moray offshore renewables ltd

Environmental Statement

Technical Appendix 4.4 A Marine Mammals Baseline

Telford, Stevenson, MacColl Wind Farms and associated Transmission Infrastructure Environmental Statement

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moray offshore renewables limited

4th Floor
40 Princes Street
Edinburgh
EH2 2BY

Tel: +44 (0)131 556 7602

APPENDIX 4.4 A

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Contents

Preface

This report contains an overview of marine mammal distribution and behaviour within the Moray Firth with a view of informing impact assessment for the development of offshore wind farms. Information within this report has been contributed by the following people:

- Chapter 2:

Dr. Sarah Canning; Natural Power Consultants, McKinven House, George Street, Falkirk.

- Chapter 3:

Dr. Helen Bailey; SMRU Ltd, New Technology Centre, North Haugh, St Andrews, Fife, KY16 9SR

Professor Paul Thompson; University of Aberdeen, Institute of Biological & Environmental Sciences, Lighthouse Field Station, Cromarty, Ross-shire IV11 8YJ.

- Chapter 4:

Dr Debbie Russell, Esther Jones, Dr Jason Matthiopoulos & Dr Kate Grellier; SMRU Ltd, New Technology Centre, North Haugh, St Andrews, Fife, KY16 9SR

- Chapter 5:

Professor Paul Thompson & Dr. Kate Brookes; University of Aberdeen, Institute of Biological & Environmental Sciences, Lighthouse Field Station, Cromarty, Ross-shire IV11 8YJ.

- Chapter 6

Professor Paul Thompson; University of Aberdeen, Institute of Biological & Environmental Sciences, Lighthouse Field Station, Cromarty, Ross-shire IV11 8YJ.

- Chapter 7:

Dr. Cormac Booth, Marjolaine Caillat, Dr. Doug Gillespie, Dr. Kate Grellier & Dr. Gordon Hastie; SMRU Ltd, New Technology Centre, North Haugh, St Andrews, Fife, KY16 9SR

- Chapter 8:

Dr Sarah Canning, Dr Gillian Lye & Laura Givens; Natural Power Consultants, McKinven House, George Street, Falkirk.

Some of the work contained in this report has been jointly commission by Beatrice Offshore Wind Ltd.

1. Introduction

This Appendix provides detailed baseline information on the use of the Moray Firth by marine mammals, established through a variety of different survey methodologies and commissioned work-streams.

The Moray Firth supports breeding populations of both harbour seals and grey seals, and sightings of at least fourteen species of cetaceans have been recorded in these waters (Grellier & Lacey, 2010). Whilst there has been a long history of research on marine mammals in this area, this has tended to focus on coastal and inshore areas. Such work has lead to estimates of distribution, population size and trends for harbour and grey seals and bottlenose dolphins. Some studies of marine mammals in the vicinity of the Smith Bank were carried out as part of the Beatrice Demonstrator project but, in general, much less is known about the distribution and abundance of marine mammals in more offshore areas within the Moray Firth.

Recently, this lack of data has been highlighted in Appropriate Assessments for oil and gas activities, particularly in relation to the potential use of offshore areas by bottlenose dolphins that inhabit the Moray Firth SAC. To address this, the Department of Energy & Climate Change (DECC) funded work in 2009 and 2010 to review existing data on cetacean distribution in the outer Moray Firth, and collect additional data to support the management of oil and gas activities in the area.

Work carried out in 2009 and 2010 under this DECC funded project greatly enhanced the data available to assess other developments in the outer Moray Firth (Thompson *et al*., 2010a). Nevertheless, following a review of the marine mammal data requirements for the Beatrice Offshore Wind Ltd (BOWL) environmental impact assessments (Grellier & Lacey, 2010), it was agreed that there were several requirements for either additional data collection or more detailed analysis of existing data. Not only are these data required to support consenting for offshore developments within the Moray Firth, but they will also be needed to provide a more robust baseline for subsequent monitoring programmes during the construction phase of these projects.

The resulting work programme was developed in discussion with the developers and regulatory bodies. Overall, the work programme has aimed to collect additional data that, in combination with existing data sources, can be used in Environmental Statements for offshore wind farm developments within the Moray Firth to address the following three objectives:

1. To characterise the three proposed sites (Telford, Stevenson and MacColl) with respect to the marine mammal species present; detail seasonality and year-to-year variability in occurrence.

A key requirement under Objective 1 was additional data on cetacean distribution and occurrence. In particular, information on seasonal and inter-annual variation in the occurrence of key species (e.g. harbour porpoises and dolphins) within the development areas was required. These data can then be used to complement existing visual data (e.g. Reid *et al*., 2003; Thompson *et al*., 2010a) and data collected from dedicated boat-based marine mammal surveys conducted by MORL (and BOWL). The agreed approach for these additional studies was to extend passive acoustic monitoring studies that were initiated during the Beatrice Demonstrator project (Bailey *et al*., 2010; Thompson *et al*., 2010b) and which had been further developed through the DECC funded project (Thompson *et al*., 2010a).

In addition to this, a two year program of monthly boat-based surveys was undertaken by Natural Power Consultants (NPC) on behalf of MORL. Part of this data was incorporated into the habitat models (Objective 2) but the primary reason was to collect site-specific, up-to-date information on the abundance and distribution of marine mammals within the three proposed development sites (Telford, Stevenson and MacColl).

2. To assess the density of animals at the proposed sites.

A key requirement under Objective 2 was for robust region-specific density estimates of cetaceans in and around the MORL and BOWL sites. Such data are required for EPS licences to estimate the number of animals that may be disturbed, where the use of region-specific data is likely to be more appropriate than using the broader scale density estimates available through SCANS (Hammond *et al*., 2002) or SCANS-II (SCANS-II, 2008).

The precise area of interest for these density data will depend upon the results of concurrent noise modelling studies, making it difficult to pre-define suitable survey areas. However, during August & September 2010, DECC funded the University of Aberdeen to conduct an intensive series of aerial line-transect surveys across two 25 x 25 km survey blocks in the central Moray Firth. One of these sites covered the whole BOWL site and a large part of the MORL R3 development area. The agreed approach for these studies was to use the high quality data from these aerial surveys within habitat association models (see e.g. Bailey & Thompson, 2009), and predict the density of cetaceans within the development sites and their surrounding waters. Subsequently it was agreed with MORL and BOWL to explore the potential for integrating available data from boat-based surveys into these habitat association analyses.

3. To assess the likelihood of exchange between local SACs and the proposed sites.

A key requirement under Objective 3 was for data to assess the likely connectivity between the MORL and BOWL development sites and marine mammal SACs in the region. The two species of concern in this respect are bottlenose dolphins using the Moray Firth SAC (Thompson *et al*., 2011) and harbour seals using the Dornoch Firth and Morrich More SAC (Cordes *et al*., 2011).

Bottlenose dolphins:

Previous studies using echolocation detectors (C-PODS) had shown relatively high levels of dolphin activity in the Outer Moray Firth (Thompson *et al*., 2010a). But used alone, C-PODS cannot discriminate between the bottlenose dolphins that might be using the Moray Firth SAC and the other species that are potentially using this area (primarily common, white-beaked and Risso's dolphin). However, SMRU Ltd has developed new approaches which can use broadband recordings to better discriminate between different dolphin species. Given the limited coverage of visual surveys in offshore areas, it was agreed that these passive acoustic techniques using broadband sound recordings would provide the greatest opportunities for assessing the probability that dolphins detected in the Outer Moray Firth were likely to be bottlenose dolphins.

Harbour seals:

Over the last two decades, over 37 individual harbour seals from the Dornoch Firth and Morrich More SAC and the nearby Loch Fleet NNR have been tracked using a variety of techniques (VHF, Satellite and GSM telemetry) (Thompson *et al*., 1994; Sharples *et al*., 2008; Cordes *et al*., 2011). It was agreed that the most appropriate method for addressing this objective for harbour seals was to use these existing data to underpin predictions of use of the MORL and BOWL sites using habitat association modelling. However, the different error structures for each of these technologies required the development of a novel Bayesian state-space approach to integrate these data into a single modelling framework. Existing procedures could then be used to predict habitat usage (Aarts *et al*., 2008) and estimate how many harbour seals from the Dornoch Firth and Morrich More SAC are likely to use habitats within the development areas (Matthiopoulos *et al*., 2004).

In addition to this, SMRU Ltd were commissioned identify how many grey seals enter the Moray Firth from other areas and to provide density estimates for the total and at sea population estimates for the Moray Firth. This was achieved by analysing telemetry data from 1992 to 2008, in addition to aerial survey data from 1996 to 2009, and the production of population models to predict the current usage of the Moray Firth to inform the MORL marine mammal impact assessment.

This report is broken down into a number of chapters relating to the work undertaken to meet these objectives, including a review of existing information on marine mammals in the Moray Firth.

2. Review of published material

In total, around 14 species of cetacean have been recorded within the Moray Firth (Table 2.1). The three most commonly sighted cetacean[1] species are the harbour porpoise, bottlenose dolphin and minke whale (Table 2.1). Harbour seals and grey seals are also both common within the Moray Firth.

All cetaceans are listed on Annex IV of the Habitats Directives as European Protected Species. The bottlenose dolphin, harbour porpoise, grey seal and harbour seal are listed on Annex II of the Habitats Directive as requiring the designation of Special Areas of Conservation (SACs). SACs have been designated within the Moray Firth for both the bottlenose dolphin and harbour seal populations (Figure 2.1).

Table 2.1: List of marine mammals recorded within the Moray Firth (adapted from Reid *et al.*, 2003; Robinson *et al.*, 2007 & Thompson *et al.*, 2010).

