The Spatial and Temporal Distribution of the Harbour Porpoise (*Phocoena phocoena*) in the Southern Outer Moray Firth, NE Scotland

Masters of Science Thesis

Marine Mammal Science

By

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Declaration

“The last fallen mahogany would lie perceptibly on the landscape, and the last black rhino would be obvious in its loneliness, but a marine species may disappear beneath the waves unobserved and the sea would seem to roll on the same as always”

-G. Carleton Roy
In “Biodiversity” National Academic Press 1988

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Abstract

Despite being the most commonly sighted cetacean in UK waters, surprisingly little is know about the ecology, life history and distribution of the harbour porpoise (*Phocoena phocoena*). Harbour porpoises were widely encountered throughout the study area. Geographical Information Systems were used to investigate the effects fixed environmental variables such as depth, aspect, slope and sediment type had on the spatial distribution of the harbour porpoise in the southern outer Moray Firth. Similar techniques were also used to observe the interactions between the harbour porpoise and the bottlenose dolphin, which have been widely reported to attack and fatally injure porpoises in this area. The results of the study highlighted some interesting correlations between the distribution of the harbour porpoise and the variables mentioned above. Harbour porpoise were found to be most commonly encountered on steep, northerly facing slopes compiled of sandy gravel sediments in average water depths of 36m. This habitat preference was thought to be highly correlated to the feeding ecology of the harbour porpoise in particular related to the sandeel, (*Ammodytes marinus*). The temporal distribution of harbour porpoise in the study area was highly varied both within and between survey seasons. The relative abundance of porpoises in the outer Moray Firth has significantly decline during the study period of 2002-2005. Reasons for this decline are discussed and include interactions with fisheries, climate change and the bottlenose dolphin. Bottlenose dolphins were commonly encountered in the survey area and despite this threat of fatal interactions and a significant difference in encounter depths of the two species, both the bottlenose dolphin and harbour porpoise occur in the same areas. As the only long term study to date on the species in this area of the Moray Firth, it is hoped that this study will aid in the understanding of the ecology and distribution of this population of porpoise.

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1. Introduction

1. Introduction

1.1 The Effect of Oceanographic Features on Cetacean Distribution

The structure of the ocean is highly complex, consisting of flat ocean plains, deep sea trenches and underwater mountain ranges. Large and small scale variations in this heterogeneous environment have been observed to significantly influence the spatial and temporal distribution of marine life all over the world (Pollock et al., 2000). A number of studies have identified a range of physical and biological factors that affect the distribution of cetaceans, including bathymetry, topography, sea surface temperature, salinity, tidal currents, eddies, fronts, prey distribution, reproductive strategies, predation and interspecific competition (Davis et al., 2002; Baumgartner et al., 2000; Raum-Suryan & Harvey, 1998; Calderan, 2003). Such factors result in the uneven distribution of cetaceans throughout the aquatic environment and the clustered hotspots of cetaceans that require attention on a conservation and management scale (Yen et al., 2004).

1.1.1 *Bathymetry*

A number of studies have proven depth to be an important factor in the distribution of cetacean species in various locations around the world. Baumgartner (1997) highlighted the significance of depth in the study of Risso's dolphins, Grampus griseus, in the Gulf of Mexico where significantly more sightings occurred between depths of 350 m and 975 m. In the Rockall Trough, off the west coast of Scotland, partitioning of species was noted in relation to depth. All sperm whales, Physeter macrocephalus, were noted to occur along the 1,000 m depth contour whilst most Risso's dolphin sightings occurred in waters shallower than 200 m (Pollock et al., 2000). Harbour porpoise, Phocoena phocoena, off the coast of northern California showed a non-uniform distribution in respect to depth, where significantly more encounters with this species occurred between the depths of 20 m and 60 m (Carretta et al., 2000). Hui (1979) indicated depth to be the variable most responsible for the difference in distribution of common dolphins, Delphis delphis, and pilot whales, Globicephala melas. A number of studies have indicated that preferred depth of

cetacean distribution is correlated to the foraging patterns of difference species (Hui, 1979; Moore et al., 2000). Cetacean species that feed on squid, such as sperm, beaked and long-finned pilot whales, are inclined to occur in deeper waters (Pollock et al., 2000).

Risso's dolphins in the Gulf of Mexico were found at greater depths than those Risso's dolphins encountered in the Rockall Trough, Scotland (Baumgartner, 1997; Pollock et al., 2000). Bottlenose dolphins and fin whales have also been recorded in varying ocean depths throughout their geographical distribution (Pollock et al., 2000; Moore et al., 2000), which may be a reflection of varying feeding habits occurring at differing locations.

1.1.2 *Topography*

Topography is the shape and structure of the seafloor and includes factors such as slope, aspect and the sediment type of the seabed. Hui (1979) proposed the importance of slope gradient, suggesting that the change in depth was a greater factor in cetacean distribution than depth itself. Sperm whales have commonly been shown to have a high affinity for continental slopes (Gannier et al., 2002; Whitehead et al., 1992; Davis et al., 2002). Areas of steep underwater topography have also been shown to attract a high density of belugas, *Delphinapterus leucas*, in Alaska (Moore et al., 2000) and northern right whales, *Eubalaena glacialis*, in the Bering Sea (Sheldon et al., 2005). Like depth, the appeal of steep slope gradients to cetaceans is related to food. Steep topography encourages physical processes such as currents, tidal mixing and eddies, resulting in the vertical migration of nutrients known as upwellings, and an increase in productivity (Davis et al., 2002; Sheldon et al., 2005; Hanby, 2003). Deep sea canyons are ideal examples of steep ocean topography concentrating prey species. Waring et al. (2001) showed that cetaceans are attracted to such areas for prey consumption with evidence that more beaked whales were encountered in relation to canyons than areas without such features.

Aspect refers to the direction that the slope of the seabed is facing. Few studies have looked at the relationship between aspect of slope and the distribution to cetaceans. In a study of minke whales, *Balaenoptera acutorostrata*, in the outer Moray Firth, Tetley

(2004) showed that significantly more encounters were recorded on northerly facing slopes. Despite this result, aspect was deemed to be unimportant in terms of minke whale distribution.

Few studies on cetacean distribution have investigated the effect of seafloor sediment type, and those that have, have proved strong correlations with this factor. Minke whales in the St Lawrence estuary, Canada, were most often encountered over sandy sediment types (Naud et al., 2003). On the other side of the Atlantic, minke whales around the Hebrides, Scotland were also found over sandy sediments types with a mixture of fine gravel in spring. However, later in the summer, minke whale distribution moved to sediments of a more gravel composition (Macleod et al., 2004). Preference for varying sediment types is thought to be related to underlying prey species and their needs and preferences.

Bathymetry and topography clearly play a role in the distribution of cetaceans; however it seems that this influence is more of a secondary affect. It is suggested that depth and seabed structure are an influence on productivity and the distribution of vital prey species, which in turn encourage the aggregation of foraging cetaceans (Hui, 1979; Johnston et al., 2005).

1.2 The Harbour Porpoise

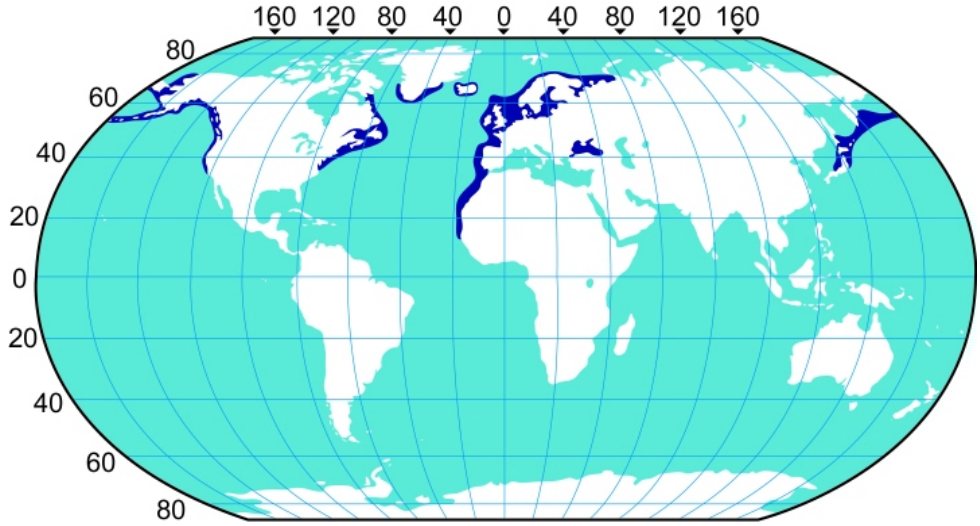


Figure 1.1: Harbour porpoise are widely distributed along the coasts of the Northern Hemisphere, shown by the areas in dark blue. (Map from the American Cetacean Society, www.acsonline.org).

Harbour porpoise, *Phocoena phocoena*, is the most commonly known and studied member of the Phocoena family. This species of small odontocete cetaceans inhabit the continental shelf of temperate waters in the northern Hemisphere, shown in figure 1.1 (Johnston *et al.*, 2005). Despite this virtually circumpolar navigation, animals from the Pacific and Atlantic Ocean and Black Sea are all reproductively isolated from each other (Bjorge & Tolley, 2004).

Harbour porpoise are small and robust, with an extremely thick blubber layer which aids in reducing heat loss in their cold water habitats. Visually, harbour porpoise have a dark dorsal side and a white ventral and despite their elusive behaviour are easily distinguished from other cetaceans by their rounded head, absence of a beak and triangular shaped dorsal fin (figures 1.2 and 1.3).

Figure 1.2: With a dark dorsal and white ventral side the porpoise is most clearly distinguished from other coastal species by its triangular shapes dorsal fin. (Photograph by Kevin Robinson).

Black or dark dorsal side

Triangular shaped dorsal

Small rounded head with no beak

White or lighter coloured ventral side

Figure 1.3: Illustration of the morphological characteristics of the harbour porpoise (*Phocoena phocoena*).

