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The long term distribution and relative abundance of harbour porpoises (*Phocoena phocoena*) in the outer southern Moray Firth.

Study hosted by the Cetacean Research & Rescue Unit (CRRU). Supervision provided by Dr. Kevin Robinson.

Photo Credit: Gary N. Haskins

"We ourselves feel that what we are doing is just a drop in the ocean. But the ocean would be less because of that missing drop."

-Mother Teresa

Declaration

All work presented within this report is my own, and has been carried out to fulfil the requirements of the *Bioscience Research Project* (module BIOL10006) within the School of Science and Sport at the University of the West of Scotland, session 2015-2016. The work reported here did not require ethics approval.

x Milo Mole

19/11/2015

Abstract

Utilising direct field observations from dedicated boat surveys, the present study aimed to determine the density and relative abundance of harbour porpoises (*Phocoena phocoena*) in the inshore coastal waters of the outer southern Moray Firth in northeast Scotland. Sightings of the harbour porpoise were recorded from May- October, 2001 to 2014 inclusive. Throughout this period, 701 encounters were recorded, accounting for 2,154 individuals across 15,480 kilometres of survey effort. This was converted to number of animals per km- found to be 0.139- for comparison with previous studies, as well as environmental variables such as sediment types and seabed slope. There was a strong aversion shown to the inshore route (along which bottlenose dolphins, *Tursiops truncatus,* are most commonly seen), suggesting that porpoise may avoid inter-specific interactions with this species, which are known to kill and injure porpoise.

The present data suggest this area provides important summer feeding ground for these animals, as well as a calving ground later in the season. The identification of key habitats and seasonal movements along this coastline is considered instrumental to support current proposals for "safe area" candidates for the species in these northern Scottish waters.

The current lack, or inaccuracy, of data on the harbour porpoise has been noted as one of the foremost reasons for the apparent complacency with which the UK government has regarded it to date– and the inapplicability of criteria laid down by the European Community's Habitats Directive (Council directive 92/43/EEC) for the designation of Special Areas of Conservation (SACs) for the species. Although progress is being made in this regard, with a current proposal for an SAC for harbour porpoise being reviewed for the Inner Hebrides and Minches (Scottish National Heritage, 2016), protection for this species is still scarce. In this respect, baseline estimates of the numbers and distribution of harbour porpoises in UK coastal locations are not only crucial to management, but of further importance to conservation policies for the implementation of SACs for this small cetacean species so clearly necessary for its protection.

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ACKNOWLEDGEMENTS

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1. Introduction

The order Cetacea comprises whales, dolphins and porpoises. It is subdivided into the baleen whales- suborder Mysticeti- and the toothed whales- suborder Odontoceti (Linnaeus, 1758). The harbour porpoise (*Phocoena phocoena*) is both the smallest and most abundant species of cetacean in the British Waters (Evans, 1992). The presence of teeth and a single blowhole place porpoises in suborder Odontoceti, along with other toothed whales, such as Orca and Bottlenose Dolphins (Barnes, 1985).

1.1. Physiology

Harbour porpoises exhibit slight sexual dimorphism, with the females reaching 75kg and males just 61kg (Read, 1997).

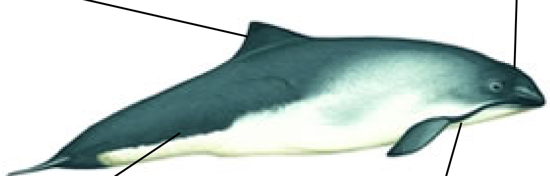

Figure 1.1.1: Diagram showing the external characteristics of *P. phocoena,* with major identifying attributes labelled (Adapted from Hebridean Whale and Dolphin Trust, 2015)

1.2. Behaviour and Identification

Many of the aforementioned attributes are very difficult to observe in the field, especially when sightings are typically fleeting. They are usually easiest to identify by their small size and 'rolling' movement when breathing. Porpoises also have a characteristic breath, taking short, sharp puffs unlike other species present in the survey area.

P. phocoena has a gestation period of around 11 months, with most births occurring around June and July and most mating activity occurring in July and August (Fisher and Harrison, 2009). The average life expectancy for the harbour porpoise ranges from 8-12 years, usually reaching sexual maturity at 3-4 years of age (Hohn and Reid, 1995). Harbour porpoises have been divided into three subspecies; *P. p. phocoena* in the North Sea and Atlantic (which are the focus of this study), *P. p. relicta* in the black sea and *P. p. vomerina* in the north pacific.

Porpoises usually travel in small groups of 2-5, however in this study, larger groups of up to 40 individuals were observed in June and September. This may be due to the fact that the porpoise breeding season is over, calves have been born and the porpoises are aggregating to travel.

1.3. Range

Harbour porpoise are very widespread, occurring in both coastal and pelagic regions. *P. phocoena* seem to prefer shallower seas, down to a depth of a maximum observed 226m dive, although they may be capable of diving further (Westgate *et al.*., 2011). Porpoise distribution may be correlated with factors such as prey availability, reproduction, surface temperatures (including thermocline locations) and human- introduced factors such as wind turbines and ship activity (Tynan *et al.*., 2005). Thermoclines generate upwellings that can provide a large amount of biological activity and prey availability in one area, and so many species can be observed foraging in and around them.

Figure 1.3.1: Probable distribution of all variants of *Phocoena phocoena.* Image adapted from IUCN Redlist (2015).

1.4. Diet

The Harbour porpoise diet consists mainly of sand eels. However, a study carried out analysing the stomach contents of stranded animals from 1992-2003 has shown them to also consume whiting, gobies, shrimp, herring and sprat, along with numerous other prey species (Santos *et al.*., 2004). It must also be considered that stranded animals are often unwell or unable to hunt effectively and so the stomach contents may not accurately represent what a healthy individual may eat. The same study showed that the diet directly reflected available prey species in the area, which varies throughout the year, taking prey from a variety of trophic levels, demonstrating great flexibility in the diet. Their prey selection may lead to a hypothesised association with certain sediment types- namely coarse, sandy gravel.

1.5. Threats and Anthropogenic Activities

There are many threats to harbour porpoises and cetaceans in general, in particular anthropogenic activities. This includes by-catch and entanglement, both acoustic and chemical pollution, micro- and macro-plastics as well as other sources such as offshore wind farms that can displace porpoise from critical habitats.