Common name	Latin name	Occurrence
Harbour Seal	Phoca vitulina	Common, all year
Grey seal	Halichoerus grypus	Common, seasonal
Harbour porpoise	Phocoena phocoena	Common, all year
Bottlenose dolphin	Tursiops truncates	Common, all year
Minke whale	Balaenoptera acutorostrata	Common, seasonal
Common dolphin	Delphinus delphis	Frequent, seasonal
White-beaked dolphin	Lagenorhynchus albirostris	Frequent, seasonal
White-sided dolphin	Lagenorhynchus acutus	Occasional
Killer whale	Orcinus orca	Occasional
Risso dolphin	Grampus griseus	Occasional
Pilot whale	Globicephala melas	Rare
Humpbacked whale	Megaptera novaengliae	Rare
Fin whale	Balaenoptera physalus	Rare
Sperm whale	Physeter macrocephalus	Rare
Northern bottlenose whale	Hyperoodon ampullatus	Rare
Beluga whale	Delphinapterus leucas	Rare

[1] Collective term for whales, dolphins and porpoises

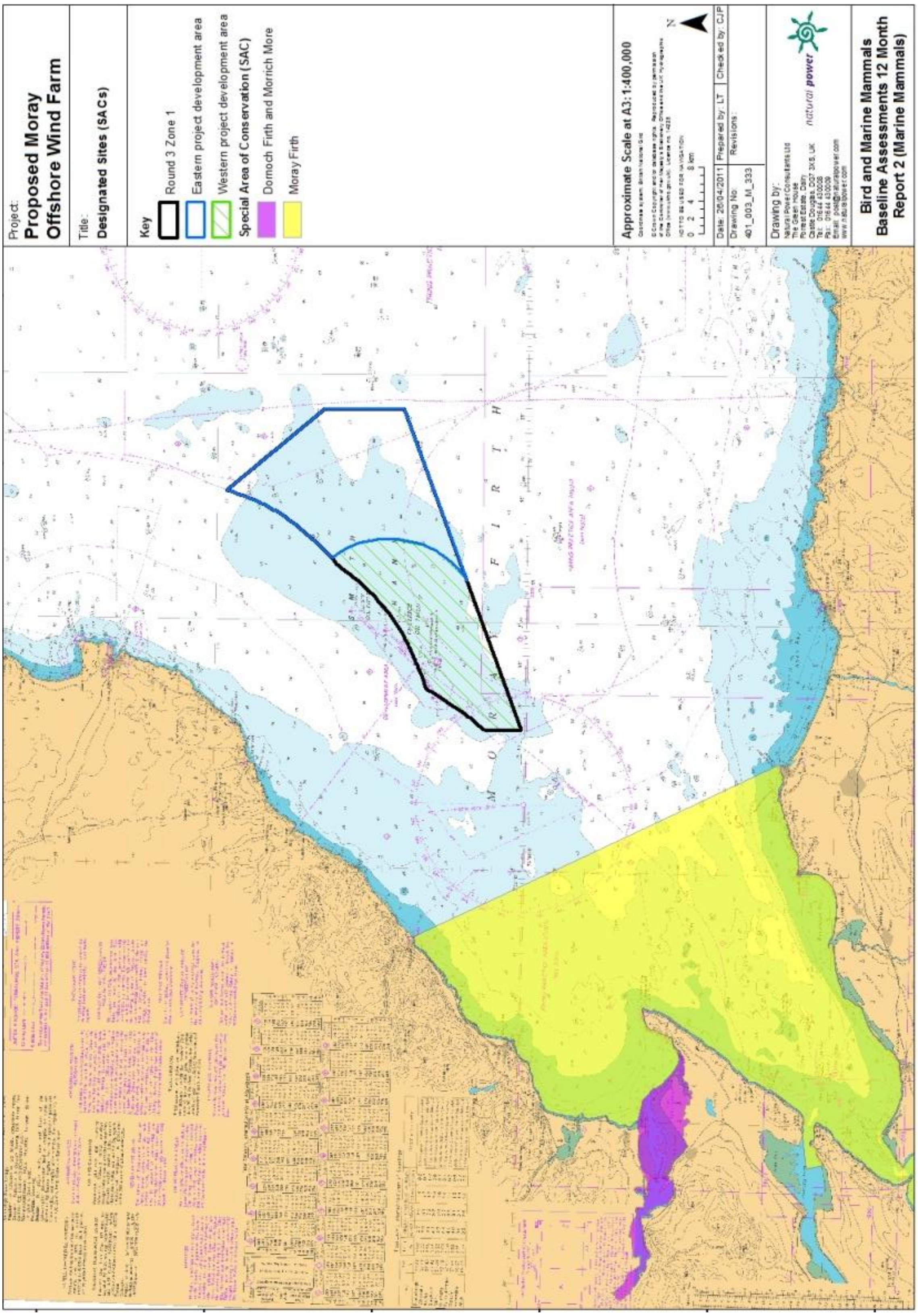

Figure 2.1: Representation of Special Areas of Conservation designated within the Moray Firth SAC for the bottlenose dolphin (yellow) and the Dornoch Firth and Morrich More SAC for harbour seal (pink) populations.

2.1 Bottlenose dolphin

The bottlenose dolphin, a member of the Delphinidae family, is found in tropical and temperate waters worldwide. Around the UK, bottlenose dolphin sightings are concentrated around two general areas – the Welsh coast (Cardigan Bay) and the north-east coast of Scotland (Moray Firth) (Figure 2.2). Both of these populations are considered resident and show a peak in numbers of sightings during the summer months (Evans, 1992).

Bottlenose dolphins are listed on Annex II of the Habitats Directive. SACs have been designated in both areas (Moray Firth and Cardigan Bay) with the local bottlenose dolphin populations as the primary feature. The Moray Firth SAC was accepted by the European Commission in October 1996 and comprises of a "triangular" area of water extending from the inner firths to Helmsdale on the northern coast and Lossiemouth on the southern coast including the Beauly/Inverness Firths, and the outer reaches of the Dornoch and Cromarty Firths (Figure 2.1). The Moray Firth population is considered to be of scientific, educational and socio-economic importance.

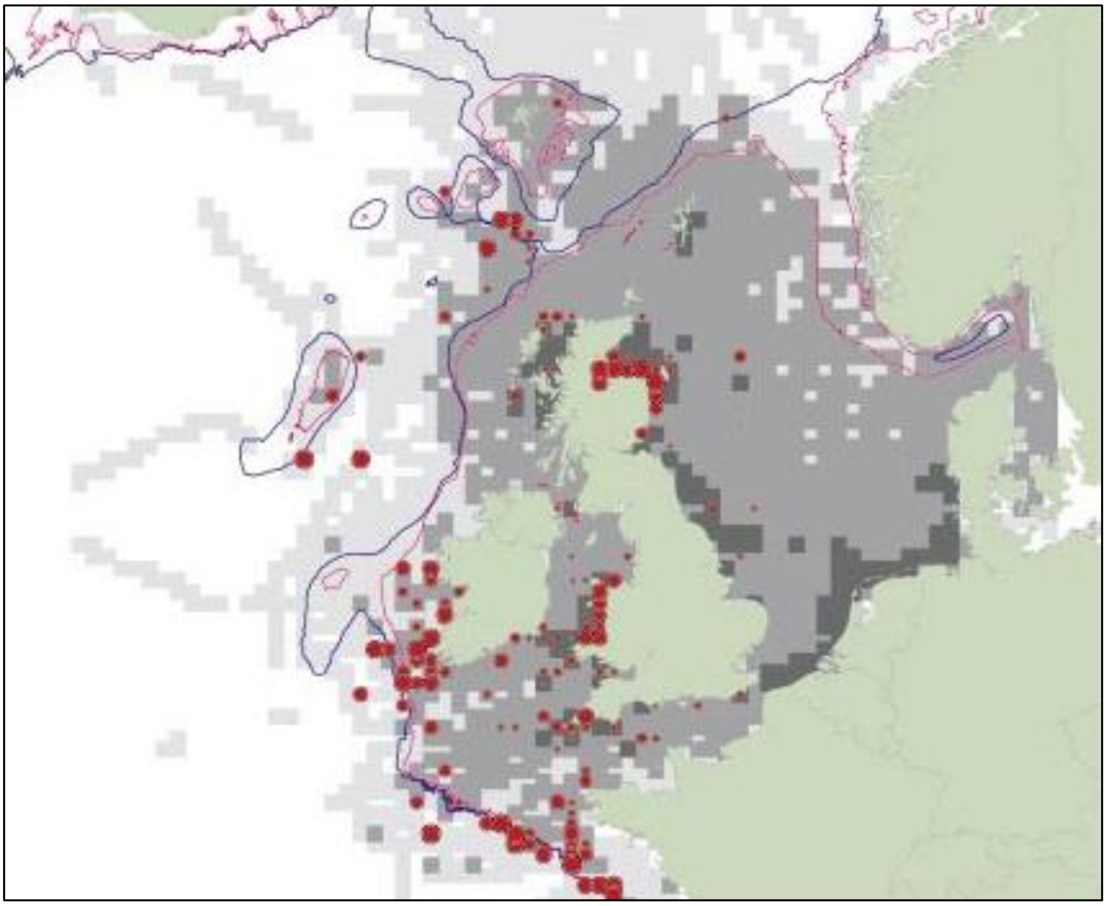

Figure 2.2: UK distribution of bottlenose dolphins (Reproduced from Reid *et al*., 2003).

The SAC population has been studied for many years, although the vast majority of this work has concentrated on the inner and southern Moray Firth. The population has been extending its distribution since the mid-1990s to include the south-east coast of Scotland with research in these areas occurring as a result (Weir & Stockin, 2001; Wilson *et al*., 2004; Stockin *et al*., 2006).

2.1.1 Distribution and abundance within Moray Firth

The most recent population estimate of dolphin abundance around the northeast coast of Scotland is 193 (95% probability interval 162-245) individuals (Thompson *et al*., 2011). Although the majority of the population (71 to 111 individuals) appear to regularly utilise the Moray Firth SAC (95% CI: 66-161), it is clear that a relatively high number individuals also frequently utilise areas outside the SAC (Thompson *et al*., 2006; 2009).