Harbour porpoise have an average life span of 8-10 years. At birth the porpoise measures 65 to 70 cm and does not reach a maximum length until 8 years of age. Once fully grown porpoise exhibit slight sexual dimorphism with males growing to 60-118 cm and 50 kg in weight and females growing to 66-118 cm and 55 kg (Lockyer, 1995). Sexual maturity occurs at 3-4 years and to maximise reproductive success in such a short lived species, the harbour porpoise gives birth once a year (Gaskin et al., 1984). Such reproductive cycles were described in harbour porpoise in the Gulf of Maine and the Bay of Fundy by Gaskin et al. (1984). Parturition was observed to occur in May followed by ovulation and conception in late June and early July. By late summer or early autumn, most females examined were pregnant. Gestation was estimated at 10.6 months, allowing females to give birth and conceive the following spring. Lactation is thought to occur for 8-12 months while the females are pregnant (Gaskin et al., 1984; Lockyer, 1995; Read, 2000; Calderan, 2003). This coincides with observations in the North Sea and around the coast of Wales where juveniles were first sighted in May and June (Pierpoint et al., 1998).

1.2.1 *Diet*

Due to their small size, harbour porpoise have a relatively high turnover of energy reserves and low energy storage capacity (Brodie, 1995). This explains why an estimated 3.5 % of the animal's body weight in prey must be consumed daily, a figure which increases by 80 % in lactating females (Yasui & Gaskin, 1986). The distribution of harbour porpoise, therefore, is restricted to areas in close proximity to the distribution of their prey (Santos & Pierce, 2003). Analysis of stomach contents of harbour porpoise stranded and by-caught in UK waters revealed important prey species to include; sandeels (*Ammodytes marinus*), gobies (*Gobius* sp.), whiting (*Merlangius merlangius*), herring (*Clupea harengis*), poor cod (*Trisopterus minutus*), haddock (*Melanogrammus aeglefinus*), Norway pout (*Trisopterus esmarki*), and pollack (*Pollachius pollachius*). Some of these prey species are displayed in figure 1.4 (Peirpoint *et al.*, 1998; Pollock *et al.*, 2000; Evans 1990).

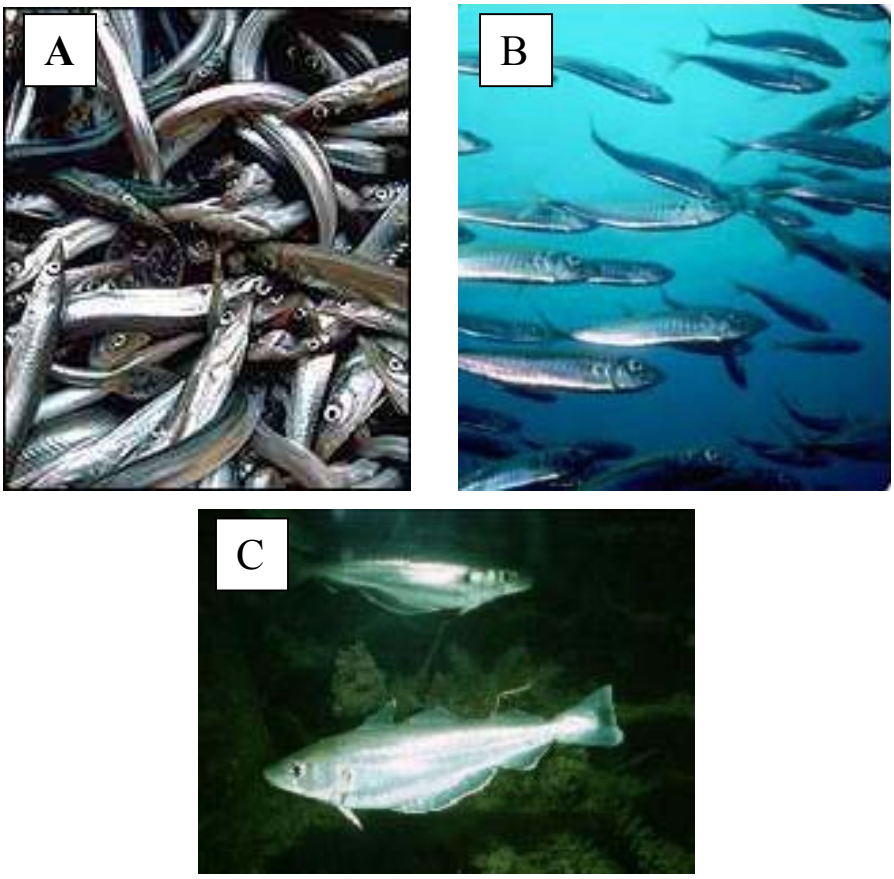


Figure 1.4: A number of prey species have been identified from the stomach contents of stranded and by-caught harbour porpoise. 3 common species include A) the sandeel (*Ammodytes marinus*), B) herring (*Clupea harengis*) and C) whiting (*Merlangius merlangius*). (Images from BBC, National Geographic and fishnet respectively).

In Scottish waters sandeels are reported to be an important part of the diet in summer, constituting 58 % of the stomach content (Payne et al., 1986), whilst other species such as haddock, whiting, herring and pollack become more important during autumn and winter when the availability of sandeels is thought to decline (Pollock et al., 2000). It has also been suggested, that of these species, only the smaller individuals are consumed by the harbour porpoise. This is thought to be due to the morphology of their jaws, which can only gape to approximately 8 cm restricting the consumption of larger fish (Calderan, 2003). Feeding behaviour of harbour porpoise includes logging at the surface, often holding position in tidal races, surface lunges, changing direction abruptly and loose aggregations of animals occurring periodically to allow cooperative foraging. Seabirds, such as gannets, Moraus bassanus, and manx shearwater, Puffinus puffinus, are also often seen in association with feeding harbour porpoise (figure 1.5), attracted by the prey driven towards the surface by the foraging porpoise and other predatory fish (Pierpoint et al., 1998).

Figure 1.5: Bird association is often observed around feeding harbour porpoise. Species of bird include, gannets (*Morus bassanus*), manx shearwater (*Puffinus puffinus*), common gulls (*Larus canus*) and kittiwakes (*Rissa tridactyla*). (Photograph by Kevin Robinson)..

1.2.2 *Harbour Porpoise on a Local Scale*

Relatively few studies have focused on the harbour porpoise in UK waters. Harbour porpoise have been found in both coastal and offshore habitats, however, in most areas sightings are confined to depths of less than 100 m (Pierpoint et al., 1998). Very little is known about the movement and migration patterns of these animals; however an inshore-offshore movement has been suggested for some areas, explaining the great

reduction in animals over the winter season (Jones, 2004; Calderan, 2003; Pierpoint et al., 1998; Robinson et al., 2005). A number of studies based around the coast of Wales found harbour porpoise to increase in numbers and aggregate during late summer and early autumn, suggesting these waters to be an important coastal habitat for the species at this time of year (Pierpoint et al., 1998; Jones, 2004). The relative abundance of 0.72 animals / km in the Welsh candidate for a Special Area of Conservation further supports this proposition (Pierpoint et al., 1998).

The SCANS survey (1994) estimated harbour porpoise abundance of 341,366 in the North Sea and adjacent waters. The SCANS survey area was divided into Blocks. Block D encompassed part of the outer Moray Firth and was estimated to have a relative abundance of 0.363 porpoise / km. This figure is significantly lower than other areas of the SCANS survey, such as the coastal northern Wadden Sea where 0.812 porpoise / km were calculated (Hammond et al., 1995). The first small-scale focal study on harbour porpoise in the outer Moray Firth calculated the relative abundance to be 0.752 porpoise / km in 2003, a significant elevation from the SCANS survey result (Whaley, 2004). This high relative abundance indicated the outer Moray Firth to have one of the highest abundance levels yet recorded in the coastal waters of the UK, even greater than that recorded in the candidate for a Special Area of Conservation in Wales.

1.2.3 *Status*

Harbour porpoise are widely distributed in the northern hemisphere, and are a commonly sighted species in many coastal areas of Ireland and Britain (Weare, 2003). However, in many areas harbour porpoise numbers have declined, such as the French coast, English Channel, Baltic Sea and Southern North Sea, while other areas have seen complete eradication of the species such as the Mediterranean Sea (Baines et al., 1997).

Harbour porpoise, like all cetaceans, are protected under UK and EU law. International protection includes; listing under the 1992 EU Habitats and Species Directive under Appendix II and IV, whereby the deliberate capture and killing of animals is prohibited. Appendix II of CITES (Convention on International Trade in Endangered Species), Appendix II of ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas) and the Bern Convention also offer protection. On a national

scale harbour porpoise are also protected under Schedule 5 of the Wildlife and Countryside Act 1981 (UK Biodiversity Group, 1999) (Jones, 2004). To establish protection of the harbour porpoise, the EU Habitats and Species Directive Annex II requires Special Areas of Conservation to be set up in identified areas of physical and biological importance to the life and reproduction of the harbour porpoise (EC, 1992; Calderan, 2003). This year, the inner Moray Firth became a Special Area of Conservation for the resident population of bottlenose dolphin and an area in west Wales is currently a candidate for a Special Area of Conservation for the same species. To date, however, no such area has been identified as highly important to harbour porpoise due to the lack of knowledge on most aspects of their ecology, distribution and habitat. (Weare, 2003). Understanding such factors is highly challenging due to their wide distribution, seasonal migration, elusive behaviour, lack of distinctive characteristics to allow identification of individuals and lack of studies concentrated on this species (Calderan, 2003).

1.2.4 *Threats*

Between 1991 and 1993, 47 % of stranded cetaceans in Scotland were harbour porpoise (Ross & Wilson, 1996) suggesting that these animals are faced with a great number of threats in these waters. Evidence has indicated that harbour porpoise numbers have declined in UK waters since the 1940s and suggested reasons for this include; incidental capture in fishing gear, pollution and environmental change (Calderan, 2003). In Wales, incidental by-catch has been identified as the greatest threat to harbour porpoise (figure 1.6) and that threat is increasing. Kirkwood et al. (1997) proved that the numbers of stranded harbour porpoise due to by-catch had increased each year between 1990 and 1995. A further significant threat to porpoise in Welsh waters is disturbance from human activities, especially during the summer season when numbers of harbour porpoise are greatest. Disturbance at this time is also highly problematic as it coincides with the breeding period (Jones, 2004).

Figure 1.6: One of the greatest threats to harbour porpoise in the UK is from the fishing industry. The threat of by-catch is increasing and is likely to be having a detrimental affect on the population. (Images from the BBC and IFAW respectively).