1.6. Current Conservation Status

Special Areas of Conservation (SACs) are habitats which have been designated as important- as defined in European Union directive (92/43/EEC), in terms of maintaining biodiversity and protecting present species. The Inner Moray Firth (See **Figure 1.6.1**) has been designated as an SAC (JNCC, 2005). The Inner Hebrides and the Minches have also been proposed as an SAC for harbour porpoise (Scottish Natural

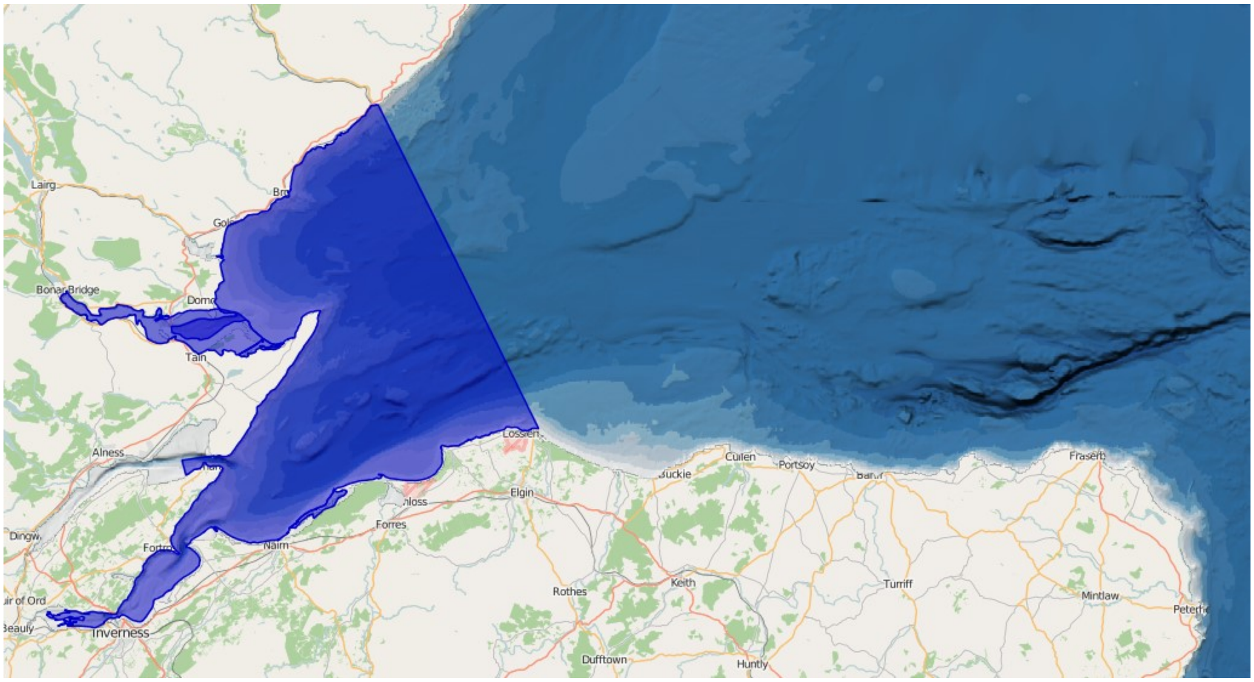

Figure 1.6.1: Map showing the position of the Special Area of Conservation covering the inner Moray Firth (Marine Scotland Planning Interactive Map).

Heritage, 2016). However, the efficacy of these management strategies have been called into question due to the continued anthropogenic use of these sites.

1.7 Aims

The aim of this paper is to highlight the abundant harbour porpoise population present in the outer southern Moray Firth, and call attention to the importance of improving current management policies in the area. This is particularly relevant in terms of reviewing and ameliorating existing conservation measures in the area.

Marine protected areas (MPAs) are zones set up by the government in which human activity is limited, including shipping traffic and fishing activity. This may allow a previously damaged area to recover or a pristine ecosystem to remain intact, with a significant reduction in the pressure of anthropogenic activity (Jobstvogt, Watson, and Kenter, 2014). The survey area in the outer southern Moray Firth is a prime candidate to become an MPA, due to its unique diversity and possibly damaging shipping activity.

2. Study Area

2.1. Description

The Moray Firth is Britain's largest Firth, measuring around 5230 km^2 (Tilbrook, 1986). It stretches from Fraserburgh in the East, up to Duncansby Head in the North and down to Inverness in the Southwest (Harding-Hill, 1993). It is divided into two geographical areas, namely; the 'outer' and 'inner' firths respectively (See **Figure 1.6.1)**. The data utilised in the present study was collected from opportunistic boat surveys along an 83km long area of southern coastline of the outer firth (illustrated in **Figure 2.1.1**), lying between Lossiemouth and Fraserburgh.

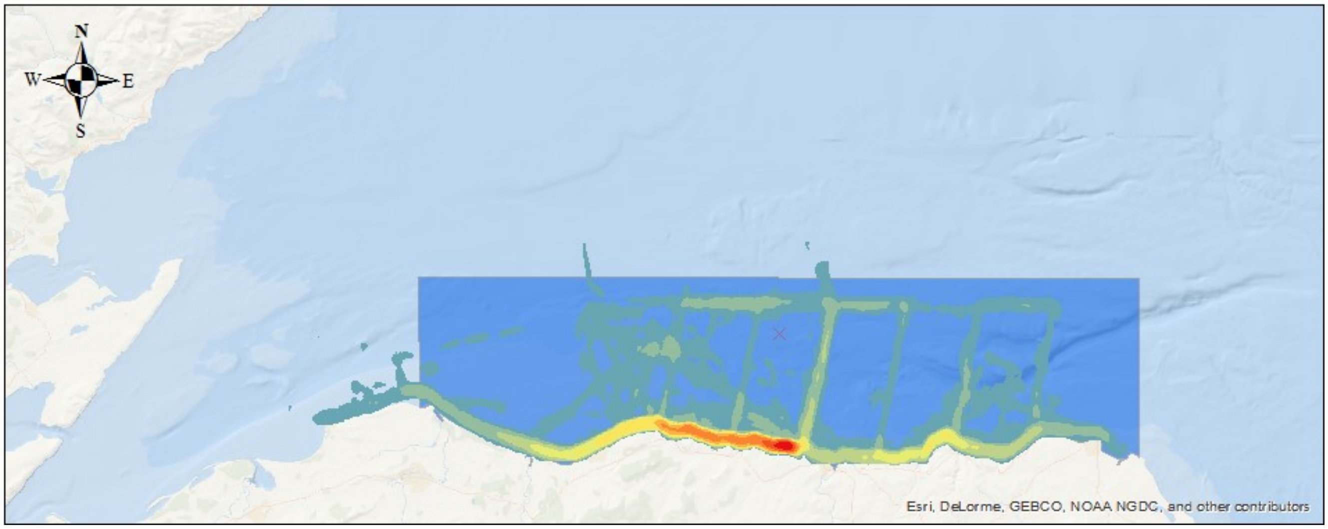

Figure 2.1.1: Map depicting the survey area and effort density in context of the Moray Firth.

2.2 Physical Characteristics

The bathymetry of the Moray Firth is relatively straightforward, with only one slight anomaly. Since Scotland sits atop the continental shelf, the surrounding seas are comparatively shallow. The Firth does not generally exceed a depth of 200m, and so the survey may not represent a true depth preference in porpoise, since the majority of waters in the area are epipelagic. The inner Moray Firth gradually slopes down to just 50m deep whereas the outer Moray Firth exhibits a much steeper curve down to over 200m in the aforementioned anomaly, the Southern Trench (Reid and MacManus, 1987).