Sightings of bottlenose dolphins within the Moray Firth tend to be close to the coast, with the majority occurring in the inner Firth and along the southern coast, generally in waters of less than 25 m deep (Hastie *et al*., 2003b; Canning, 2007; Robinson *et al*., 2007). Analysis has also shown long-distance movement between the east and west coast of Scotland and between Scottish and Irish waters (Robinson *et al*., 2009). Recent data collected from the outer Moray Firth as part of the DECC-funded project assessing the impact of seismic surveys on marine mammals has found an increase in dolphin occurrence towards the outer edge of the Firth, although species identity is unknown and durations were short (Bailey *et al.,* 2010; Thompson *et al*., 2010).

Abundance within the inner firth exhibits a strong seasonal pattern with greater numbers being recorded during the summer months (Wilson *et al.*, 1997). Sightings are concentrated in three areas within the inner Moray Firth, all of which are narrow, deep channels associated with strong tidal currents (Wilson *et al.*, 1997). The dolphins show a clear preference for these areas and the predominant behaviour within them is foraging (Hastie *et al.*, 2003b). It has been suggested that the increase in bottlenose dolphin sightings in these areas during the summer months is linked to the large numbers of salmon that pass through these areas on their up-river migration for spawning (Wilson *et al.*, 1997).

2.1.2 Habitat use

Habitat use by bottlenose dolphins varies between and within populations (reviewed in Shane *et al.*, 1986 and Wells & Scott, 1999). Associations between dolphin abundance and tidal state have been observed within the inner Moray Firth, with the dolphins moving into the channel areas with the incoming tide and leaving before the tide turns (Mizon, 1998; Robertson, 1998; Mendes *et al.*, 2002). Spatial distribution within these areas is associated with the tidal front, presumably a result of the accumulation of prey that is associated with these zones (Mendes *et al.*, 2002).

Even though sightings data suggest that the outer Moray Firth is rarely utilised by bottlenose dolphins (Hastie *et al*., 2003a), acoustic studies conducted outside of the SAC (Thompson *et al*., 2011) recorded the highest detection rates at Spey Bay, to the east of a potential export cable route landfall, with a peak in recordings observed during the summer. Outside of the Moray Firth, the highest level of acoustic detection was recorded at Stonehaven, 28 km south of Aberdeen, again with a summer peak.

Short-term movements are often assumed to be a reaction to prey behaviour as they are usually followed by prolonged periods of feeding (Saayman & Taylor, 1973; Würsig & Würsig, 1979; Ballance, 1992; Wilson *et al.*, 1997; Harzen, 1998; Mendez *et al.*, 2002). The coastline along the southern Moray Firth differs from the inner Firth, being comprised of exposed beaches and small bays, as opposed to the narrow channels of the inner Firth. There appear to be differences in how the bottlenose dolphins utilise these different areas, with areas with narrow channels appearing more preferable foraging areas (Wilson *et al.*, 1997; Canning, 2007). Visual surveys conducted off the Aberdeenshire coast recorded four times as many sightings at the entrance to the River Dee (Aberdeen harbour) compared to Stonehaven Bay, with a significant increase in frequency at Aberdeen during the winter and spring (Canning, 2007). Sightings at Aberdeen were primarily of foraging animals while those observed at Stonehaven were transiting with transit group size tending to be larger than those foraging. Similar results have been observed within the Moray Firth, where group size within the inner Firth (narrow channel areas associated with foraging) tend to be half the size of groups observed along the southern, outer Firth (Eisfeld, 2003).

2.1.3 Diet

The bottlenose dolphin diet varies with locality and a wide range of fish and squid are known to be taken (Cockcroft & Ross, 1990; van Waerebeak *et al.*, 1990; Relini *et al.*, 1994; Santos *et al.*, 1995; de Pierrepont *et al.*, 2005). In Scottish waters, cod, saithe and whiting were the predominant prey species recovered during stomach contents analysis (Santos *et al.*, 2001). Other species recovered included salmon, haddock, sandeel and several squid species. This wide variation in diet has lead to the belief that they are opportunistic feeders although work carried out in Australia has suggested that they will show preference in prey type if given a choice (Corkeron *et al.*, 1990), particularly towards species with a high fat content.

2.1.4 Breeding season

Breeding is usually seasonal and varies with location but parturition tends to be associated with the warmer months (Wells & Scott, 1999). Gestation in bottlenose dolphins is around 12 months and the reproductive life span of females is long, with no indication of senescence (Cockcroft *et al.*, 1989).

2.2 Harbour porpoise

Harbour porpoises are found throughout the temperate shelf waters of the northern hemisphere (Read, 1999; Figure 2.3) and they are the most abundant cetacean recorded in British and Irish waters (Evans, 1992; Hammond *et al.*, 2002; Reid *et al.*, 2003) with sightings being widely distributed all around the coast. Their distribution across the North Sea is not uniform (Hammond *et al*, 2002; Reid *et al.*, 2003): sightings were considered rare in the southern parts and the English Channel, although recent work (i.e.

Camphuysen, 2004; SCANS II, 2007) suggest this is changing. They are the most frequently sighted species along the southern Moray Firth (Robinson *et al.*, 2007), and in the boat-surveys described in this report (see Chapter 8 of this report).

Although the original SCANS surveys did not encompass the Moray Firth, estimates of porpoise density for the closest surveyed regions were 0.36 and 0.78 animals/km^2 (Hammond *et al.*, 2002) with spatially smoothed predictions of porpoise density suggesting relatively high densities within the Moray Firth (1.2 animals/km^2). The SCANS II survey did included the Moray Firth (SCANS II, 2007) and estimated harbour porpoise densities within the ranges of the original SCANS estimates but lower than the smoothed prediction for the Moray Firth (0.4 to 0.6 animals/km^2). Recent data collected from the outer Moray Firth (DECC funded project) assessing the impact of seismic surveys on marine mammals supports the relatively high occurrence of porpoises throughout the Firth with high detection rates of porpoises using autonomous passive acoustic detectors (CPODs)(Bailey *et al.*, 2010; Thompson *et al.*, 2010).

Harbour porpoise are listed on Annex II of the Habitats Directive, requiring the designation of protected areas, although to date, no such areas have been designated for this species in UK waters. They are listed as non-qualifying features on a number of sites including the candidate Dogger Bank, Inner Dowsing and Haisborough sites.

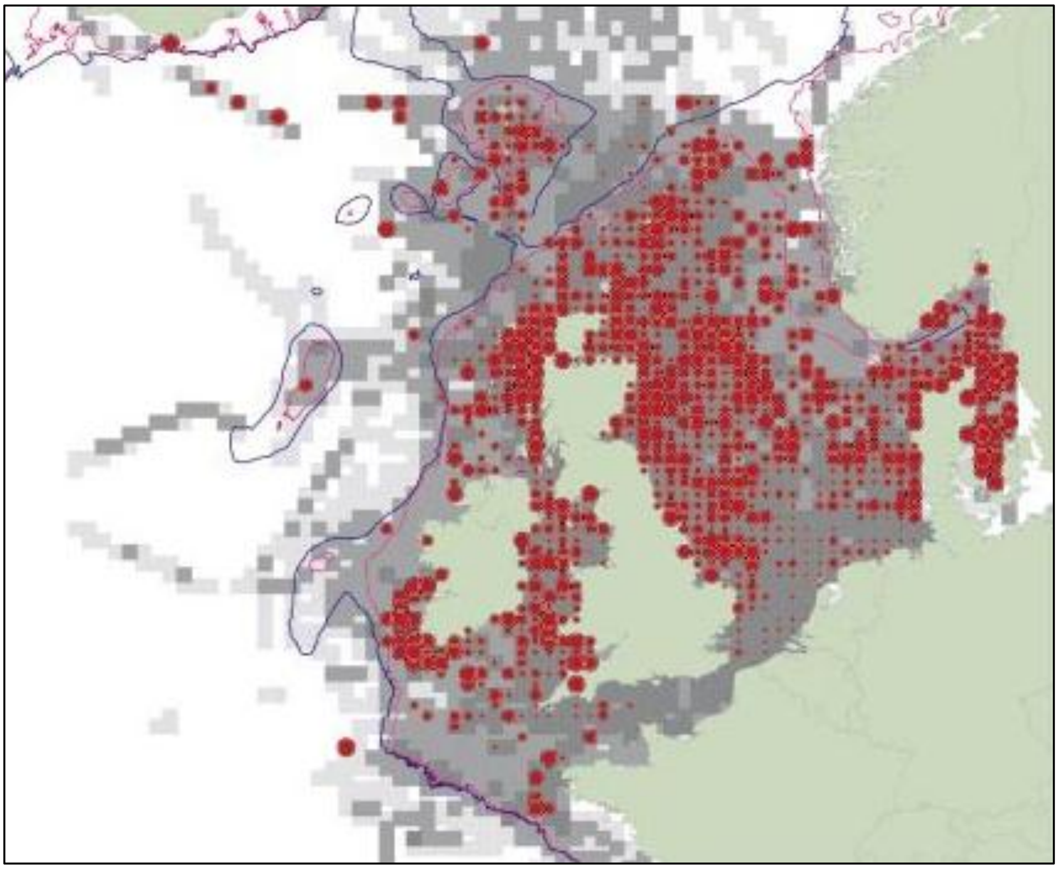

Figure 2.3: UK distribution of harbour porpoise (Reproduced from Reid *et al.*, 2003).