Other threats identified in UK waters include; contaminants such as polychlorinated biphenyls (PCBs) which increase infectious disease in the population, noise disturbance, oil and gas exploration, interspecific interactions, in particular with bottlenose dolphins, and increases in boat traffic (Pierpoint et al., 1998; Jones, 2004; Patterson et al., 1998). Such threats contribute to the high level of mortality recorded in harbour porpoise with 50 % of animals not reaching the age of 4 years and a total annual mortality of 17 % estimated in Scottish waters. This is likely to be detrimental to the population, as the annual reproductive rate was calculated at only 8 % (Learmouth et al, 2005). As a short lived species, that breeds annually it is likely that the harbour porpoise is already maximising its rate of reproduction. It is vital, therefore, that these threats discussed are severely reduced or eliminated to slow the decline of this species. Learmouth et al (2005) showed that, should the effect of interspecific interactions with bottlenose dolphins be removed, the annual mortality would decline by 1 %, a significant proportion for a threatened species.

1.3 Interspecific Interactions

A total of 227 stranded or by-caught harbour porpoise off the east coast of Scotland were examined between 1990 and 2001, of these 227 animals, 61% revealed signs of interspecific interactions with bottlenose dolphins (Wilson et al, 2004). Interactions between the harbour porpoise and bottlenose dolphins were first identified in the Moray Firth by Ross and Wilson (1996), where 42 out of 44 examined porpoise showed signs

of blunt force trauma. Such injuries included; extensive bruising and haemorrhaging in the subcutaneous tissue and musculature, fractured rib cages, perforation of the lungs, fractured vertebrae and injuries to abdominal organs. Of the animals displaying these injuries, 64% of them exhibited skin damage consisting of parallel 'rake' marks linking the attacks to the bottlenose dolphin by its inter-tooth interval measurement (Ross & Wilson 1996). The first eye witness account of these interactions was first documented in 1993 and since then a number of incidences have been recorded (Patterson et al. 1998). However, such interactions are suspected to have been occurring for many years, but a lack of post-mortems and research has prevented it from being realised (Dunn et al. 2002).

(A) (B)

Figure 1.7: Injuries attained from interspecific interactions with the bottlenose dolphin in the Moray Firth. A) Post-mortem image shows bleeding and haemorrhaging of the blubber layer caused by blunt force trauma (DEFRA). B) Shows the characteristic 'rake' marks that implement bottlenose dolphin teeth by the individual inter-tooth interval measurement (Aberdeen University).

A number of reasons for these interactions have been suggested including; prey shortage enhancing competition, male aggression due to lack of females, accidental death during 'play' and the most widely accepted and documented, the practice of infanticide, a behaviour thought to occur in bottlenose dolphins (Ross & Wilson, 1996; Patterson et al., 1998; Dunn et al., 2002). Evidence of infanticide (the killing of an infant) occurring in bottlenose dolphin comes mainly from similar injuries to those described in porpoises occurring in bottlenose calves in the Moray Firth and Virginia, USA. The identical size of harbour porpoise victims to the bottlenose calf victims of infanticide has led to the belief that bottlenose dolphins practise 'infanticidal' behaviour on harbour porpoise to enhance their reproductive success (Patterson et al., 1998).

With bottlenose dolphins presenting a significant threat to the harbour porpoise in the Moray Firth it is suspected that species partitioning occurs between the 2 species with harbour porpoise avoiding areas where dolphins are present. In other areas of the world species partitioning has been reported to be due to other factors such as prey competition. In the northwest Atlantic, fin, humpback and minke whales were observed to be segregated by depth to avoid direct competition for prey (Pollock *et al.*, 2000).

1.4 Aims of the Study

In recent years, more and more demands have been placed on the conservation of cetaceans in UK waters. As discussed above, the populations of harbour porpoise in the UK are facing a great number of threats resulting in observed population declines and an uncertain future. To effectively manage and conserve cetaceans, knowledge of their spatial and temporal distribution is required on both large and small scales. For example off the coast of California harbour porpoise were rarely found in depths greater than 110m, whilst in contrast, near the San Juan Islands, they were frequently encountered in depths greater than 100 m (Carretta *et al.*, 2000). It is, therefore, clearly important to examine defining variables on local scales. Identification of harbour porpoise habitat preference will enhance our knowledge of the ecology and life history of this species on a local scale, enabling greater awareness of population trends and aiding in the establishment of marine protected areas (Macleod *et al.*, 2004).

Therefore, the aim of this study is to analyse spatial and temporal trends of harbour porpoise, *Phocoena phocoena*, in the outer Moray Firth and to highlight annual patterns in distribution. Various techniques, including Geographical Information Systems (GIS), will be used in the identification of preferred habitat types and factors affecting the distribution of the harbour porpoise, which will greatly aid in the knowledge of the ecology of this population and in identifying areas of importance for the species.

1.4.1 *Summary of Aims*

1) To highlight spatial trends in the distribution of harbour porpoise in the outer Moray Firth. Variables include:
    a. Depth
    b. Slope gradient
    c. Aspect
    d. Sediment Type

2) To highlight the temporal patterns in harbour porpoise distribution. Analysis within and between years and changes in group sizes are observed.
3) Interspecific interactions with bottlenose dolphins in the outer Moray Firth are suspected to have a serious impact on harbour porpoise. In this section the effect of bottlenose dolphins on porpoise distribution is examined.

2. The Study Area

2 The Study Area

The Moray Firth is the largest of three embyments on the east coast of Scotland. The total area of the Moray Firth is approximately 5,230 km^2 (Tilbrook, 1986) and is divided into the 'inner' and 'outer' Moray Firth (Figure 2.1). The inner region lies to the west of the line running from Helmsdale to Spey Bay, within which there are three smaller firths; the Dunoch, Cromarty and Inverness Firths. The outer region is to the east of the dividing line, which stretches as far as Wick to the north and Fraserburgh to the south. The physical and environmental conditions vary between the inner and outer Moray Firth, with the inner Moray Firth more estuarine and the outer Moray Firth resembling a more open sea environment.

Figure 2.1: Showing the entire Moray Firth area located in the North East Scotland. The study area covers the southern coastline of the outer Moray Firth, lying between the coastal ports of Lossiemouth and Fraserburgh (Robinson *et al.*, 2005).

The coastline of the outer Moray Firth is typically rugged and irregular, consisting of steep cliffs, headlands, and small bays. The seabed topography in this area is also uneven, dropping to depths of 60 m within only 5-10 km of the coast (Hardy-Hill, 1993). Depths also fluctuate due to the presence of oceanographic structures, such as submarine banks, and deep sea trenches (Wilson, 1996). The most prominent of these trenches is known as the Southern Trench, located at the southeast side of the outer Moray Firth, only 7 km from the coast, and can reach depths of up to 250 m. In contrast, the inner Firth coastline consists of smooth mud or sandflats, sanddunes and cliffs, with seabed depths only reaching 50 m approximately 15 km from the shore (Admiralty Charts C22, 1997). The coastal regions of the Moray Firth primarily consist of sand and gravel sediments, but an inverse relationship between depth and gradient size is observed with finer, muddy sediments in deeper, offshore waters (Reid and McManus, 1987).

As part of the wider North Sea basin, both coastal and mixed (coastal and oceanic) waters occur in the Moray Firth (Adams, 1987). The main current influencing the Moray Firth is the Dooleys Current, which brings mixed waters into the region from the north, which then circulates in a clockwise direction inside the Moray Firth.

Temperature and salinity also vary both spatially and temporally in this northeast location. The southern coast and inner Moray Firth are influenced greatly by the 12 major rivers which run into the Firth. These rivers result in warmer temperatures in summer, colder temperatures in winter, and reduced salinity in the inner part of the Firth. Subsequently estuarine conditions decline with distance from the inner Moray Firth to more 'mixed' waters in the outer regions, where salinities exceed 34.8 and temperatures are generally warmer in winter and colder in summer (Wilson, 1996).

The Moray Firth has long been regarded as an important area in terms of biodiversity and productivity which has led to heavy utilisation by man. Such activities include fishing, shipping, recreation and exploration for oil and gas. Fishing is an economically important activity for the local communities. Some of the more important species include herring (*Clupea harengus*), over wintering sprat (*Sprattus sprattus*), migrating mackerel (*Scomber scomber*), sandeels (*Ammodytes marinus*) and Atlantic salmon (*Salmosalnar*) (Harding-Hill, 1993). It is these species that support such a diverse range of seabirds and marine mammals in the Moray Firth area. The most commonly encountered marine mammals are the bottlenose dolphin (*Tursiops truncatus*), the harbour porpoise (*Phocoena phocoena*),

minke whale (*Balaenoptera acutorostrata*), grey seal (*Halichoerus grypus*) and common seal (*Phoca vitulina*). In total 23 species of cetaceans have been recorded in Moray Firth waters (Harding-Hill, 1993).

It is the presence of the bottlenose dolphin that has resulted in the inner Moray Firth being awarded Special Area of Conservation (SAC) status. The European Commission Habitat Directive demands the presence of conservation areas, in order to conserve the 189 habitat types and 788 species in most need of protection, highlighted in Annexes I and II of the Habitats Directive (JNCC 2005). The bottlenose dolphin is included in this category, as the only known resident population of bottlenose dolphins in the North Sea, making the Moray Firth one of only two known outstanding localities of this species in the UK.

3. Methods

3 Method

3.1 Data Collection

Figure 3.1: Staff and trained volunteers survey in one of the CRRU's 5.4m RIBs (photo by Kevin Robinson).

Data was collected during dedicated boat surveys carried out during the years of 2002 and 2005 and between the months of May and October, with the exception of October 2005 when no surveys were conducted. The survey vessels left from the harbour of Whitehills, situated in the centre of an 880 km^2 survey route. The survey route ran from Lossiemouth in the west to Fraserburgh in the east between 4 designated waypoints. The survey route was further divided into four different survey paths. The inner most route labelled 'Survey Route 1'. The other three survey routes were labelled 2, 3 and 4, each separated by 45 minutes of longitude and situated progressively further from the coastline (figure 3.2).