The Firth is fed freshwater from a series of rivers and estuaries which substantially reduces salinity, especially near land. As the Fair Isle Current moves across North Scotland from the west, water is pulled into the Moray Firth and rotates clockwise within the Firth, mixing salty Atlantic water with estuarine freshwater. This creates a dynamic salinity gradient in the Moray Firth, again leading to more diverse habitat range.

The majority of the Moray Firth sediment is sandy. Reid and MacManus (1987) found that grain size was inversely correlated with depth in the Moray Firth. This leads to a concentration of sandy gravel patches in the shallows closer to the shoreline and more muddy sediments further offshore in deeper waters (British Geological Society, 2015). Sand eels, a predominant prey type of *P. phocoena,* are closely associated with sandy gravel, using it to burrow when avoiding predation. This would lead to an expectation to find a higher concentration of porpoises in the shallower waters with a higher prey abundance. The benthos in each sediment type effectively controls how the ecosystem unfolds further up the trophic chain. **Figure 2.2.1** gives the impression of distinct barriers between sediment types, however it is a gradual, clinal change with depth.

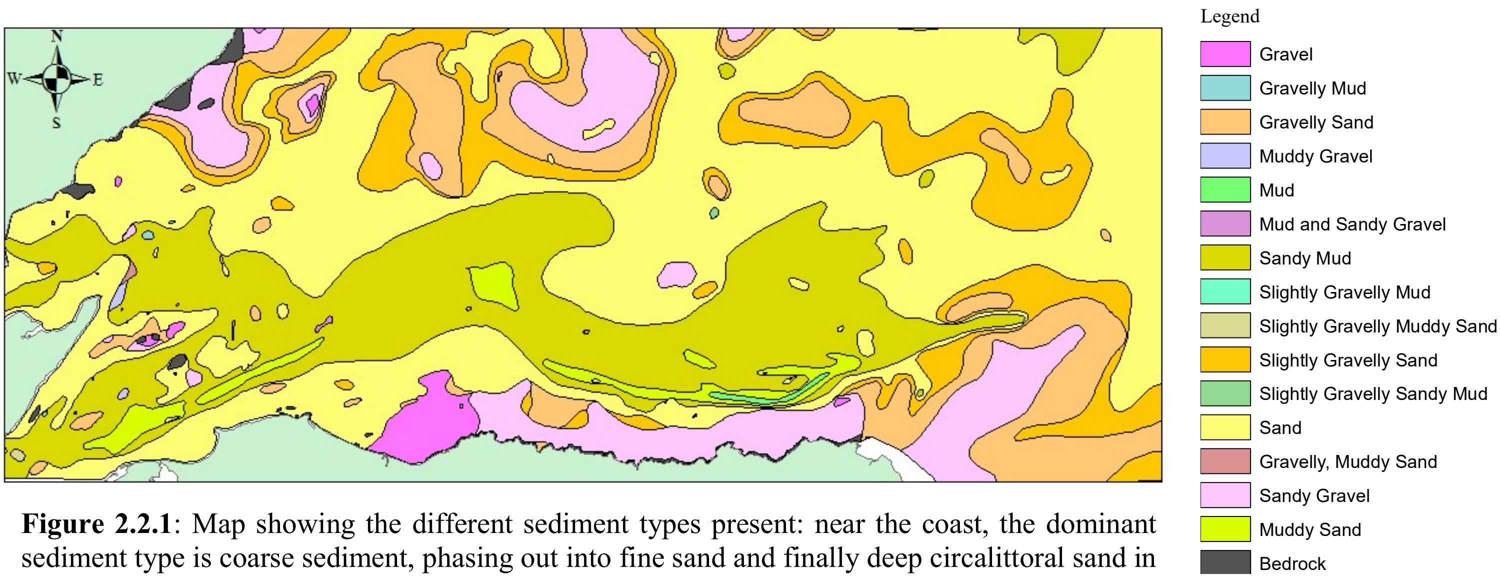

Figure 2.2.1: Map showing the different sediment types present: near the coast, the dominant sediment type is coarse sediment, phasing out into fine sand and finally deep circalittoral sand in epipelagic waters (Data Supplied by the British Geological Survey, 2016)

Although the study area is relatively large, in comparison to the total estimated range of the porpoise (see **Figure 1.3.1**), it is extremely small. Nonetheless, due to the extremely diverse nature of the area, the results may be a very ecologically relevant, disproportionate to its size.

Further study of this small, enigmatic animal is an absolute necessity to further consolidate the need for its- and other species in similar circumstances- protection. The present study aims to map the distribution and calculate relative abundance of the Harbour porpoise in the outer southern Moray Firth from 2001 to 2014. By doing so, and observing any trends in habitat preference through different months, it will be possible to see to what degree of importance this area is, and suggest the steps necessary to aid in the preservation of, and prevent further degradation of, a very important population of animals.

3. Materials and Methods

3.1. Data Collection

The data set used in the current study was collated by the Cetacean Research & Rescue Unit (CRRU) during opportunistic boat surveys in the outer southern Moray Firth between May and October 2001 to 2014 inclusive. The surveys were conducted along an 83 km length of the southern Moray Firth coastline between the ports of Lossiemouth and Fraserburgh, using 5.4 m outboard boats at mean vessel speeds of 7 knots in visibility ≥1 km and Beaufort Sea States ≤3. A crew of 2 experienced and up to 4 additional trained observers were utilised during surveys. All observers searched the water using a continuous scanning method (after Mann 1999), from directly in front of the boat to 90 degrees left and right of the track line. To ensure animals were sighted before they reacted to the presence of the survey vessel, binoculars were used from the observation frame to scan far from the boat, while the remaining crew searched closer to the vessel with the naked eye (Robinson *et al.,* 2007). During trips, both the vessel position (using Global Positioning System) and respective environmental data were recorded. When animals were spotted, the boat was gradually slowed (and circled back where necessary) to allow absolute identification of the species and ensure accurate counts of the number of animals sighted.

3.2. Data Analysis

Once back on shore, information concerning the trip were uploaded to Microsoft Excel. This included latitude/ longitude information and respective environmental data such as encounters and sea state.

After the co-ordinates and respective data had been uploaded, the raw data are filtered to only show those relating to sea state ≤1. This was then split into months and years and converted into a CSV file. These files were added to ArcGIS (Environmental Systems Research Institute, USA). For effort data, the MARINElife Ecological Survey Data Analyst (MESDA) tool was used to extract a trackline shapefile from the excel file, ready for input to ArcGIS.

A Geographic Information System (GIS) of the study area was created using ArcMap 10.1. Kriging and Math tools were used in conjunction with the Spatial Analyst toolbox to produce heatmaps of porpoise density that accounted for effort. The attributes table in ArcGIS was used to determine effort length for years, months and separate areas of the study area (i.e., Offshore, Inshore, Eastern, Central, Western and Spey Bay).