2.2.1 Distribution and abundance within Moray Firth

Porpoise distribution within the Moray Firth differs from that of the bottlenose dolphin: while bottlenose dolphin sightings are strictly coastal and predominantly within the inner Firth, harbour porpoise are distributed throughout the area (Hastie *et al.*, 2003a; Thompson *et al*., 2010). Whether this indicates exploitation of different habitats or avoidance of bottlenose dolphins is unclear. Similar results have been found along the southern Moray Firth and east Aberdeenshire coast, with porpoise distribution covering a much wider distance from shore than the bottlenose dolphins (Canning, 2007; Robinson *et al.*, 2007).

North Sea porpoises are thought to comprise two sub-populations, 'British' and 'Danish' (Andersen *et al.*, 2001). On the Danish side of the North Sea, porpoises are thought to migrate up and down the Danish and Norwegian coasts, and research indicates porpoises are migrating from the western (British) to the eastern side of the North Sea (Andersen *et al.*, 2001).

2.2.2 Habitat use

The species is limited to the waters of the continental shelf by its foraging behaviour and diving capacity (Read, 1999) and they are seldom found in waters warmer than 17°C (Gaskin *et al.*, 1993).

Although generally described as a coastal species (Evans, 1992; Carwardine, 1995), harbour porpoises have been recorded throughout the North Sea, in the deep waters between the Faeroe Islands and Iceland and at depths of up to 1,500m off the west coast of Scotland (Northridge *et al.*, 1995; Hammond *et al.*, 2002; MacLeod *et al.*, 2003). Satellite telemetry studies suggest that porpoises are highly mobile and capable of covering large distances in short time periods, with daily distances travelled in the Bay of Fundy varying from 14 to 58 km (Read & Westgate, 1997).

Porpoise foraging behaviour has been associated with tidal currents. Surveys carried out in the Irish Sea found higher porpoise abundance associated with the front that forms during the summer (Weir & O'Brien, 2000), particularly on the "mixed side" to the east rather than in the deeper, stratified waters to the west. In the Bay of Fundy, porpoise exhibit "focal regions" that coincide with oceanographic features driven by the tidal circulation (Johnston *et al.*, 2005). Features such as islands or headlands create wakes in the tidal flow, causing aggregations of plankton leading to an abundance of fish, which attract predators such as the porpoise.

2.2.3 Diet

Harbour porpoise feed on small, schooling fish usually between 10 and 30 cm in length (Read, 1999). In Scottish waters, whiting and sandeels are the most important prey items (Santos *et al.*, 2004). There is seasonal and geographical variation within the Scottish diet, with the sandeel being more important during the summer and on the east coast.

Of the five species of sandeels inhabiting the North Sea, the lesser sandeel *Ammodytes marinus* is the most abundant and comprises over 90% of sandeel fishery catches. *A. marinus* inhabits shallow (less than 150 m), turbulent sandy areas such as the edge of sand banks (Macer, 1966; Reay 1970; Pinto *et al*., 1984; Wright *et al*., 2000). An optimal depth range of 30-70 m has been determined (Wright *et al*., 2000) and the low abundance of sandeels in deeper waters may be related to the decline in water movement with depth.

The distribution of harbour porpoise (and seals) observed during the surveys under discussion in this report (see Chapter 8) most likely reflect the distribution of prey species such as sandeels.

2.2.4 Breeding season

Time of breeding varies with geographical location but it generally occurs in the spring or summer. In Scottish waters, mating and parturition is thought to occur between May and August, with gestation lasting about 11 months (Learmonth, 2006). Females in Denmark and the Bay of Fundy are thought to produce young annually (Read, 1990; Sorensen & Kinze, 1994; Read & Hohn, 1995) but in Scottish waters this is thought to occur every two years (Learmonth, 2006).

2.3 Minke whale

The minke whale is the smallest species of baleen whale and the commonest whale species recorded in UK waters (Reid *et al*., 2003), with the majority of records occurring between May and September. Sighitngs are mainly distributed around Scotland and in the northern and central North Sea (Evans *et al*., 2003; Reid *et al*., 2003). Their distributed is restricted to the northern hemisphere. The species can often be seen close to land where it sometimes enters bays, inlets and estuaries.

2.3.1 Distribution and abundance within the Moray Firth

The Minke whale is the commonest whale species sighted within the Moray Firth, with sightings being reported throughout the area (Reid *et al*., 2003; Robinson *et al*., 2007; Thompson *et al*., 2010). Although as a species minke whales are not wholly migratory, an increase in numbers is noted around northern Britain between May and October. A distribution map is provided in Figure 2.4.

The SCANS II Survey (2007) gave an overall abundance estimate for minke whale of 18,614 (95% CI = 10,445-33,171) and a density estimate for the Moray Firth, Orkney and Shetland areas combined of 0.022 animals per km2 (1.02 CV).

2.3.2 Habitat use

Observations most commonly occur in deeper waters further from the shore, typically along isobaths (Robinson *et al*., 2007; Eisfeld *et al*., 2009). A correlation has been observed between the Dooley current and a warm water plume extending from the inner Moray Firth into the wider area (Tetley *et al*., 2008). The presence of underwater sand dunes has a significant positive effect on minke whale distribution (Naud *et al.,* 2003), linked with favoured prey types. Along the southern Moray Firth, frequency was found to be highly correlated with sediment type and water depth, with a preference for water of between 20 and 50 m deep with a sandy-gravel sediment (Robinson et al., 2009).

Minke whales along the southern Moray Firth are often observed feeding in the presence of seabirds such as herring gull, kittiwake and guillemots (Robinson & Tetley, 2007), all of which are thought to be attracted to concentrations of prey.

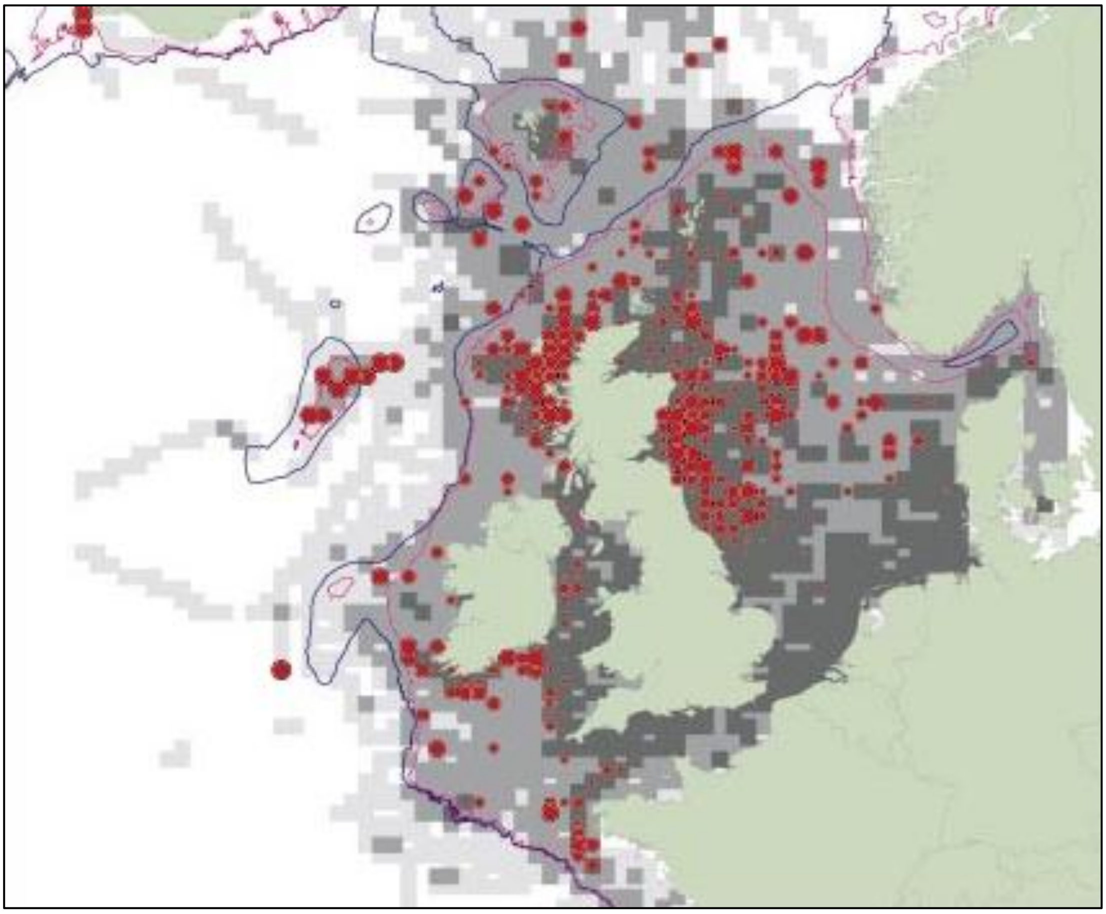

Figure 2.4: UK distribution of minke whale (Reproduced from Reid *et al.*, 2003).

2.3.3 Diet

The diet of the minke whale contains a range of different species including fish, crustaceans and cephalopods although composition varies greatly between different regions. In the north-east Atlantic and British Isles, the primary prey species identified were the sandeel (*Ammodytes marinus*), sprat (*Sprattus sprattus*) and herring (*Clupea harengus*) (Haug *et al*., 1997; Lindstrom *et al*., 2002). Work carried out on animals from Scottish waters found the diet comprised mainly sandeels (Ammodytidae, around two-thirds of the diet by number or weight) and clupeids (herring and sprat), consistent with results from whaling catches in the North Sea (Pierce *et al*., 2004). However, it has been shown that minke whales only select and feed on single prey species aggregations (Tamura & Fujise, 2002).

It has been suggested minke whale migrations may be linked with the migrations of certain prey species, such as spawning herring, or changing between prey species which become more abundant than one another during the time spent at foraging sites (MacLeod *et al*., 2004).

2.3.4 Breeding season

Breeding peaks during the summer months with gestation lasting about 11 months. Calving is thought to occur, on average, once every two years. Minke calves nurse for approximately six months.