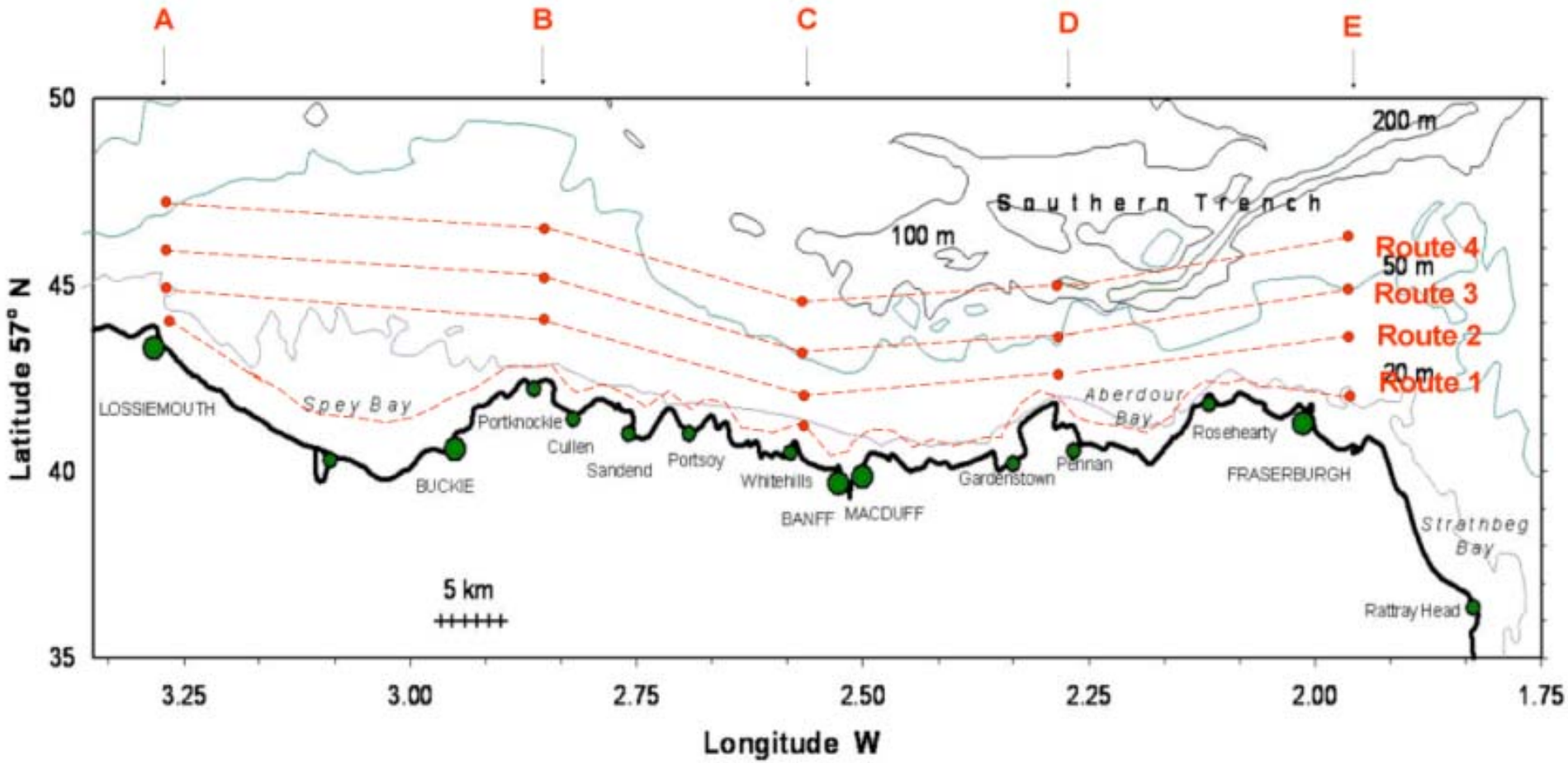


Figure 3.2: Showing the southern coastline of the outer Moray Firth and the survey routes used by the CRRU during systematic boat surveys between the ports of Fraserburgh and Lossiemouth. The transects are divided into 3 longitudinal outer routes (routes 2 to 4 respectively), each approximately 45 minutes apart in latitude, and an inner coastal route used during dedicated bottlenose dolphin surveys.

The 2 survey vessels were Avon Searider inflatable boats (RIBs), 5.4 metres in length. During surveys, speed was kept to 8 to 12 km hr^{-1} and routes were followed using a Lowrance 330 C Global Positioning System (GPS). The crew consisted of 3 to 7 trained observers who continuously scanned for cetaceans. Surveys required fair light conditions and sea states of 3 or lower. Should conditions deteriorate from these minimum requirements, surveys were aborted.

A Trip log (see appendix 1) was filled at the beginning each survey. This recorded survey start time, location and the observers on board. When bottlenose dolphins or harbour porpoises were encountered, the boat was slowed to an appropriate speed and encounter details were recorded on Encounter Log laminated sheets for the relevant species (see appendix 2 for the harbour porpoise encounter log and appendix 3 for the bottlenose dolphin encounter log). Such details included encounter time, GPS of the animal(s), general area and/or landmarks, number of animals in the group, their direction of travel and behaviour or activity. At the end of the survey the Trip log was completed with the end time, GPS and location of the end position along with sea state and weather conditions of the survey trip.

3.2 Data Recording

Onshore, the survey and encounter details were copied first onto hard paper copies (see appendix 4 and 5 for the harbour porpoise and for the bottlenose dolphin respectively) and then into species specific databases which stores and plots the locations of encounters. For harbour porpoise encounters, an Excel Spread sheet was used and Access Database was used to record bottlenose dolphins. Finally tidal states and tide height was calculated using Belfield's Tidal Program and stored in the database.

3.3 Geographical Information System

A GIS or Geographical Information System enables an accurate picture of the study area to be produced. GIS calculates and displays the oceanographic variables; depth, aspect, slope and sediment type of the area as individual layers or themes Each harbour porpoise or bottlenose dolphin sighting was then plotted over these themes and the data for each variable at the exact location of the encounter can be obtained. The GIS program used for this study was ArcView 3.3.

3.3.1 *Bathymetry and Topography*

Depth of the study area was obtained using Admiralty Charts and a digitising tablet to plot the depth contours. The area was then divided into 1 km^2 blocks using a grid, and for each cell the minimum, maximum and mean depth was calculated. This data was then imported into ArcView 3.3 as a Dbase IV file. The theme was then converted to a 'Mercator' projection which allowed the depth to be viewed as gradual colour changes. Finally contours were plotted and a land mask of the survey area applied.

Modelling functions in ArcView 3.3 used the depth data to directly calculate the maximum rate of change between each map cell and its neighbours, known as slope. Using a similar function the slope direction of each cell was determined (north, south, east and west), this was known as aspect.

3.3.2 *Sediment Type*

A similar process as that used to create depth was used to determine and display the sediment type of the sea bed. Admiralty Charts of the survey area were divided into 200 m^2 grid cells and for each the sediment type was noted. A Dbase file of each grid cell and its sediment type was then created and imported into ArcView 3.3. As with depth, this theme was then converted into a 'Mercator' projection and displayed.

3.3.3 *Sightings*

The longitudinal and latitudinal positions of each harbour porpoise and bottlenose dolphin encounter were converted into decimal positions for importing into ArcView 3.3, using the equation:

degrees + (minutes / 60)

The converted positions of each species were then saved as a Dbase file and imported into ArcView 3.3. Each sighting could subsequently be plotted in relation to the physical factors of that exact position.

In order for clear presentation and statistical analysis, the depth, aspect, slope and sediment types at each encounter location were then extracted using the grid analysis function in ArcView 3.3. This enabled the variables common to each species to be compared and statistically analysed.

Encounter density for each species could also be calculated by converting the sightings data from an event theme to a grid theme and then to a 'Mercator' projection. The data was then displayed as a series of colours representing the number of encounters recorded in each individual grid cell over the 4 survey seasons 2002-2005.

3.4 SPUE

SPUE or sightings per unit effort was calculated for each of the 4 survey routes using the equation:

$$\text{SPUE} = \frac{\text{number of sightings}}{\text{total survey effort}}$$

3.5 Relative Abundance

In order to estimate the number of harbour porpoise in the outer Moray Firth during each survey season 2002-2005, the relative abundance was calculated:

$$\text{Relative Abundance} = \frac{\text{number of animals recorded}}{\text{total survey area}}$$

3.6 Statistical Analysis

During each statistical test, an Anderson Darling's test for normality was first used. If the data was found to be normal (> 0.05) a stronger parametric test was used. However, when the data was not normally distributed (<0.05) a nonparametric test was used. Statistical tests used during this study included; Kruskall Wallis to test for variance, Pearson's Correlation and Regression Analysis for correlations and trends and Mann Whitney for comparisons.

4. Results

4 Results

4.1 Survey Effort

A total of 203 days were spent surveying over the study period of 2002-2005 inclusive, resulting in the completion of 338 individual survey trips, and an overall survey effort of 794 hours and 40 minutes. Table 4.1 shows the individual survey effort for each season of the study. 2002 exhibits the greatest effort, with 98 trips carried out over 66 days, and a total of 230 hours and 8 minutes spent surveying. In comparison the survey effort for 2004 was low with only 74 trips over 35 days, resulting in a total survey time of 148 hours and 46 minutes. Statistical analysis using the Mann-Whitney U test showed the survey effort in 2004 to be significantly lower than that of 2002 and 2003 (W = 8240.5, ETA2 = 0.0261 and W = 9197.0, ETA2 = <0.01 respectively).

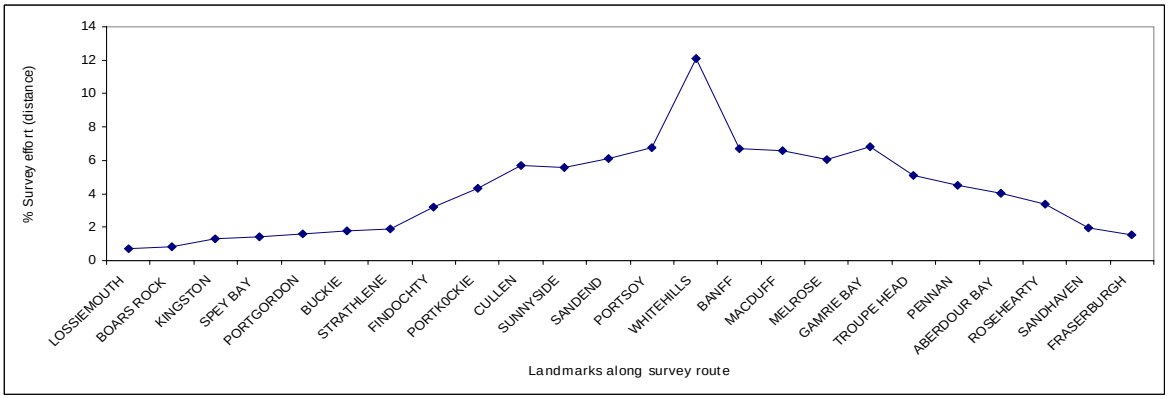
In terms of distance, the survey effort was relatively evenly distributed across the survey area. Figure 4.1a shows a peak in effort at the survey starting location of Whitehills and a fairly unbiased divide of effort in the east and west directions for the entire study period 2002-2005. There is, however, a slight reduction in effort between the landmarks of Strathlene and Lossiemouth in the far west of the survey area. Figure 4.1b shows variation in the distances covered each month during the survey period of 2002-2005. July displays the greatest survey effort, followed by September then August. Reduced survey effort occurred in May and October due to surveys only taking place during part of these months. Each month, however, showed a similar distribution of effort, with Strathlene to Lossiemouth exhibiting least effort.