The relative abundance was calculated in Microsoft Excel as: (Individuals Sighted)/ (km Survey effort). Group sizes are presented as average ± 1SD.

4. Results

4.1. Effort

Between May and Oct 2001 to 2014 inclusive, a distance of 15,480 km was surveyed in sea state ≤1 (See **Table 4.2.1**).

4.2. Encounters

Across the 14 year period, there were a total of 701 encounters, comprising 2,154 animals. The average group size was 3.1 ± 3.6 animals. Group sizes ranged from a minimum of 1 to a maximum of 40 individuals. The largest groups were encountered in August and October. Small group sizes were by far the most prevalent, with 61% of all encounters comprised of either 1 or 2 individuals. The species was recorded throughout the study area at depths ranging from 7.9m to 200m, with an average of 54.8 ± 39.7m.

Table 4.2.1: Showing the sightings, individuals, effort and average group size of porpoise each year, for sea state ≤1.

Year	No. of sightings	No. of individuals	Effort (km)	Average Group Size
2001	9	33	541	3.7
2002	94	289	1441	3.1
2003	80	314	1166	3.9
2004	40	86	1390	2.2
2005	37	71	1024	1.9
2006	90	181	2108	2.0
2007	27	74	1498	2.7
2008	43	171	1057	4.0
2009	42	108	860	2.6
2010	51	137	768	2.7
2011	36	96	745	2.7
2012	62	222	918	3.6
2013	71	325	1395	4.6
2014	20	43	570	2.2

4.3. Abundance

The overall relative abundance for the survey area, expressed as individuals per km survey effort, was 0.139. The year with the highest relative abundance was 2003, with 0.269 individuals per km. The lowest abundance was seen in 2007 with just 0.049 individuals seen per km, less than one- fifth that of 2003.

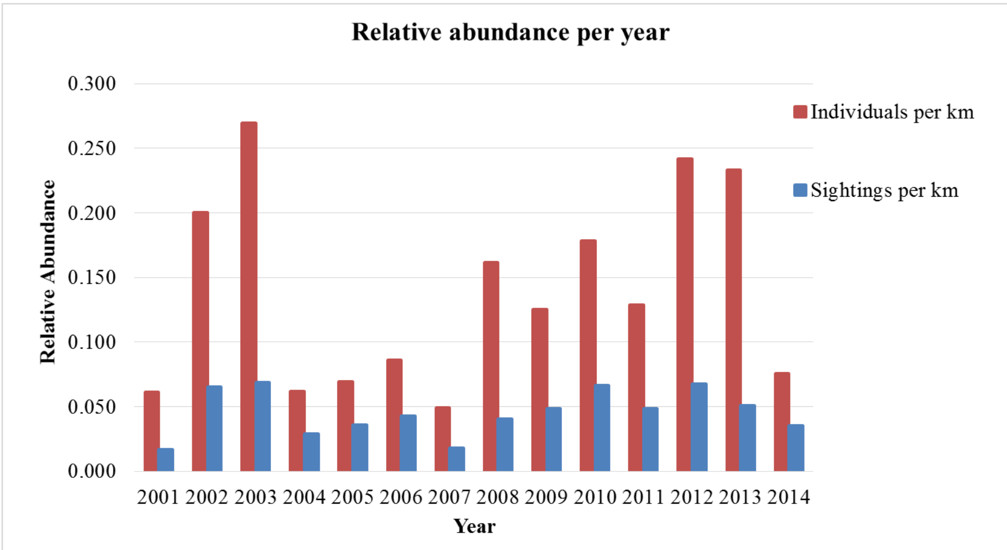

Figure 4.3.1: Histogram showing the encounter rate and relative abundance through all years of the study. Spikes are visible in 2002, 2003, 2012 and 2013.

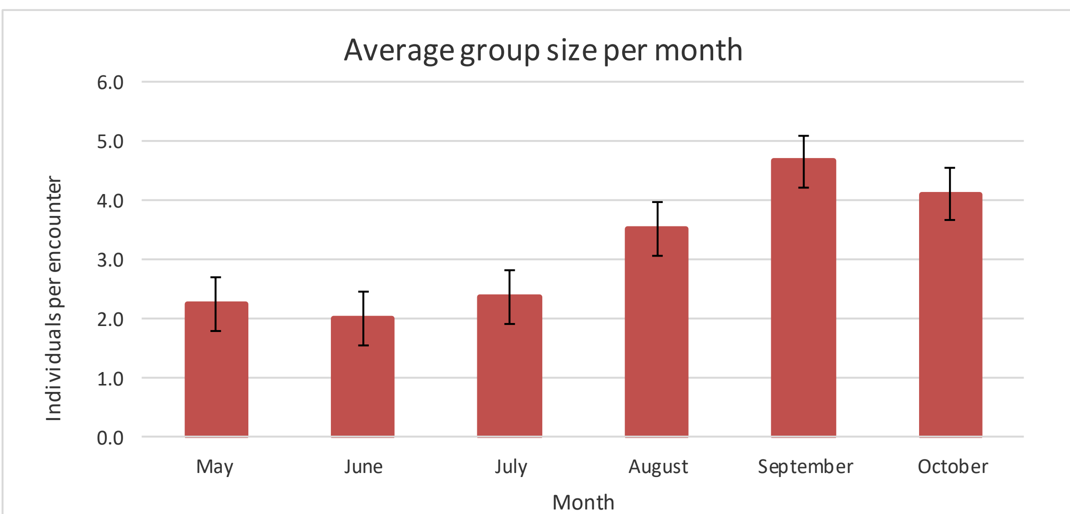

Figure 4.3.2: Showing a significantly higher average group size later in the year (P=0.023), with a peak in September, beginning to drop off in October and showing a low in June.

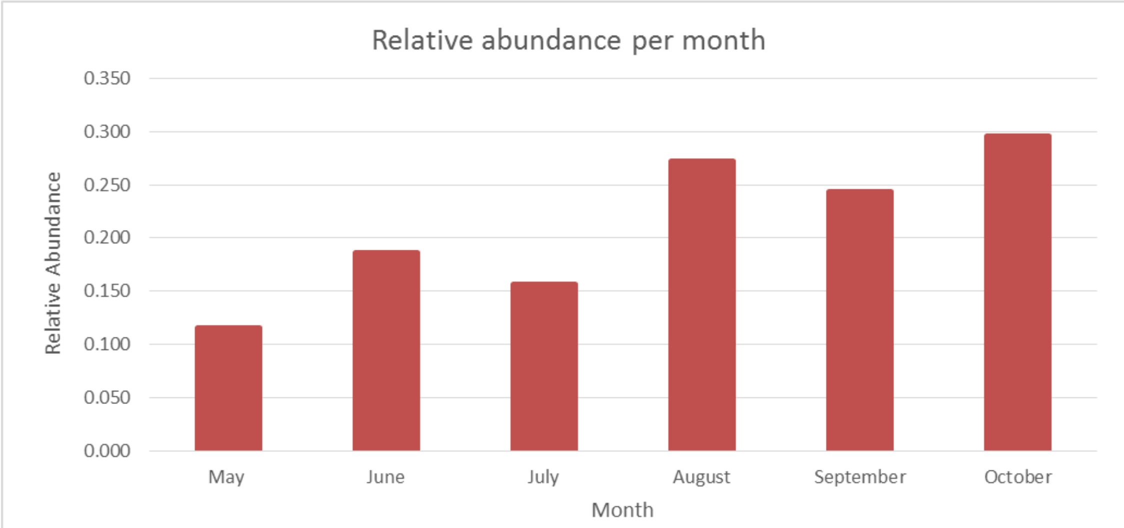

Figure 4.3.3: Showing Relative abundance per month in years 2001-2008, demonstrating a significantly higher relative abundance ($P<0.05$) later in the year, showing a low in May and a high in October.