2.4 Frequently occurring cetacean species

A number of other cetacean species are recorded in the literature in the Moray Firth on a semi-regular basis:

2.4.1 Killer whale

Killer whale population movements in the north Atlantic and into the North Sea appear to be driven by prey abundance, and have they been recorded throughout the year in UK waters. They are commonly sighted around the north and west of Scotland with in-shore sightings mostly between April and October (Reid et al., 2003; Figure 2.5).

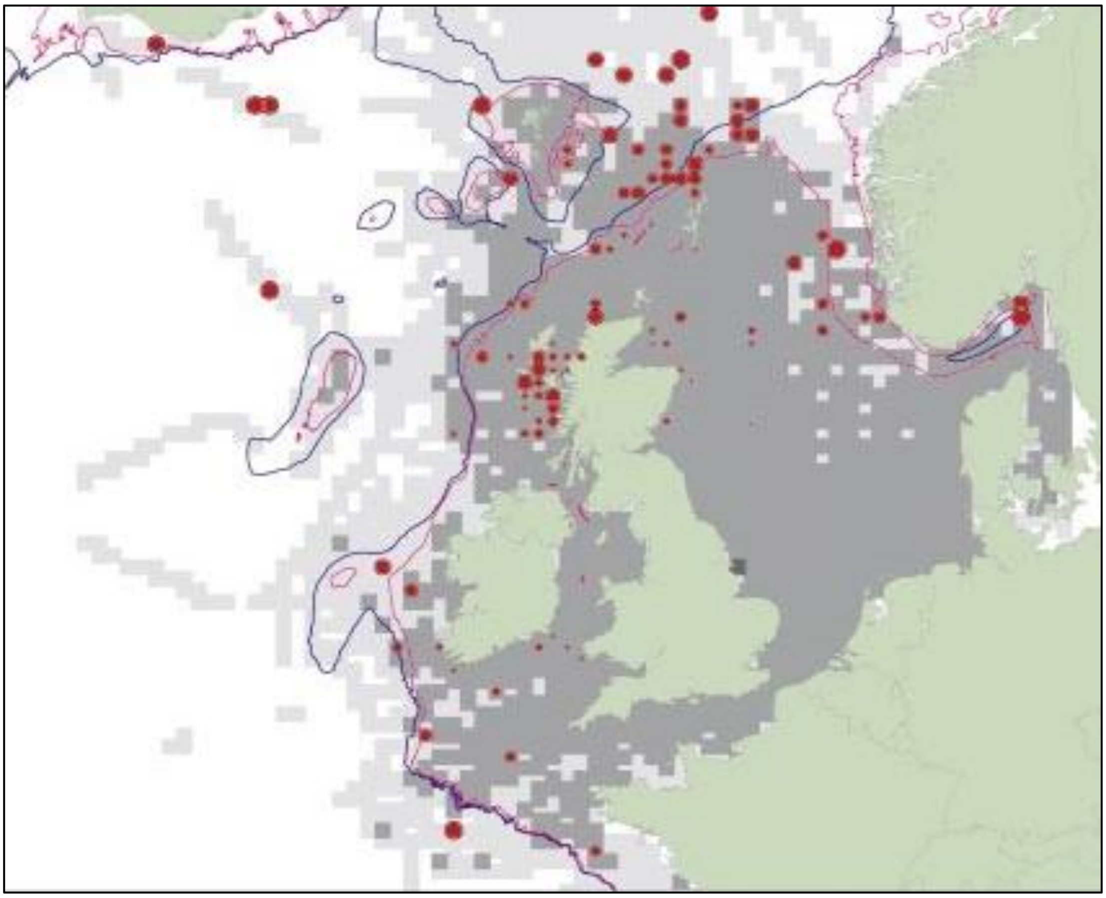

Figure 2.5: UK distribution of killer whale (Reproduced from Reid *et al*., 2003).

2.4.2 Common dolphin

The common dolphin is predominantly found in the continental shelf waters in the Celtic Sea and the western approaches to the English Channel (Figure 2.6). In Scotland it is frequently recorded in the Sea of Hebrides during the summer and occasionally in the North Sea, primarily in the Moray Firth region, with sightings becoming regular here during the summer months since 2006 (Robinson *et al*., 2010).

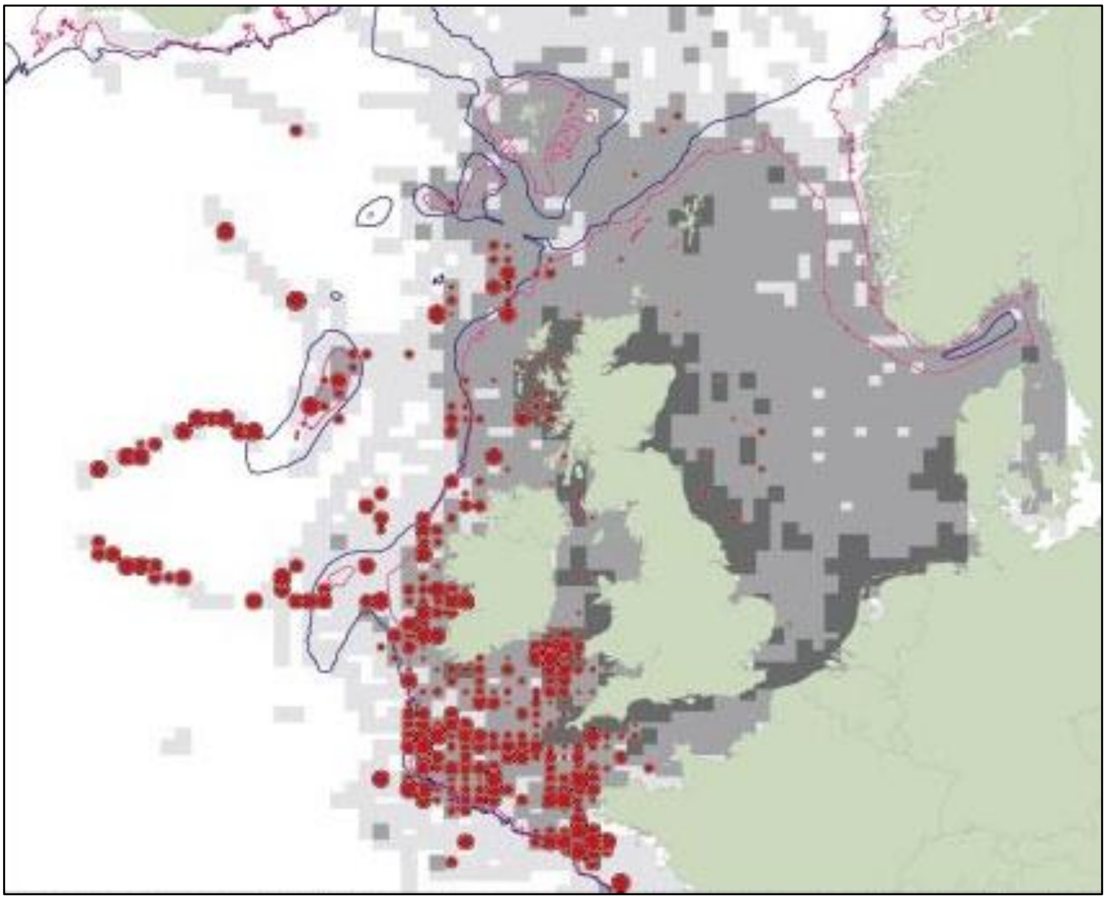

Figure 2.6: UK distribution of common dolphin (Reproduced from Reid *et al*., 2003).

2.4.3 White-beaked dolphin

White-beaked dolphins are predominantly recorded in the UK from around Scotland and the east coast of England (Northridge *et al.*, 1995; Reid *et al.*, 2003; Figure 2.7), although sightings within the Moray Firth are low compared to other areas. White-beaked dolphins are recorded in UK waters all year round, with an increase in sighting frequency during the summer months when the animals move inshore (Evans, 1992; Northridge *et al.*, 1995; Weir *et al.*, 2007).

Little is known about the reproductive behaviour of this species but mating is thought to occur during the summer with parturition occurring the following summer (Kinze *et al.*, 1997). It has been suggested that parturition is the reason they move into coastal waters during the summer months (Canning *et al*., 2009).