Variation in effort was also seen along the different survey routes (figure 4.2). Greater survey time was spent on the more coastal route 1, than the other three routes. However, little difference was observed between routes 2, 3 and 4. This bias may influence the distribution patterns of the animals and a possible underestimation in their numbers.

Table 4.1: Dedicated survey effort shown by number of survey days, number of survey trips and hours spend surveying for each of the four survey seasons 2002-2005 inclusive.

Survey Season	Number of Survey Days	Number of Survey Trips	Number of Survey Hours:Minutes
2002	66	98	230:08
2003	60	80	226:07
2004	35	74	148:56
2005	42	86	189:30
Total	**203**	**338**	**794:40**

(a)



(b)

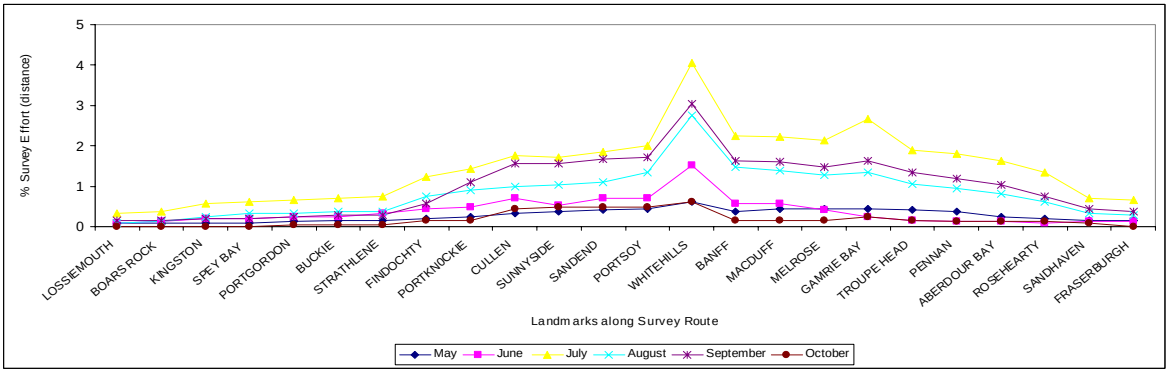


Figure 4.1: Dedicated survey effort in terms of distance along the survey area using landmarks along the coastline. Graph (a) shows the total survey effort over the seasons 2002-2005 inclusive while (b) shows this survey effort by month over the same survey period.

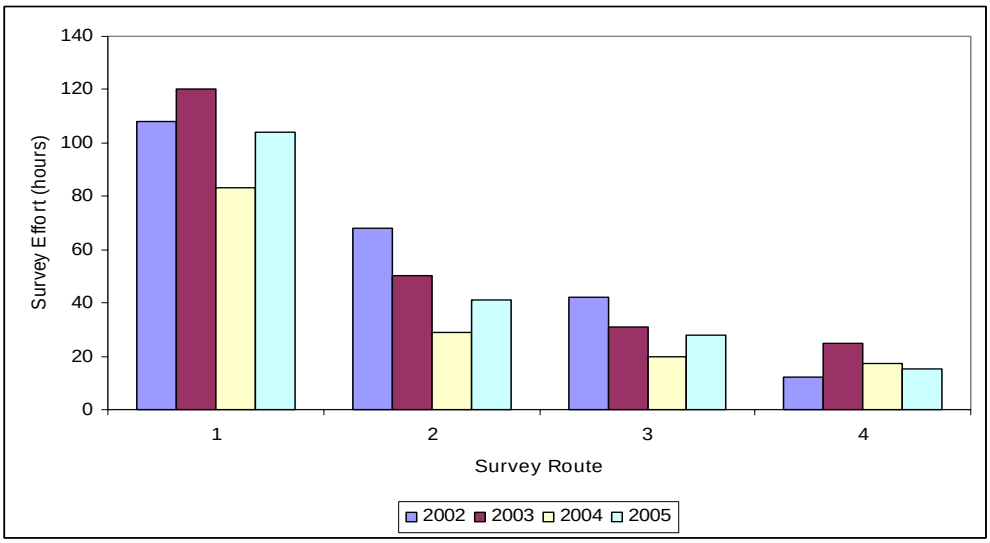


Figure 4.2: Survey effort in terms of time for each of the 4 survey routes for the different survey seasons.

4.2 Sightings and Encounters

Between May and October 2002-2005, a total of 668 cetaceans were encountered; 63% (n = 422) harbour porpoises and 11.5% (n = 76) bottlenose dolphins (Figure 4.3). Minke whales were also frequently observed making up 25% of all encounters. Rissso's dolphins were also recorded during the study, classified as other cetaceans, these encounters only made up 0.5% of all sightings. During each survey season, a greater number of encounters occur with harbour porpoises than bottlenose dolphins. Despite a greater number of encounters, the total number of individual harbour porpoises seen in 2004 and 2005 was less than the total number of bottlenose dolphins. 2002-2005 inclusive recorded 1138 harbour porpoises and 900 bottlenose dolphins (table 4.2).

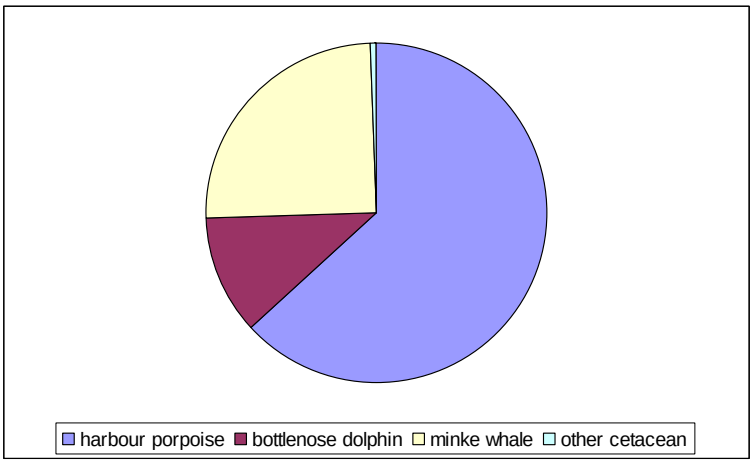


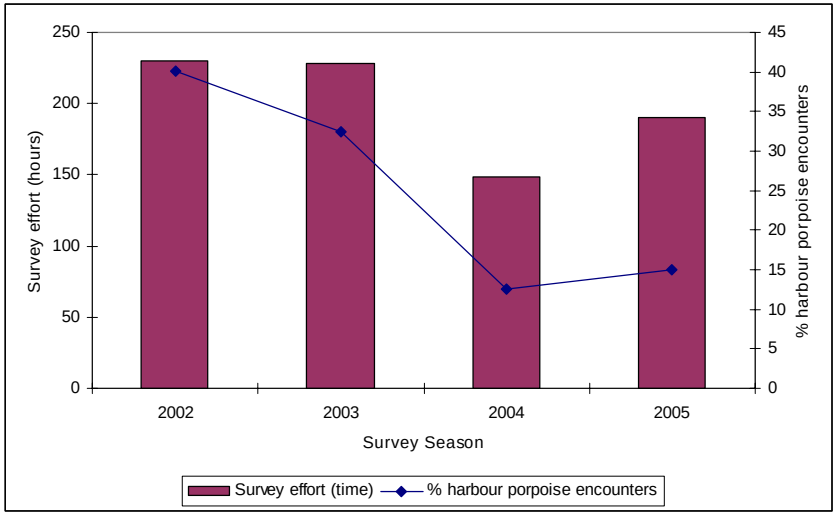
Figure 4.3: Harbour porpoise, bottlenose dolphins and minke whales are the three most commonly sighted cetaceans in the survey area between May and October 2002-2005 inclusive. The other cetaceans observed were risso's dolphins.

Figure 4.4 shows the encounters of harbour porpoises and bottlenose dolphins with time spent surveying during each season of the study. The pattern of encounters by season for each of the two species is very different. A decline in harbour porpoise from 2002 to 2004 is shown, with only a slight increase in encounters during 2005. The reduced survey effort in 2004 can only partly explain this decline (figure 4.4a). Bottlenose dolphin encounters show a more irregular pattern, with an increase in encounters from 2002 to 2003, without any increase in survey effort. Encounters decreased highly significantly in 2004, partly explained by the reduced survey effort. The survey effort increased in 2005 and with it a significant increase in encounters (figure 4.4b).

Table 4.2: Encounters of harbour porpoise and bottlenose dolphin during each of the four field seasons 2002-2005 and the total number of animals for each species encountered during this time

Survey Season	Number of Encounters		Total Number of Animals	
	Harbour porpoise	Bottlenose dolphin	Harbour porpoise	Bottlenose dolphin
2002	169	15	415	148
2003	137	20	461	240
2004	53	9	117	179
2005	65	32	145	333
Total	**422**	**67**	**1138**	**900**

(a)



(b)

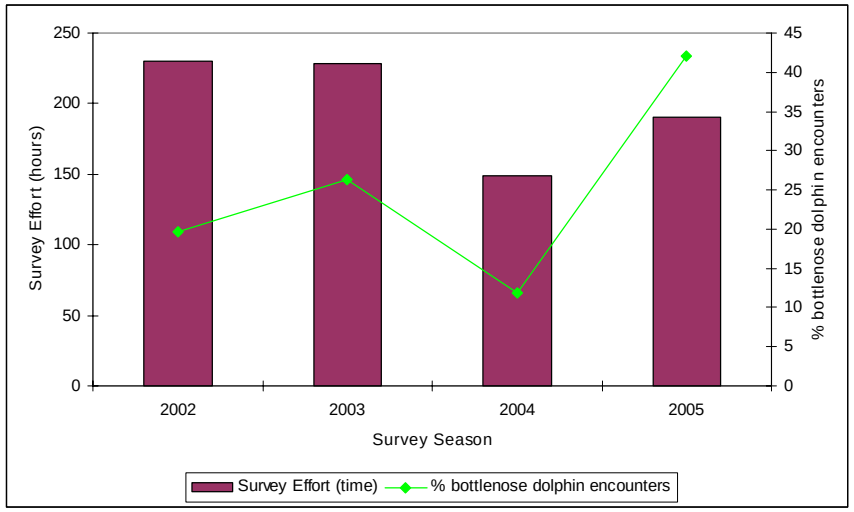


Figure 4.4: Survey effort in terms of time (hours) for each of the four survey seasons 2002-2005 inclusive plotted for (a) the number of harbour porpoises and (b) the number of bottlenose dolphins encountered during the survey period.