4.4. Distribution

The porpoises were found ubiquitously throughout the study area through all years and all months. Figures **4.4.2** through **4.4.4** show the distribution within the study area. The animals were observed throughout the study area and there appeared to be no significant skew in years 2009-2014 inclusive, where effort data were available. For previous years, comments cannot be made on the relative abundance in different areas as effort concentration is not known.

The central zone was arbitrarily defined as the area between Findochty in the West to Gardenstown in the East, with the western and eastern zones lying on either side. In the western zone, the relative abundance was 0.178 individuals per km. In the central and eastern zones, the relative abundance was 0.142 and 0.090 individuals per km respectively.

Inshore, the relative abundance was found to be 0.070 individuals per km, compared to 0.359 individuals per km offshore, demonstrating a strong preference. The area with the lowest relative abundance was found to be the inshore region of Spey Bay, with only 18 individuals encountered over 1,012km of survey effort, amounting to a relative abundance of just 0.018 individuals per km.

The relative abundance was also found to change with sediment type. In areas with sandy gravel or gravelly sand (see **Figure 2.2.1**), there were 1,962 individuals encountered over the whole period, and a relative abundance of 0.083 individuals per km in the period from 2009-2014, compared to the overall 0.13 individuals per km over this period.

Slope was also investigated as a possible factor influencing distribution. **Figure 4.4.1** shows the relationship between slope and relative abundance in 2009- 2014 inclusive. Appendix 1 shows the slope in the Moray Firth.

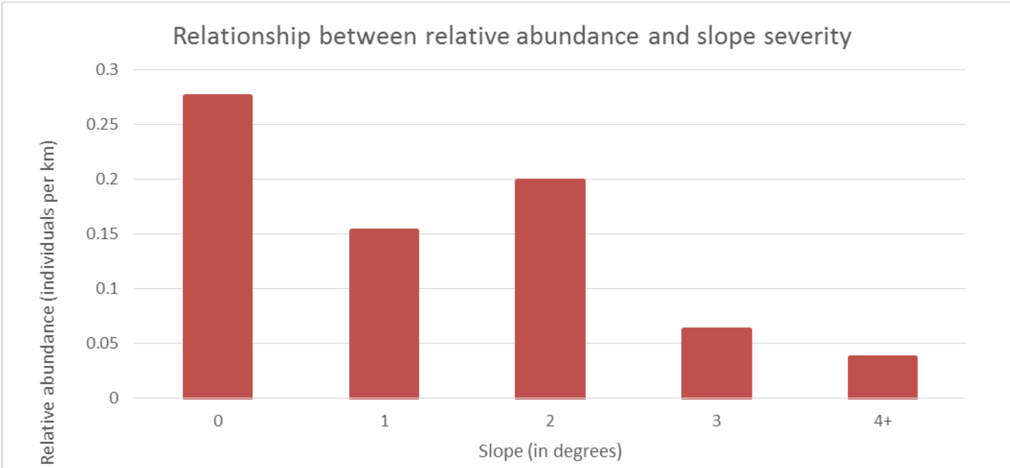

Figure 4.4.1: Showing the relationship between slope severity and relative abundance. A significant chance was noted (P<0.05) from a higher relative abundance on less sloped seabed to a lower on more sloped seabed.

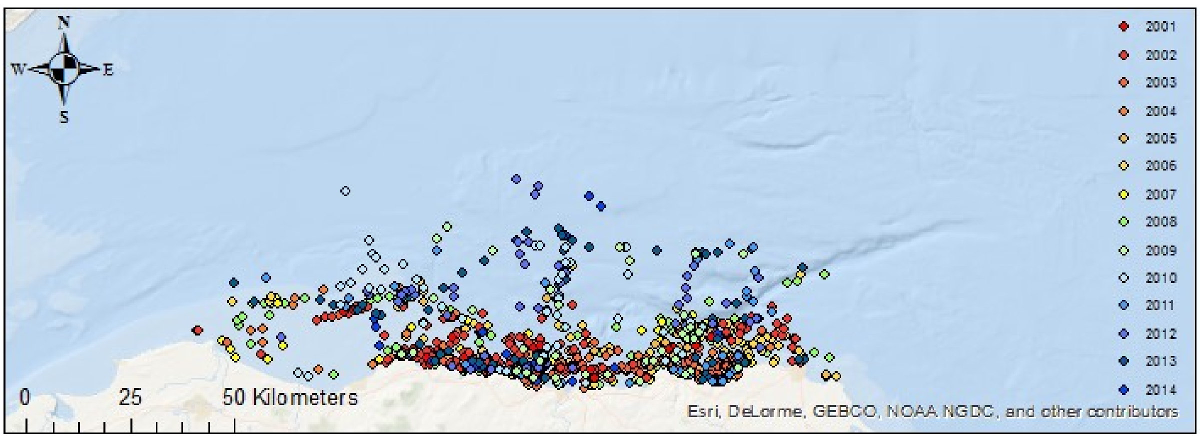

Figure 4.4.2: Showing all sightings from 2001 to 2014 inclusive (*n*= 701) Porpoise were found throughout the study site but were more typically observed in eastern and central zones of the area, with a notable reduction in encounter rate within and to the west of Spey Bay.