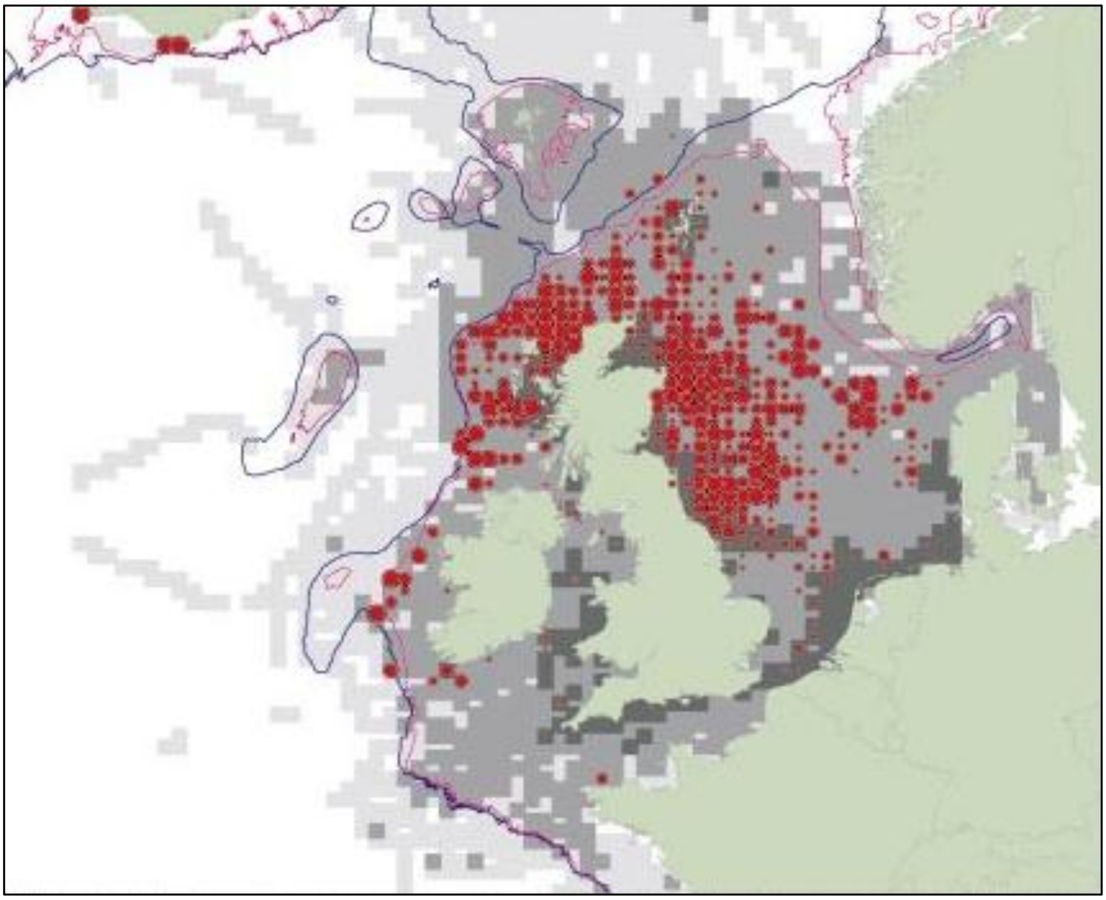

Figure 2.7: UK distribution of white-beaked dolphin (Reproduced from Reid *et al.*, 2003).

White-beaked dolphins eat a variety of prey including fish, squid and some crustaceans. The diet of those found around Britain includes whiting, hake, herring, cod, mackerel, scad, sand eel, long rough dab, *Trisopterus sp*, and the squid *Eledone cirrhosa* (Evans, 1992; Santos *et al.*, 1994; Canning *et al.*, 2009).

2.4.4 Rarely observed cetaceans

The following species (in no particular order) have been recorded within the Moray Firth area but are generally considered rare:

- Risso's dolphins appear to be a continental species with most sightings occurring around off western Scotland, in particular the Outer Hebrides and southern Irish Sea. There are a few records from the central and southern North Sea (Reid *et al*., 2003).
- Atlantic white-sided dolphins are not frequently recorded within the Moray Firth area, although they are not unknown. Due to difficulties in distinguishing between this species and white-beaked dolphins in the field, the two are often grouped together during surveys (Reid *et al*., 2003).

- Humpback whales are rare in UK waters but have been on occasion recorded within the Moray Firth (Reid *et al*., 2003; Robinson *et al*., 2007). Sightings are usually of single animals or pairs and are almost exclusively associated with waters greater than 200 m deep. Most sightings occur between May and September.
- Fin whales are rare in British waters with most sighting being associated with the 500 m depth contour or close to the continental shelf edge. A small number have been recorded along the east coast of Scotland, including within the Moray Firth (Reid *et al*., 2003). Sightings around northern Britain mostly occur between June and August and sightings are usually of single animals or pairs.
- Sperm whales are usually associated with waters greater than 200 m deep and are rare in in-shore waters. Most sightings in UK waters have been associated with the Northern Isles although a very small number have been observed within the Moray Firth (Reid *et al*., 2003). Sightings primarily occur between July and December.
- Northern bottlenose whales are considered rare in the North Sea although not unknown, preferring the deep waters of the continental shelf to the north and west of Scotland. They favour waters between 0 and 25° and feed predominantly on squid (Reid *et al*., 2003).
- The beluga whale is considered a vagrant in UK waters, with its distribution normally restricted to the Arctic and Sub-Arctic. There have been a total of 15 reports in UK waters, all around the north coast of Scotland and the Northern Isles. Some of these reports were made at a similar time and it's been suggested they may have been of the same animals (Reid *et al*., 2003).

2.5 Harbour (Common) seal

Approximately 30% of the European population of harbour seals can be found around Britain. Approximately 25,650 were recorded around the UK in recent counts (SCOS 2010; Figure 2.8) with 79% of these in Scotland, widely distributed along the Scottish North Sea coast.

2.5.1 Distribution and abundance within the Moray Firth

A number of haul-out sites for harbour seals can be found within the Moray Firth, primarily in the Beauly, Cromarty and Dornoch firths (Thompson *et al*., 1996a; SCOS, 2011).

Harbour seals occur throughout the year in these areas, with peak numbers at haul-out sites between June and August (Thompson & Miller, 1990; Thompson *et al*., 1996a). Tagging studies within the Firth have found that harbour seals tend to forage quite close to their haul-out sites, generally travelling no more than 60 km. They tend to forage slightly further afield in the winter with seasonal differences were found in the areas used (Thompson *et al*., 1996a).

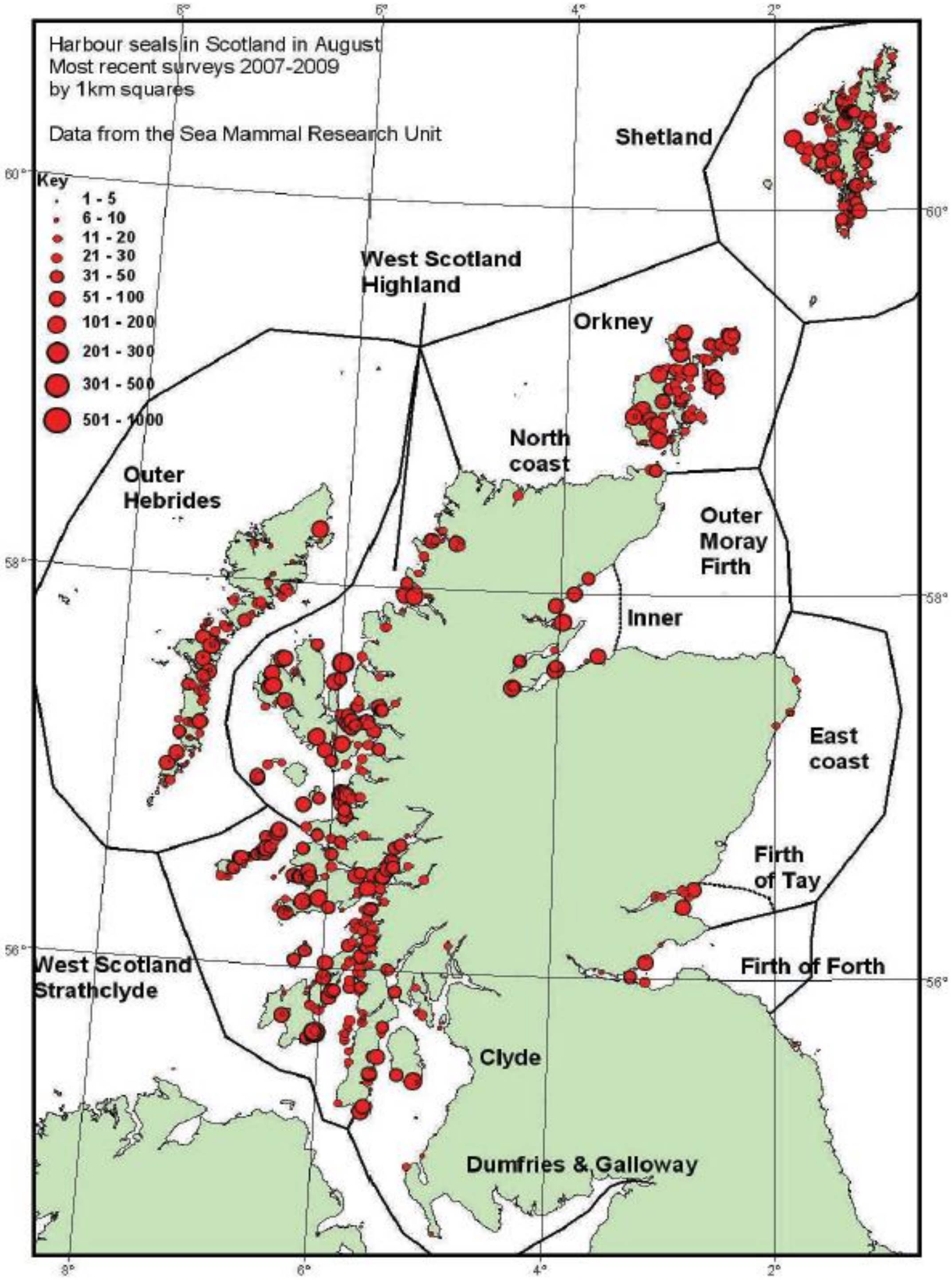

Figure 2.8: The number and distribution of harbour seals in management areas around the Scottish coast during surveys conducted between August 2007 and 2009. Reproduced from SCOS, 2010.

The harbour seal population in the Moray Firth has declined by about 50% compared to numbers recorded in the mid 1990's, but the population has remained relatively stable in the last five years with an increase in numbers of

40% observed in 2010 compared to 2009 (SCOS, 2010; 2011; Figure 2.9). Two aerial surveys of the inner Moray Firth were conducted in August 2008 (SCOS, 2009) with numbers hauled out ranging between 478 and 582. If it is assumed that 60 to 70% of the population were hauled out, a population estimate for the entire Moray Firth area of 1050 to 1230 is produced. These counts are slightly lower than for 2006 and 2007 (Figure 2.9).