4.3 Harbour Porpoise on a Spatial Scale

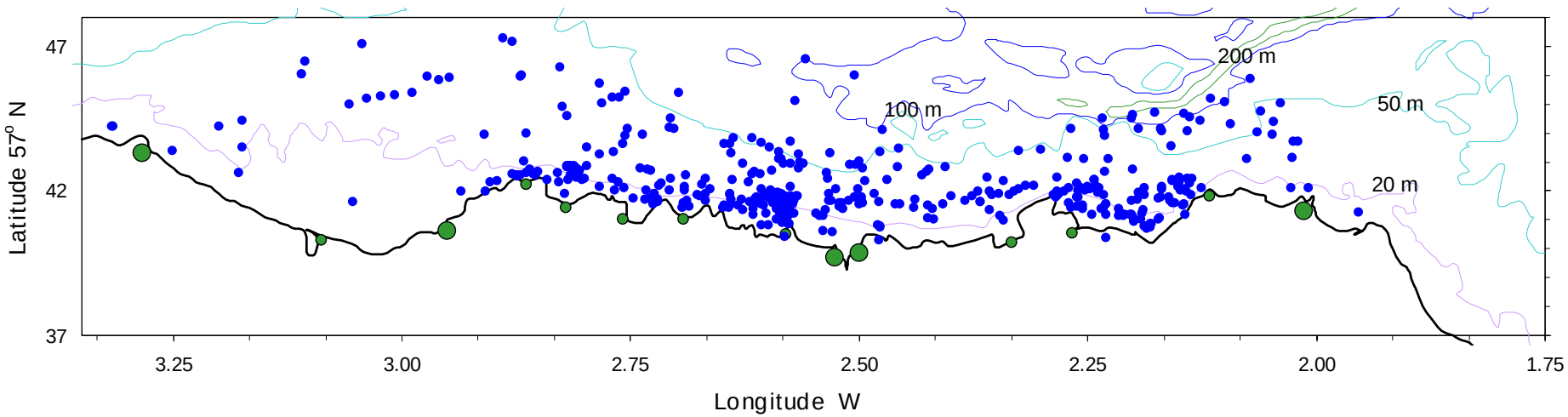


Figure 4.5: Plot shows the location of all harbour porpoise encounters during the study period of May to October 2002-2005 inclusive. Green dots indicate the major towns along the coastline of the survey area and 20 m, 50 m, 100 m and 200 m depth contours are also displayed.

Harbour porpoises are encountered across the entire study area from Lossiemouth in the west to Fraserburgh in the east. Figure 4.5 shows harbour porpoise to be most often observed close to shore between the towns of Rosehearty and Buckie in water depths of around 20 m. However a fairly significant number of encounters were also observed in deeper, more offshore waters in depths up to 150 m.

Figure 4.5 does not reflect the distribution of survey effort which may influence the perception of harbour porpoise distribution over the survey area. Figure 4.6 displays the proportion of harbour porpoise encounters alongside the amount of effort spent on each of the four survey routes (1-4). Most effort was spent on the coastal survey route number 1, which resulted in only 30% of the harbour porpoise encounters. Less than half this effort was spent on the 2nd survey route, however, a greater number of encounters were recorded (34%). Survey routes 3 and 4 exhibited progressively less effort and with it fewer encounters, 23% and 14% respectively.

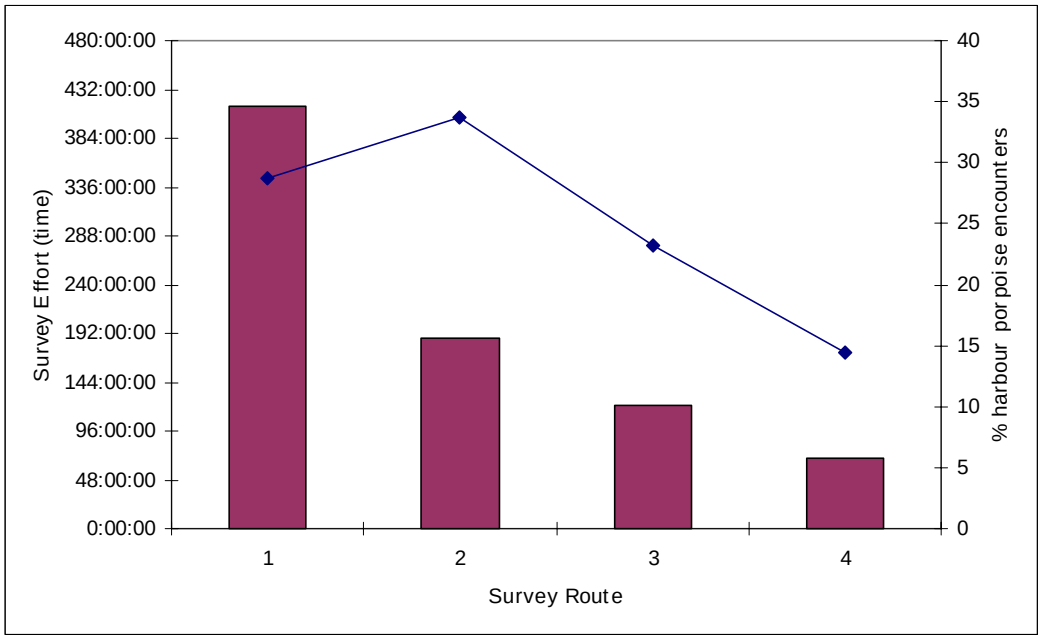


Figure 4.6: Dedicated survey effort in terms of time and number of encounters by survey route for each survey season 2002-2005. The four survey routes are labelled 1 – 4. Survey route 1 is closest to the coast and 2-4 are progressively further offshore.

SPUE (sightings per unit effort) of harbour porpoise was calculated for each of the four survey routes from the number of encounters recorded and the effort spent on each route (table 4.3). Survey route 4 is located furthest from shore, and exhibited the highest SPUE at 0.9 sightings / hour. The harbour porpoise SPUE declined with decreasing distance from

shore with the coastal survey route (1) displaying the lowest value. This trend suggests that a greater number of harbour porpoise would be encountered in deeper, more offshore waters if the survey effort on these routes was increased. This further indicated that the number of harbour porpoise recorded in this study area is likely to be an underestimation of the true numbers of harbour porpoise in the study area of the outer Moray Firth.

Table 4.3: SPUE (sightings per unit effort) of harbour porpoise calculated for each of the 4 survey routes over the entire study period.

Survey Route	Time	No. of harbour porpoise encounters	SPUE No. sightings/ hour
1	432:59	121	0.28
2	173:43	142	0.82
3	114:14	98	0.86
4	66:45	61	0.9

The distribution of effort across the different survey routes has been shown to influence the locations and numbers of harbour porpoise encounters. The sea state during individual surveys is also shown to influence the probability of encountering porpoise. Harbour porpoise are particularly susceptible to this bias due to their small size and elusive behaviour towards boats. Figure 4.7 shows that the proportion of harbour porpoise encounters declines with increasing sea state up to Beaufort Scale 5, when no survey trips were carried out.

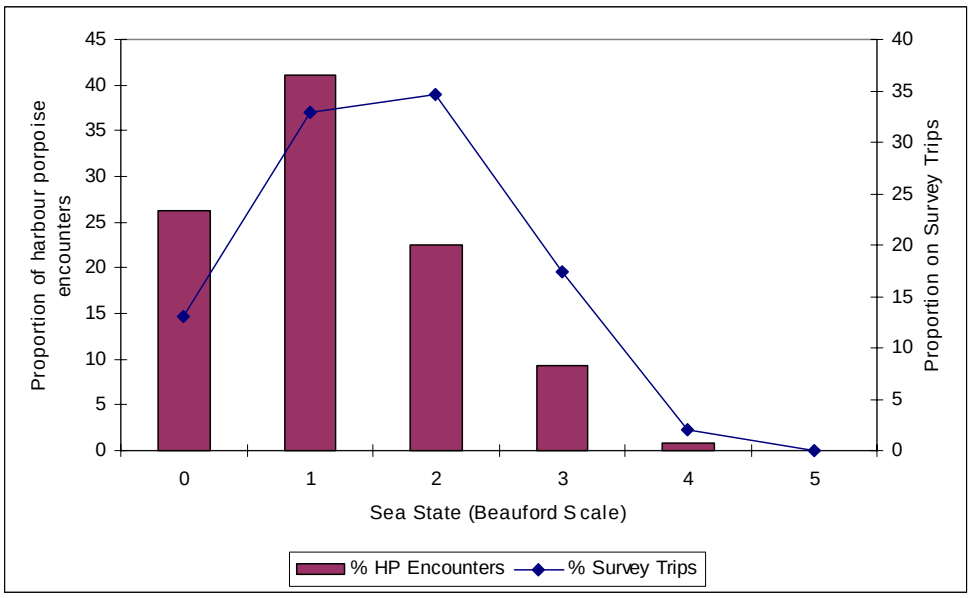


Figure 4.7: Proportions of harbour porpoise encounters and survey trips carried out during the study period at varying sea states.

4.3.1 *Geographical Information System*

ArcView 3.3 was used to create and display the oceanographic structure of the survey area using the variables depth, aspect, slope, and sediment type. Figure 4.8 shows the GIS layouts for each variable. Depth along the coastline is shallow only reaching about 20 m within few hundred metres of shore. The west side of the survey area, particularly Spey Bay region, remains shallow only reaching 50 m in depth 15 km from the coast. In contrast, the east side of the survey area shows larger depth gradients as depths reach over 100 m within only 8 km of the shore around the oceanographic feature of the 'Southern Trench'. Slope gradients are high in all areas of the survey with the exception of the shallower Spey Bay. The inshore slopes predominantly face north. Further offshore, principally around the Southern Trench, the aspect is highly variable. Along the coastline sediment types vary from sand and gravel in Spey Bay to sandy gravel along the rest of the coastline. Offshore sea beds consist of finer grains of sandy sediments and mud.