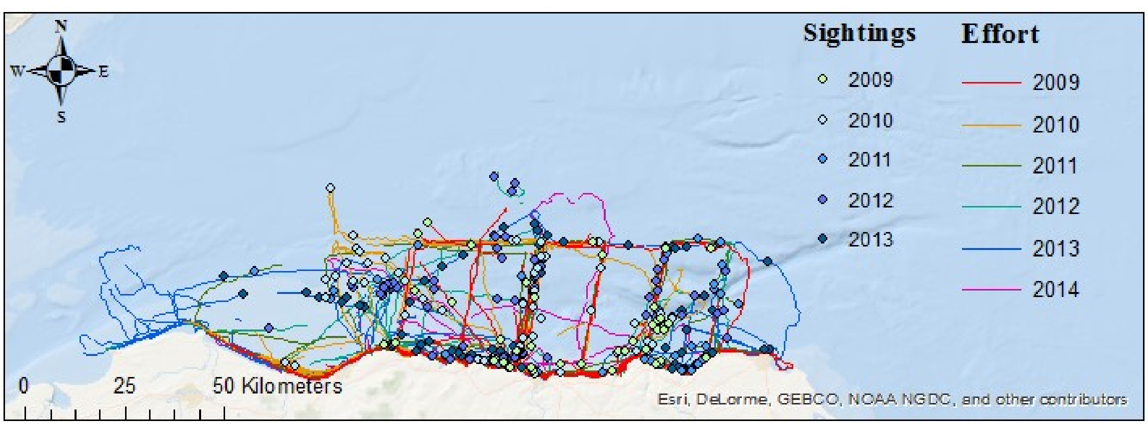

Figure 4.4.3: Showing both sightings and effort data for years 2009-2014 inclusive. (Effort distance= 15,437; *n*= 282)

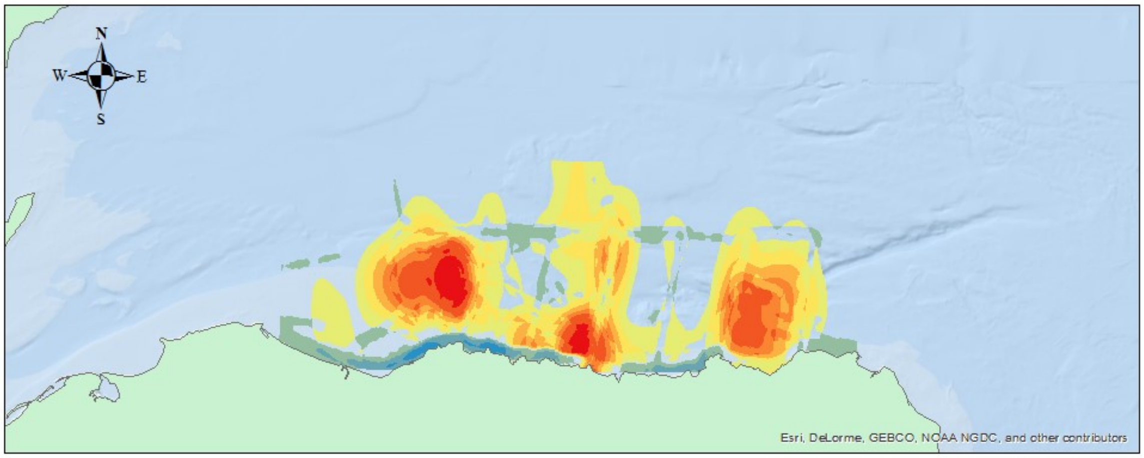

Figure 4.4.4: Showing sighting concentration through the whole study period, accounting for effort skew. Red patches denote a high density and blue patches show a low density.

5. Discussion

5.1. Abundance

The overall abundance in the present study, expressed as individuals per km, was 0.139. A study undertaken off the coast of South West Wales found an average of 0.433 individuals per km (Pierpoint, 2001), showing a much higher relative abundance than was found here. However, Pierpoint's study encompassed a much smaller time span than the present study and comprised of different bathymetry than the present one. Next to South West Ireland, a single- day study observed an incredibly high count of individuals- 251 porpoise over 270km, a relative abundance of 0.930 individuals per km. This survey was, however, very localised and conducted under exceptional weather conditions, possibly positively biasing the results. Weir *et al.*. (2001) recorded just 1,318 individuals from 155,308km survey effort, an overall relative abundance of 0.008 individuals per km. These figures compare well with the present study- especially offshore, where there was a relative abundance of 0.359 individuals per km, only marginally lower than that of Pierpoint's study- and may suggest that the Outer Southern Moray Firth provides an important habitat for porpoises.

Despite showing a high relative abundance, it is still probable that the presented figures are underestimates for the area, due to the difficulties involved when studying the species. There are many factors that influence observation rate. There are both observer-dependant factors, and observer-independent (environmental) factors:

Table 5.1.1: Listing some factors that may influence observation rate of marine species.

Observer-Dependant Factors	Observer-Independent Factors
Experience observing species	Sea state
Alertness and awareness	Swell
Perception (ability to see and recognise species)	Group size and dynamic
Focus	Behaviour of animal
Eyesight	Visibility and overall weather conditions

Availability bias also has a hand in determining the sighting of all cetaceans, most of all those inconspicuous species such as porpoise. Phocoenid species spend a minimal amount of time at the surface, and display unobtrusive behaviour while visible. Reed *et al.*. (2000) observed around 89% of time spent underwater, whereas Barlow *et al.*. (1988) documented 24% of time spent at the surface. This indicates that hydrophones may be an effective method of detection in future studies. Porpoises are typically less 'boat friendly' than other species such as bottlenose or common Dolphins. Most sightings are brief and breaching is very seldom observed. *Phocoena phocoena* rarely approach boats.

The relative abundance was observed to significantly increase ($P<0.05$) from May through October, peaking in October and seeing a low in May (see **Figure 4.3.3**). Porpoises may be feeding elsewhere during May and June, and come to the Firth to use this area for aggregation or as a travelling channel after calving.

5.2. Distribution

Porpoise were observed to frequent the entire study area through all months and all years (**Figures 4.4.2** through **4.4.4**), suggesting that this is an area of importance in terms of feeding and, later in the year, calving and aggregation. Despite this widespread distribution, there was a noticeable concentration (see section 4.4) offshore, with porpoises being observed more than 5 times more frequently than inshore. Culloch and Robinson (2008) found that bottlenose dolphins show a strong preference for inshore routes within the survey area, which is consistent with the hypothesis that porpoise may avoid encounters with bottlenose dolphins. In the years since 2009, where effort data are available, the relative abundance for the inshore area within and to the west of Spey Bay was calculated 0.018; much lower than the overall relative abundance for the study (0.139).

Porpoise abundance was found to decrease in areas with sandy gravel and gravelly sand, going against the hypothesis that they may be found more commonly here, due to their association with sandeels. However due to the varied diet of porpoise and sandeel use of finer substrate, it is likely that this distribution shift could be explained by other factors. Sandy gravel is much more common inshore in the survey area (see **Figure 2.2.1**), and so coincides with the preferred habitat of bottlenose dolphins.

Similarly, an inverse correlation was found between relative abundance and seabed slope. This, however, may also be due to the fact that the more heavily sloped areas tend to be closer into shore (See Appendix 1), and so the influencing factor may be the presence of bottlenose dolphins, rather than slope severity.

5.4. Group Sizes

The overall mean group size was 3.1 ± 3.6, which was higher than described in previous studies. Pierpoint (2001) found a mean group size of 1.97 in Welsh waters; Hammond *et al.* (1995) showed an average of 1.42 for the Block D area (which encompasses the Moray Firth) of the SCANS survey; Bjørge and Øien (1995) found a mean group size of 2.15 in Norwegian waters.