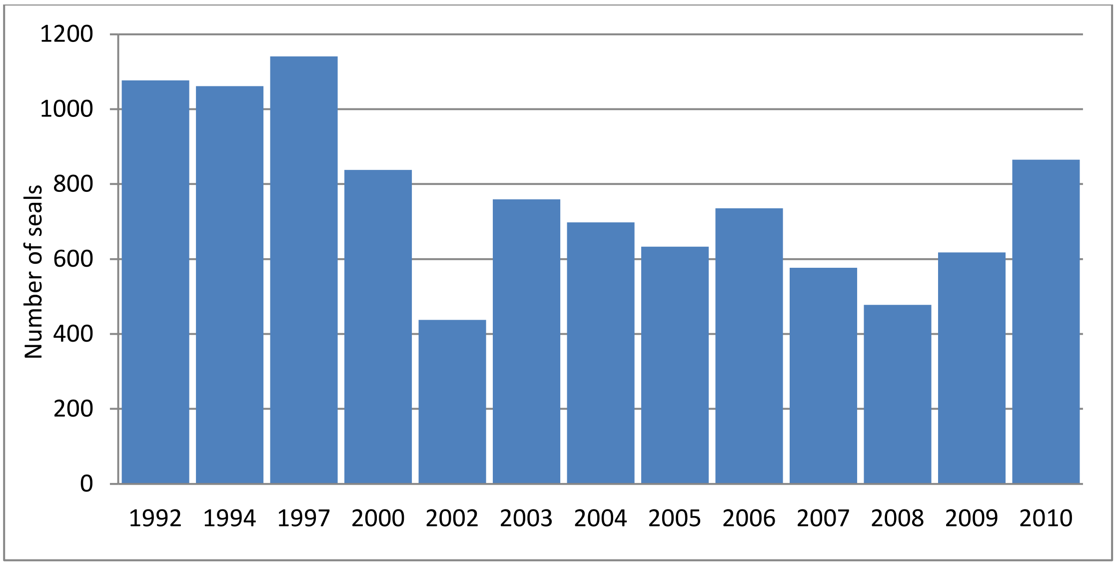

Figure 2.9: Number of harbour seals recorded in the Moray Firth during the month of August. Data adapted from SCOS, 2010 and 2011.

A Special Area of Conservation has been designated for harbour seals within the Moray Firth, encompassing Dornoch Firth and Morrich More (Figure 2.1). A Seal Management Plan was formulated for the Moray Firth in 2002 with the aim of integrating obligations under the Habitats Directive with the Conservation of Seals Act 1970 and protection given to salmon under the Salmon Act 1996. Both harbour and grey seals are considered a threat to Atlantic salmon and sea trout stocks. 17 major salmon rivers drain into the Moray Firth and seals have been regularly shot in order to control damage (Rae, 1960; 1965; Parrish & Shearer, 1977). Harbour seals in particular are considered a threat as they frequent rivers and estuaries more often than grey seals.

2.5.2 Habitat use

Harbour seals are coastal feeders rarely venturing more than a few kilometres from the shore (Spalding 1964; Rae 1968). They will, however travel relatively large distances from their haul-out sites and remain away for several days. Tagging studies have shown movement by adults between Orkney and Shetland; Orkney and the Moray Firth and between all the English sites (SCOS, 2010).

Work in the Moray Firth found harbour seals would travel distances of between 45 and 60 km from their haul-out site on foraging trips lasting up to six days (Thompson & Miller, 1990; Thompson *et al*., 1996a). It cannot be assumed that all time spent in the water involves feeding as haul-out in the Moray Firth is restricted to the hours around low tide.

It has been suggested that seals feed at night, taking advantage of changes in schooling behaviour and vertical distribution of prey species (Trillmich & Mohren, 1981; Croxall *et al*., 1985; Thompson *et al*., 1989; Thompson & Miller 1990). Harbour seals in the Moray Firth may follow prey movement into the inner firth (Thompson *et al*., 1991). Seals within the Moray Firth are found to forage in waters of 10-50 m deep over areas with predominantly sandy sea beds. They generally dive on or close to the sea bed (Tollit *et al*., 1998).

2.5.3 Diet

They take a wide variety of prey including sandeels, gadoids, herring and sprat, flatfish, octopus and squid (Pierce *et al*., 1991a; Thompson *et al.,* 1991). Diet varies seasonally and from region to region. Because of their smaller size, common seals eat less food than grey seals; 3-5 kg per seal per day depending on the prey species.

2.5.4 Breeding season

Female harbour seals give birth on land but spend much of the lactation period in the water with their pups. A variety of different habitats are used including ice, rocky shores and intertidal sandbanks (Bigg, 1981). Females restrict their foraging range during the pupping period and increase the amount of time spent on land (Thompson *et al*., 1994). Pups are born in June/July and moult in August. Females in the Moray Firth will remain near their haul-out sites for between 10 and 24 days (Thompson *et al*., 2004), with parturition occurring 2-6 days into this period. Females feed little at the start of the lactation period, which lasts between 24 and 31 days (Bowen, 1991; Allen, 1988). The extent of feeding during lactation is linked with body size with larger females remaining inshore for longer periods (Thompson *et al*., 1994). It is unknown whether pups travel with their mothers on foraging trips or remain near the haul-out sites. Females come into oestrus when the pup is weaned (Fisher, 1954; Harrison, 1960; Reijnders, 1990). Males continue to travel widely during the early pupping season but then restrict their range once females begin to forage more widely (Van Parijs *et al*., 1997).

2.6 Grey seal

Grey seals come ashore on remote islands and coastlines to give birth to their pups in the autumn, to moult in spring, and at other times of the year to haul-out and rest between foraging trips to sea. Scottish distribution is provided in Figure 2.10. Approximately 38% of the world population (based on pup production) is found around Britain with a large proportion of these breeding in Scotland. UK grey seal pup production in 2009 was estimated to be 47,540 producing a population estimate of 119,400 (95% CI 92,500-156,200) with North Sea production continuing to increase (SCOS, 2010).

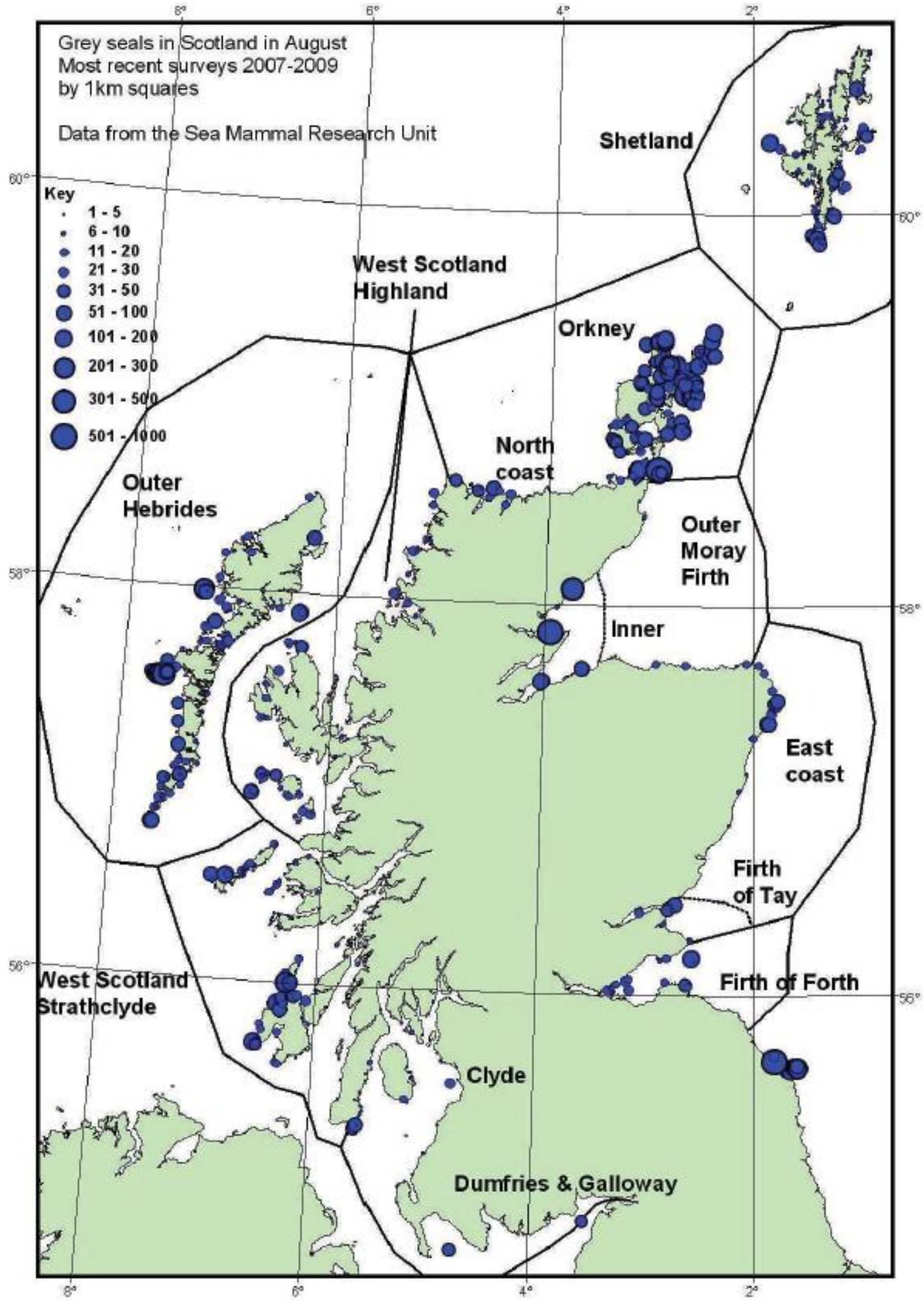

Figure 2.10: The number and distribution of grey seals in management areas in Scottish waters surveyed between 2007 and 2009. Reproduced from SCOS 2010.