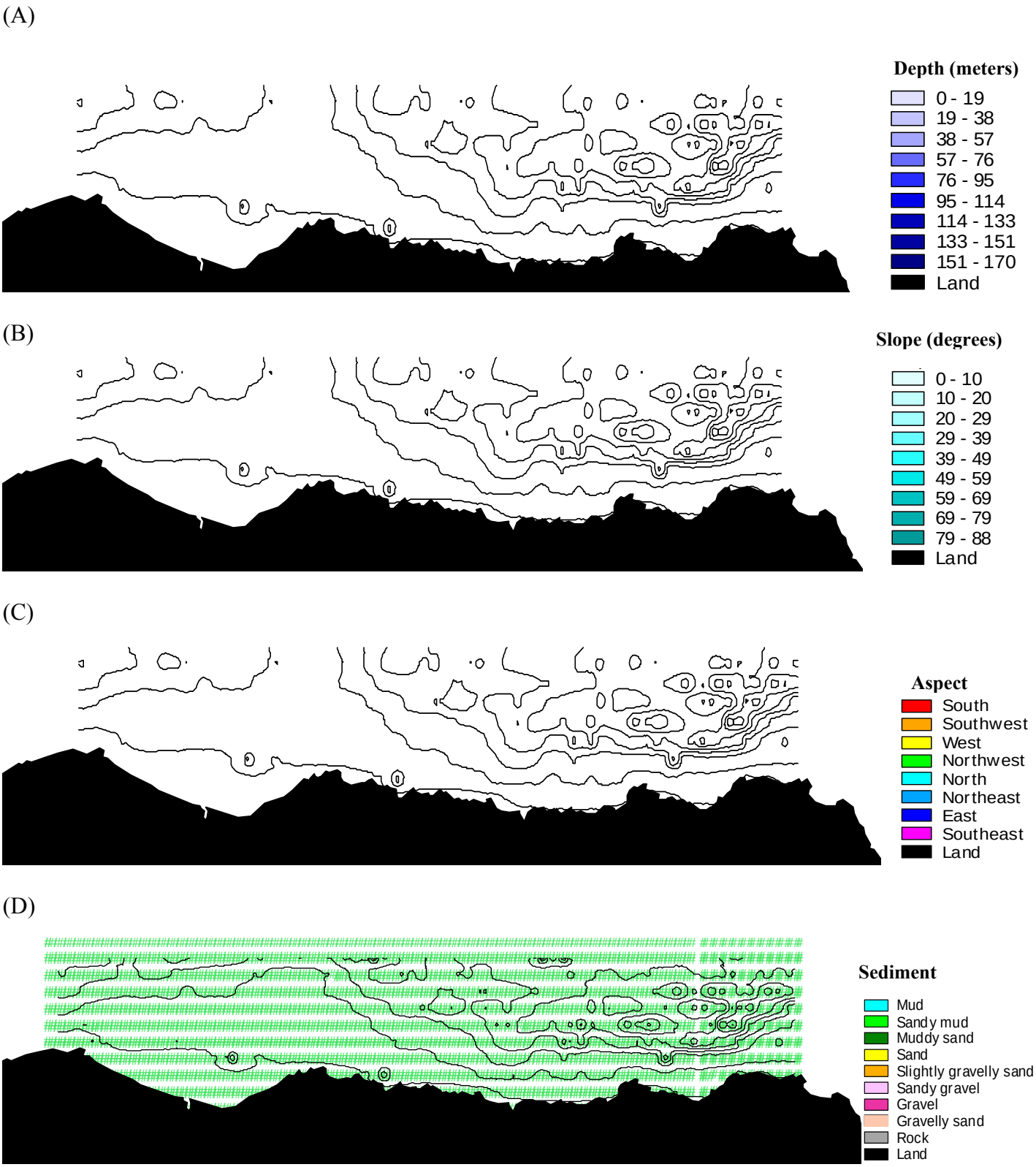


Figure 4.8: Fixed environmental variables of the survey area, Lossiemouth to Fraserburgh. Depth (A), gradient of slope (B), aspect of slope (C) and sediment type of the seabed (D) and displayed and calculated using ArcView 3.3. 20 metre depth contours are also displayed.

4.3.2 *Harbour Porpoise Encounter Frequency*

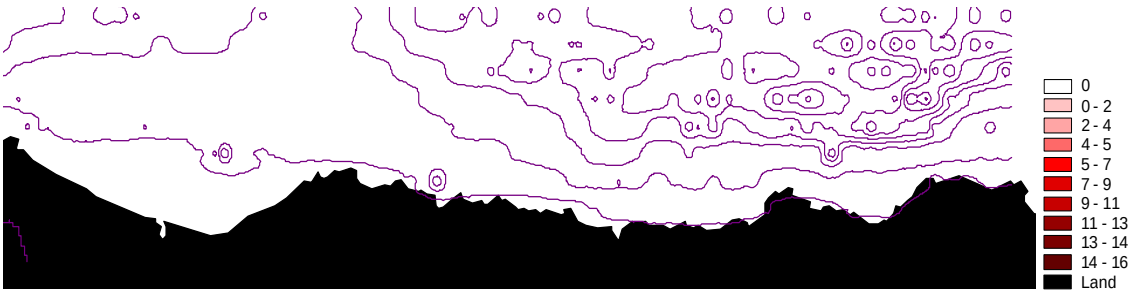


Figure 4.9: The encounter density of harbour porpoise within the survey area. Map was constructed using the interpolate function in ArcView 3.3.

The encounter frequency of harbour porpoise is generally concentrated along the coast up to depths of 50 m (figure 4.9). There is an obvious lack of encounters in the Spey Bay area with only a few encounters distributed further offshore. A concentration of encounters occurred at Whitehills, where 14-16 encounters were recorded. This encounter 'hotspot' can be partly explained by the high survey effort in this location.

ArcView 3.3 was used to extract the harbour porpoise encounters along with specific data for each of the 4 variables, depth, aspect, slope and sediment type at each sighting location (figure 4.10). Observations of harbour porpoise increased with depth from a minimum of 6.86 m to 40 m, after which observations declined with depth up to 70 m. Above 70 m, only a few encounters were recorded in each depth category up to the maximum depth of 145.62 m. Encounters increased with gradient of slope (mean 74.1ûû) and were recorded on all slope aspects (0-360ûû) with significantly higher numbers on those facing north and south. The sediment type at the majority of encounter locations was sandy gravel although harbour porpoise were recorded at least once in areas consisting of each of the 9 sediment types.

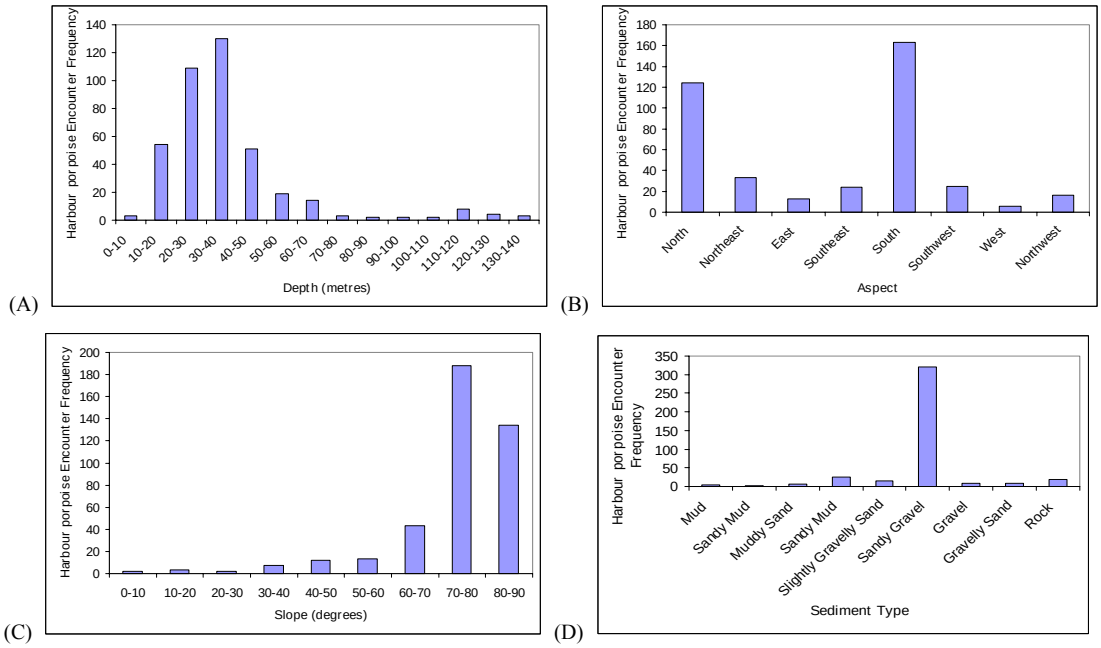


Figure 4.10: Encounter frequency of harbour porpoise with the environmental variables depth, aspect, slope and sediment type.

The data was statistically analysed for trends and correlations using Kruskall Wallis to test for variance (table 4.4) and Pearson's Correlation and Regression analysis to further test these relationships. Each variable displayed significant variance with harbour porpoise encounter frequency. However, only depth and slope were calculated to have a significant relationship with encounter frequency by Pearson's Correlation. Depth was shown to have a negative correlation = -0.578, P-value = 0.030 and slope to have a positive correlation, Pearson's Correlation = 0.781, P-value = 0.01. Aspect and sediment type showed no such relationship. Despite a significant correlation, the regression analysis indicates the relationship with depth and slope to not be functional suggesting other factors to be further influencing their relationship with harbour porpoise encounter frequency (R^2 = 0.3692 and R^2 = 0.5629 respectively).

Table 4.4: Minimum, maximum and mean depths, aspect, slope gradient and sediment type that harbour porpoise encounters occurred at during the survey period of 2002-2005 inclusive. Each variable was tested for variance against the encounter frequency of harbour porpoise using Kruskall Wallis statistical test (* indicates a significant result).