The porpoises were oft observed in small group sizes. Taylor and Dawson (1984) noted that porpoises are most often seen as solitary animals or in small groups. This study was no exception, with 61% of all encounters comprising of just 1 or 2 individuals. Nevertheless, Evans (1976) noted that larger group sizes were more common in the later period from July-October, after calving. In the present study, groups of size ≥ 8 were only present in this period, consistent with Evans' findings. The maximum group size was 40, seen in September.

The group size increased significantly (P=0.023) from May through October (see **Figure 4.3.2**). The lowest was seen in June (mean 2.0) and the highest in September (mean 4.7). These larger group sizes may be explained by a necessity for the raising and protection of new calves (Hughes, 1998), as well as alloparental care (Wilson 1980), all of which are conducive to existing in larger group sizes.

5.5. Ethics

Animals inevitably react to the physical presence of a boat, with different species displaying differing degrees of reaction, varying from extreme avoidance behaviour to bow riding and other 'boat friendly' displays. This type of behaviour would not occur in the absence of boats and may interfere with other behaviour, such as feeding or breeding.

The boat, however, remains a necessity. Although the burning of large amounts of fuel and disturbance caused to the animals may appear excessive, it also has major implications linked with the continued prosperity of porpoise and other species like it. Precautions are taken around the animals to minimise the disturbance caused, as noted in section 3.1.

6. Conclusion

Overall, the findings in this study intimate a strong case for the implementation of a Marine Protected Area in the Outer Southern Moray Firth, further supporting the already cogent proposal. This is due to its relatively high abundance and activity throughout the period that is representative of their need for, and continued use of, this study area.

Although there were hotspots observed, most notably offshore in western and eastern areas of the site (see **Figure 4.4.4**), the nomadic nature of *Phocoena phocoena*, as well as their continued and ubiquitous use of the whole site, is indicative perhaps of the need for a Protected Area that extends beyond the area borders.

Further study of behaviour and distribution both within and outside the site is recommended, especially in relationship with bottlenose dolphin distribution and interaction. Studies of cetacean avoidance and relationship with high traffic shipping routes, offshore windfarms and as well as interaction with other anthropogenic sources is also advocated. Other methods of observation should be considered and explored; acoustic surveillance devices such as towed hydrophones or static systems (C-PODs or otherwise) could be further implemented. Acoustic monitoring allows for constant observations to be made, regardless of the time of day, sea state or many other environmental conditions. They would also be able to provide a systematic review of acoustic behaviours exhibited by porpoise, of which there are few data available currently. When employed, these techniques and their resulting data can measure fine- scale temporal cycles of presence, absence and activity of multiple species within one area, invaluable as a supplement to the existing and future data from similar sources such as that provided by the CRRU.

Continued research such as that carried out by the CRRU and similar organisations remain fundamental and imperative to the continued survival of species such as *Phocoena phocoena,* as well as the protection and protraction of conservation biology as a whole.

7. References

Barlow, J., Oliver, C.W., Jackson, T.D. and Taylor, B.L. (1988) *Harbour Porpoise, Phocoena phocoena, abundance estimatesfor California, Oregon and Washington II: Arial Surveys.* Available at: http://swfsc.noaa.gov/publications/CR/1988/8810.PDF (Accessed: 25 March 2016).

Barnes, L.G. (1985) 'Evolution, Taxonomy and Antitropical Distributions of the Porpoises (Phocoenidae, Mammalia)', *Marine Mammal Science*, 1(2), pp. 149–165.

Bjørge, A. and Øien, N. (1995) 'Distribution and abundance of harbour porpoise, Phocoena phocoena, in Norweigian waters', *Report of the International Whaling Commission*, (16), pp. 89–98.

British Geological Society (2015) *UK geology: Onshore & offshore, bedrock & superficial web map service (WMS) British geological survey (BGS)*. Available at: http://www.bgs.ac.uk/data/services/geolwms.html (Accessed: 18 November 2015).

Choi, M., Moon, H.-B., An, Y.-R., Choi, S.-G. and Choi, H.-G. (2011) 'Accumulation of butyltin compounds in cetaceans from Korean coastal waters', *Marine Pollution Bulletin*, 62(5), pp. 1120–1123.

Clark, N.M. (2005) *The Spatial and Temporal Distribution of the Harbour Porpoise (Phocoena phocoena) in the Southern Outer Moray Firth, NE Scotland*. Msc Thesis thesis. University of Wales, Bangor. Available at: http://www.crru.org.uk/cust_images/pdfs/clark_thesis.pdf (Accessed: 14 November 2015).

Culik, B.M., Koschinski, S., Tregenza, N. and Ellis, G.M. (2001) 'Reactions of harbor porpoises Phocoena phocoena and herring Clupea harengus to acoustic alarms', *Marine Ecology Progress Series*, 211, pp. 255–260.

Culloch, R.M. and Robinson, K.P. (2008) 'Bottlenose dolphins using coastal regions adjacent to a special area of conservation in north-east Scotland', *Journal of the Marine Biological Association of the United Kingdom*, 88(06), pp. 1237–1243.

Digital Globe (no date) *High Resolution Earth Imagery*. Available at: https://www.digitalglobe.com/ (Accessed: 28 October 2015a).

EVANS, P.G.H. (1976) 'An analysis of sightings of Cetacea in British waters', *Mammal Review*, 6(1), pp. 5–14.

Fisher, H.D. and Harrison, R.J. (2009) 'Reproduction in the common porpoise (Phocoena phocoena) of the North Atlantic', *Journal of Zoology*, 161(2), pp. 471–486.

Gaskin, D.E., Smith, G.J.D., Arnold, P.W., Louisy, M.V., Frank, R., Holdrinet, M. and McWade, J.W. (1974) 'Mercury, DDT, Dieldrin, and PCB in Two Species of Odontoceti (Cetacea) from St. Lucia, Lesser Antilles', *Journal of the Fisheries Research Board of Canada*, 31(7), pp. 1235–1239.

Hammond, P.S., Berggren, P., Benke, H., Borchers, D.L., Collet, A., Heide-Jørgensen, M.P., Heimlich, S., Hiby, A.R., Leopold, M.F. and Øien, N. (2002) 'Abundance of harbour porpoise and other cetaceans in the north sea and adjacent waters', *Journal of Applied Ecology*, 39(2), pp. 361–376.

Hohn, A.A. and Read, A.J. (1995) 'LIFE IN THE FAST LANE: THE LIFE HISTORY OF HARBOR PORPOISES FROM THE GULF OF MAINE', *Marine Mammal Science*, 11(4), pp. 423–440.

IUCN (2015) *IUCN Red List Maps*. Available at: http://maps.iucnredlist.org/map.html?id=17027 (Accessed: 28 October 2015).

Jobstvogt, N., Watson, V. and Kenter, J.O. (2014) 'Looking below the surface: The cultural ecosystem service values of UK marine protected areas (MPAs)', *Ecosystem Services*, 10, pp. 97–110.

