favourable survey design to record harbour porpoises, indicating that the group size estimates are underestimations.

Recommendations are to extend survey effort to all months of the year; total annual distribution and abundance would better assist in the of the overall movements of the species within the Moray Firth. Creating a dedicated transect route may enable CRRU to see exact interannual patterns, which can be relayed with other environmental and anthropogenic factors for more accurate assessments of habitat use and movements. Based on the three points of SAC justification for harbour porpoises presented by Pinn (2009), the southern coastline of the Outer Moray Firth fits the criteria of (1) the continuous or regular presence of the species (although subject to seasonal variations) and (2) good population density (in relation to neighbouring areas). Although as of yet there is no dedicated SAC for harbour porpoises in the Moray Firth, the ongoing conservation efforts of the Southern Trench MPA will provide some protection to the species. The data presented in this thesis updates the current knowledge of the species within the Moray Firth which are vital for assessing the conservation status of harbour porpoises and further supporting efforts to implement conservation measures. More research still needs to be carried out if an SAC for harbour porpoises is to be implemented within the Moray Firth.

# Supplementary Material

*Supplementary Table 1. SCANS survey estimates for harbour porpoises in the Moray Firth region. Data reproduced from Hammond et al. 1995; Hammond et al. 2006 and Hammond et al. 2017.*

| Year (Survey) | Survey Block - Survey Method | Abundance Estimate (Individuals/km) | Survey Section Extent |
|---|---|---|---|
| **1994 (SCANS-I)** | Section D – Aerial<br>Section J - Vessel | Section D - 0.363<br>Section J – 0.959 | Section D – Outer Firth and immediate North Sea<br>Section J – Inner Firth, Orkney and Shetlands |
| **2005 (SCANS-II)** | Section J - Aerial | 0.27 | Moray Firth, Orkney and Shetlands |
| **2016 (SCANS-III)** | Section S - Aerial | 0.152 | Moray Firth and Orkney |

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