Variable	Minimum	Maximum	Mean	Test for Variance
Depth	6.86m	145.62m	35.96m	H = 14.29 P = <0.01 *
Aspect	0.62°	359.7°	186.9°	H = 23.26 P = 0.002 *
Slope	2.2°	87.7°	74.1°	H = 25.23 P = 0.001 *
Sediment	Mud (1)	Rock (9)	Sandy Gravel (6)	H = 20.54 P = 0.008 *

4.3.3 *Harbour Porpoise Group Size*

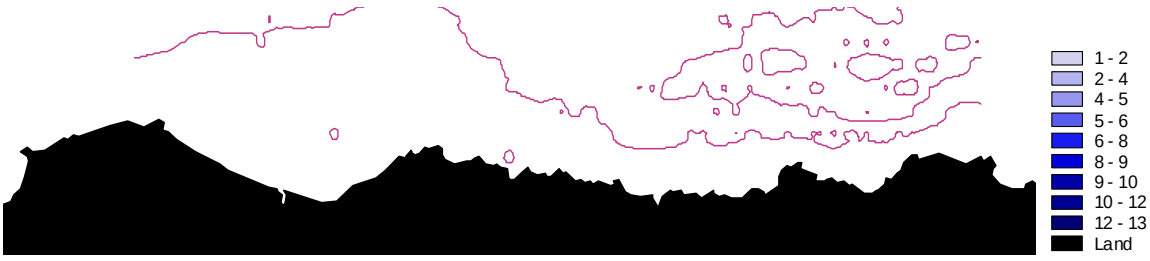


Figure 4.11: Plot shows the location and sizes of encountered harbour porpoise groups. An unusual sighting of a group of 44 animals was recorded in September 2003, this encounter was discarded for the purpose of this figure so a general trend could be observed.

Harbour porpoise were primarily encountered in small groups of 2-3 animals. The mean group size over the 4 survey seasons was 2.9 animals, although groups were observed to consist of 1 to 44 animals. Figure 4.11 shows larger groups tended to be encountered in more coastal waters. Larger groups were observed at a number of locations along the coast, including Aberdour Bay, Banff, Portsoy, and Buckie.

To identify whether variables encourage aggregation of harbour porpoise into larger groups, each variable was analysed again, but this time against the number of animals in each encounter (Table 4.5). Only depth showed significant variance between group size and variable (H = 30.88, P = 0.004). Pearson's Correlation indicated a slight negative correlation with depth suggesting that group size declines with decreasing depth, however, this relationship was not found to be significant (Pearson's Correlation = -0.088, P-value = 0.077). Figure 4.12 clearly displays little variance between the variables and the size of harbour porpoise groups.

Table 4.5: Group size of harbour porpoise encountered were analysed for variance (Kruskall Wallis) with the variables, depth, aspect, slope and sediment type. Only depth showed significant variance and this relationship with group size was explored further with Pearsons Correlation (* indicates significance).

Variable	Variance	Correlation	Regression
Depth	H = 30.88 P = 0.004 *	Correlation = -0.088 P Value = 0.077	n/a
Aspect	H = 10.65 P = 0.155	n/a	n/a
Slope	H = 12.56 P = 0.128	n/a	n/a
Sediment	H = 13.34 P = 0.101	n/a	n/a

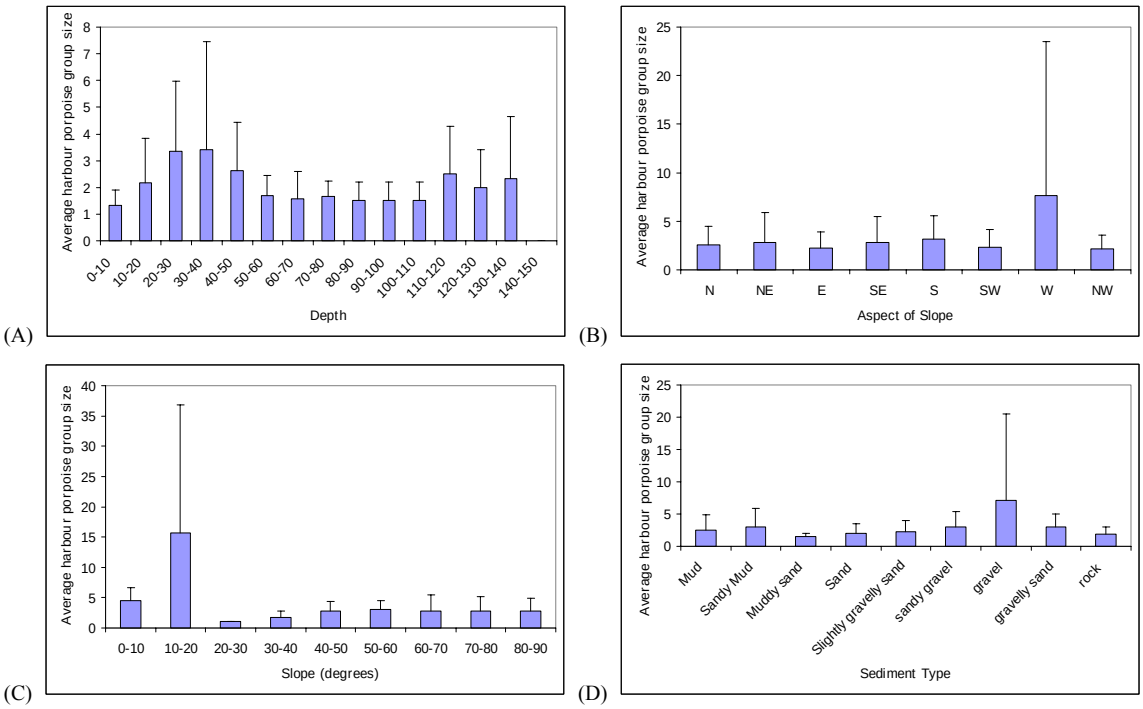


Figure 4.12: Varying average group sizes of harbour porpoise with the variables depth, aspect, slope and sediment type. Error bars show the variation of group sizes in each category.

4.4 Harbour Porpoise on a Temporal Scale

4.4.1 *Harbour porpoise encounter frequency*

Harbour porpoise were encountered 422 times over the 4 survey seasons and encounters were recorded in all months with the exception of May 2005 (Table 4.6). The number of encounters recorded in a month range from 1 in May and October 2004 up to 59 encounters in September 2002. In 2002 and 2005, harbour porpoise sightings peaked in September at 59 and 20 encounters respectively, whilst in 2003 and 2004 this peak occurred in July. In general over the 4 survey seasons, encounters were noted to increase from May to a peak in July, a slight drop during August before a second peak in September (figure 4.13). The variance between these two factors was found to be statistically significant (H = 13.33 DF = 5 P = 0.021). The number of encounters also ranged significantly between the survey seasons, from 169 in 2002 to a low of 53 in 2004 although this variance was not found to be significant.

Table 4.6: Temporal distribution of harbour porpoise in the outer Moray Firth by month and survey season from May to October, 2002-2005 inclusive.

Survey Season	May	June	July	August	Sept	October	Total
2002	3	24	45	27	59	11	**169**
2003	14	4	45	37	34	3	**137**
2004	1	6	29	7	9	1	**53**
2005	0	16	8	19	20	-	**63**
Total	**18**	**50**	**127**	**90**	**122**	**15**	**422**

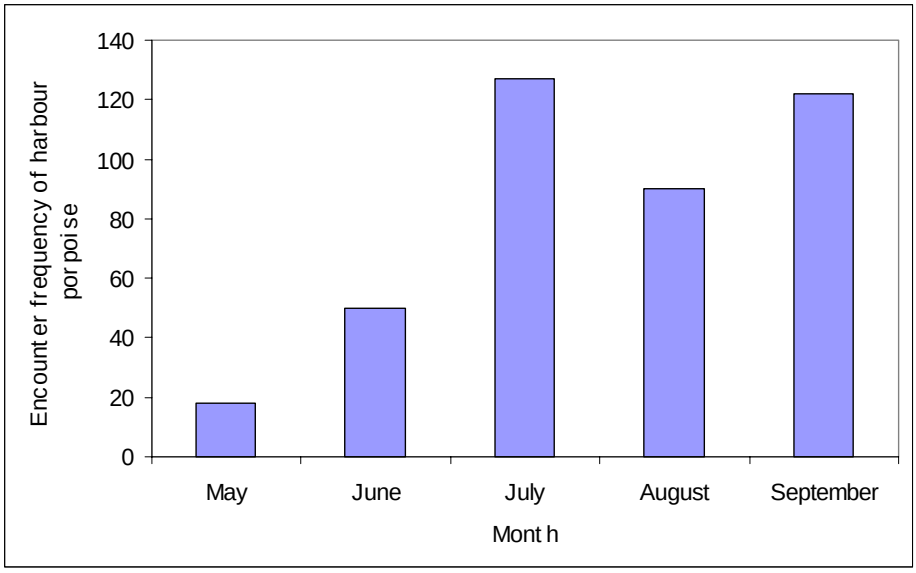
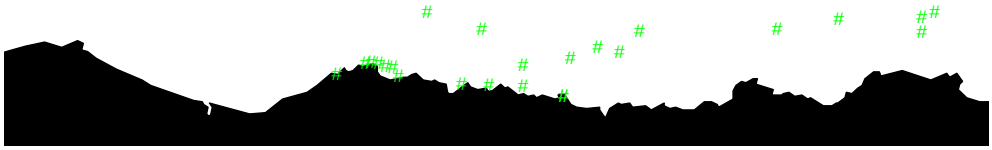


Figure 4.13: Frequency of harbour porpoise encounters varies through the season. Number of encounters is shown over the months of May to September inclusive.

The distribution of harbour porpoise encounters was displayed and visually analysed by month and survey season using ArcView 3.3. The distribution across survey season 2002-2005 was highly variable and showed no trends. 2002 showed widely distributed encounters with some concentration between Portknockie and Whitehills. 2003 showed a more uneven distribution with encounters concentrated between Portsoy and Rosehearty. 2004 showed significantly fewer sightings but widely distributed. Finally 2005 showed sightings to be more restricted to areas west of Cullen. Figure 4.14 shows the distribution of encounters through the season of 2002 by month. Encounters are observed to be widely distributed during May to July before moving further inshore and becoming more clustered during the month of August. This pattern was not observed in any other survey season, nor was any other pattern observed.

May

June



July