Joint Nature Conservation Comittee (no date) *Moray Firth - special area of conservation - SAC - habitats directive*. Available at: http://jncc.defra.gov.uk/protectedsites/sacselection/sac.asp?EUcode=UK0019808 (Accessed: 3 November 2005).

Kastelein, R.A., Jennings, N., Verboom, W.C., de Haan, D. and Schooneman, N.M. (2006) 'Differences in the response of a striped dolphin and a harbour porpoise to an acoustic alarm', *Marine Environmental Research*, 61(3), pp. 363–378.

Kellogg, W.N. and Bennett, T.L. (1973) *Perception: an Adaptive Process*. New York: MSS Information Corps.

Kulken, T., Kirkwood, J., Bennett, P., Jepson, P., Simpson, V. and Baker, J. (1997) 'Entanglement in fishing gear and other causes of death in cetaceans stranded on the coasts of England and Wales.', *The Veterinary record*, 141(4), pp. 94–98.

Leopold, M.F., Wolf, P.A. and Van Der Meer, J. (1992) 'The elusive harbour porpoise exposed: Strip transect counts off southwestern Ireland', *Netherlands Journal of Sea Research*, 29(4), pp. 395–402.

Linnaeus, C. (1758) *Systema Naturae*. 10th edn. .

Marine Scotland (2015) *National Marine Plan interactive*. Available at: https://marinescotland.atkinsgeospatial.com/nmpi/ (Accessed: 17 November 2015).

Martin, J.H.A. and Adams, J.A. (1986) 'The hydrography and plankton of the Moray Firth', *Proceedings of the Royal Society of Edinburgh. Section B. Biological Sciences*, 91, pp. 37–56.

Norris, K.S., Prescott, J.H., Asa-Dorian, P.V. and Perkins, P. (1961) 'An Experimental Demonstration of Echo-Location Behavior in the Porpoise, Tursiops truncatus (Montagu)', *Biological Bulletin*, 120(2), pp. 163–176.

O'Shea, T.J., Brownell, R.L., Clark, D.R., Walker, W.A., Gay, M.L. and Lamont, T.G. (1980) 'Organochlorine pollutants in small cetaceans from the pacific and south Atlantic oceans, November 1968-June 1976', *Pesticides monitoring journal*, 14(2), pp. 35–46.

Patterson, I.A.P., Reid, R.J., Wilson, B., Grellier, K., Ross, H.M. and Thompson, P.M. (1998) 'Evidence for infanticide in bottlenose dolphins: an explanation for violent interactions with harbour porpoises?', *Proceedings of the Royal Society B: Biological Sciences*, 265(1402), pp. 1167–1170.

Pierpoint, C.J.L. (2001) 'Harbour porpoise distribution in the coastal waters of SW

Wales', *Report for the International Fund for Animal Welfare*, .

Read, A.J. (1997) *The biology of the harbour porpoise*. Woerden, The Netherlands: De Spil Publishers.

Reed, J., Chambers, C., Hunter, C., Lockyer, C., Kastelein, R., Fedak, M. and Boutilier, R. (2000) 'Gas exchange and heart rate in the harbour porpoise, Phocoena phocoena', *Journal of comparative physiology. B, Biochemical, systemic, and environmental physiology.*, 170(1), pp. 1–10.

Reid, G. and McManus, J. (1987) 'Sediment exchanges along the coastal margin of the Moray Firth, eastern Scotland', *Journal of the Geological Society*, 144(1), pp. 179–185.

Santos, M.B., Pierce, G.J., Learmonth, J.A., Reid, R.J., Ross, H.M., Patterson, I.A.P., Reid, D.G. and Beare, D. (2004) 'Variability in the Diet of Harbor Porpoises (Phocoena phocoena) in Scottish Waters 1992–2003', *Marine Mammal Science*, 20(1), pp. 1–27.

Scottish Natural Heritage (2016a) *2016 Harbour porpoise pSAC consultation*. Available at: http://www.snh.gov.uk/protecting-scotlands-nature/protected-areas/2016-harbour-porpoise-consultation/ (Accessed: 14 April 2016).

Scottish Natural Heritage (2016b) *Inner Hebrides and the Minches proposed special area of conservation for the protection of harbour porpoise. Questions & answers*. Available at: http://www.snh.gov.uk/docs/A1921467.pdf (Accessed: 16 April 2016).

South Africa Coast (no date) *Dolphin Anatomy*. Available at: http://www.sacoast.ioisa.org.za/education/events/images/dolphinanat.gif (Accessed: 11 November 2015b).

Takahashi, S., Tanabe, S., Takeuchi, I., Miyazaki, N., Takahashi, S., Tanabe, S., Takeuchi, I. and Miyazaki, N. (1999) 'Distribution and specific Bioaccumulation of Butyltin compounds in a Marine Ecosystem', *Archives of Environmental Contamination and Toxicology*, 37(1), pp. 50–61. doi: 10.1007/s002449900489.

Taylor, B.L. and Dawson, P.K. (1984) 'Seasonal changes in density and behaviour of harbour porpoise affecting census methodology in Glacier Bay National Park, Alaska', *Reports of the International Whaling Commission*, (34), pp. 479–483.

Tilbrook, P.J. (1986) 'Nature conservation in the Moray Firth', *Proceedings of the Royal Society of Edinburgh. Section B. Biological Sciences*, 91, pp. 13–25.

Tynan, C.T., Ainley, D.G., Barth, J.A., Cowles, T.J., Pierce, S.D. and Spear, L.B. (2005) 'Cetacean distributions relative to ocean processes in the northern California Current System', *Deep Sea Research Part II: Topical Studies in Oceanography*, 52(s 1–2), pp. 145–167.

Weir, C.R., Pollock, C., Cronin, C. and Taylor, S. (2001) 'Cetaceans of the Atlantic frontier, north and west of Scotland', *Continental Shelf Research*, 21(8-10), pp. 1047–1071.

Westgate, A.J., Head, A.J., Berggren, P., Koopman, H.N. and Gaskin, D.E. (1995) 'Diving behaviour of harbour porpoises, Phocoena phocoena', *Canadian Journal of Fisheries and Aquatic Sciences*, 52(5), pp. 1064–1073.

Wiirsig, B. and Jefferson, T.A. (1990) *Individual recognition of cetaceans: use of* *photo-identification and other techniques to estimate population parameters: incorporating the proceedings of the Symposium and Workshop on Individual Recognition and the Estimation of Cetacean Population Parame*. Edited by Sally A. Mizroch and Gregory P. Donovan. Cambridge: International Whaling Commission.

Wilson, E.O. (1980) *Sociobiology*. London, England: Harvard University Press.

Yebra, D.M., Kiil, S. and Dam-Johansen, K. (2004) 'Antifouling technology—past, present and future steps towards efficient and environmentally friendly antifouling coatings', *Progress in Organic Coatings*, 50(2), pp. 75–104.

Appendix 1

Map showing the slope throughout the study area and Moray Firth.