2.6.1 Distribution and abundance within Moray Firth

Within the Moray Firth, grey seals are predominantly observed during the summer although a few can be found throughout the year. Non-breeding grey seals have been observed at the same intertidal sites within the firths used by harbour seals. Breeding grey seals are mostly found at the rocky beaches and caves to the north (Thompson *et al*., 1996b). It is thought that grey seals travel into the Moray Firth from different breeding sites (such as the Orkney, Firth of Forth and Farne Islands) and use the area for food and non-breeding haul-out.

2.6.2 Habitat use

Grey seal movements can be highly variable with routes between haul-out sites and foraging areas not clearly defined (SCOS, 2010).

Data obtained from individuals tagged at Abertay and the Farne Islands (McConnell *et al*., 1999) has found that grey seal foraging trips fall into two categories: long distance trips (up to 21,000 km) and short, regular trips to local feeding areas. The majority of trips recorded (88%) constituted these shorter trips, which tended to involve the individuals returning to the same haul-out area after travelling a distance of around 40 km on each foraging bout. Tagging studies within the Moray Firth found have grey seals foraged over a much wider area compared to the harbour seal, with great variation between individuals.

The mean sea depth recorded for diving seals tagged in the Farne Islands was 65 m with 87% of dives at depths of between 50 and 90 m (McConnell *et al*., 1999). Most dives at deeper, offshore areas were to the sea bed with some occurring over local submerged banks. Diving occurred over areas of mixed gravel and sand, the preferred sediment type for sandeel (Reay, 1970; Wheeler, 1978).

2.6.3 Diet

Grey seals feed mostly on fish that live on or close to the seabed. In the UK their diet is composed primarily of sandeels, whitefish (cod, haddock, whiting, ling), and flatfish (plaice, sole, flounder, dab) but varies seasonally and from region to region (Hammond *et al* 1994a; 1994b; Pierce *et al*., 1989; Pierce *et al*., 1991b).

2.6.4 Breeding season

Grey seal breeding colonies can be found around Scotland (Figure 2.11). Females mature at 3-5 years and males at 3-6 years although they don’t normally mate until eight years or older. Grey seals come ashore on remote islands and coastlines to give birth to their pups in the autumn (October to November), to moult in spring (January to March), and at other times of the year to haul-out and rest between foraging trips to sea. Each mature female gives birth to a single white-coated pup, which is nursed for about three weeks before being weaned and moulting into its adult coat.

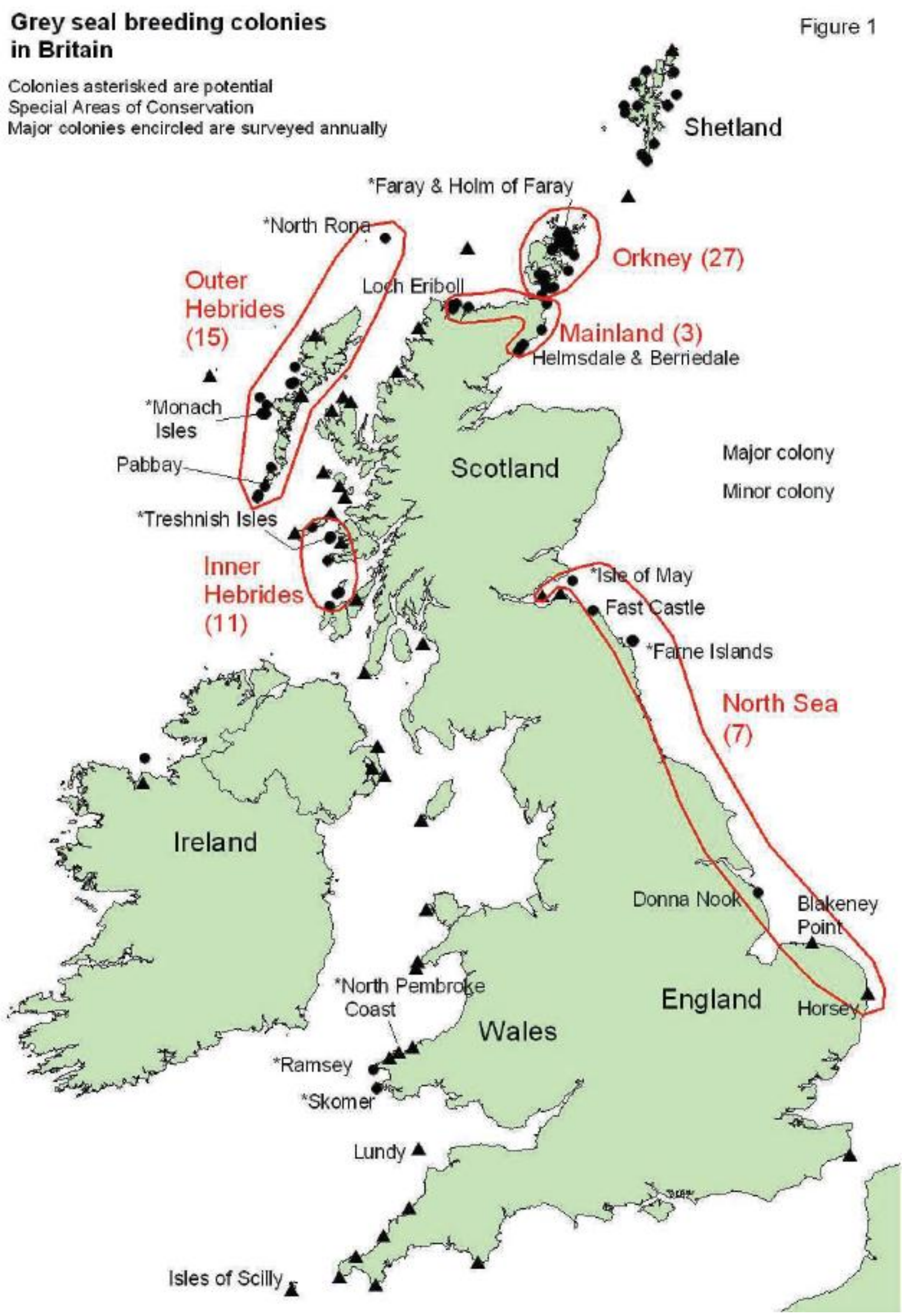

Figure 2.11: Distribution of grey seal breeding colonies around Britain. Reproduced from SCOS, 2010.

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3. Harbour seal telemetry and habitat modelling

3.1 Background

Harbour seals are resident in the Moray Firth throughout the year, breeding and resting on inter-tidal sandbanks in the inner Moray Firth (Thompson *et al*. 1996), and making regular foraging trips into the central and outer Moray Firth (Thompson *et al*. 1998). Although there are a few non-breeding haul-out sites along the outer Moray Firth coast (see Grellier & Lacey, 2010), most of this population is found at haul-out sites within the inner firths. The closest known harbour seal breeding site to the MORL and BOWL wind farm sites is in the Loch Fleet National Nature Reserve (NNR), and the next nearest is in the Dornoch Firth (Figure 3.1).

In the early 1990's, the Moray Firth harbour seal population was estimated to contain approximately 1650 individuals (Thompson *et al*., 1997). Although this formed a relatively small proportion of the UK population, it did represent the largest breeding population on the east coast of Scotland. Within the Moray Firth, over half the population was found breeding in the Dornoch Firth (Thompson *et al*., 1997) and, as a result, harbour seals are one of the key features that led to the designation of this area as the Dornoch Firth and Morrich More Special Area of Conservation (SAC).

A series of research projects during the late 1980's and 1990's resulted in the Moray Firth population becoming one of the most intensively studied harbour seal populations in the world. As a result, there is a wide-range of published studies on different aspects of their ecology, including work on foraging and diving behaviour (Thompson *et al*., 1998; Tollit *et al*., 1998), diet (Pierce *et al*., 1991; Tollit & Thompson, 1996), female reproductive biology (Thompson *et al*., 1994; Gardiner *et al*., 1996; Thompson & Wheeler, 2008), male vocalizations and display behaviour (Van Parijs *et al*., 1997; 1999), the impacts of disease and parasite burdens (Thompson *et al*., 1998; 2002) and interactions with salmonid fisheries (Middlemas *et al*., 2005; Butler *et al*., 2008). Regular annual surveys in both the June/July pupping season and the August moult were also carried out to explore how observed variations in natural environmental conditions and human impacts such as shooting influenced population dynamics (Thompson *et al*., 2007). These annual surveys were conducted by the University of Aberdeen between 1987 and 2004, and have since been integrated into the NERC Sea Mammal Research Unit's broader scale monitoring programme for UK harbour seals.

Broad-scale surveys across Scotland have revealed that harbour seals have declined significantly in most areas (Lonergan *et al*., 2008; Scottish Government, 2011). This pattern of population change is markedly different to that seen in areas affected by the phocine distemper virus outbreaks between 1988 and 2002 (Harkonen *et al*., 2006), resulting in the factors driving harbour seal declines in Scottish waters remaining unclear (Lonergan *et al*., 2008).

Within the Moray Firth, shooting by fisheries managers has clearly contributed to observed declines (Thompson *et al*., 2007). Marine Scotland now limits the number of harbour seals that can be shot each year through the Moray Firth Seal Management Plan (Butler *et al*., 2008). However, despite extensive research on other aspects of their biology, limited understanding of variation in key demographic parameters such as reproductive rates and survival has constrained our ability to model recovery rates or to assess key drivers of population dynamics in this or any other harbour seal population worldwide. This is largely a result of the harbour seal's reproductive behaviour, because mothers and pups move readily in and out of the water (Boness & Bowen, 1996) and it is therefore difficult to collect demographic data from these species compared with other pinnipeds such as grey seals that stay ashore during the breeding season.

A key requirement for EIA is an assessment of the connectivity between the proposed wind farm sites and protected species in locals SACs. In the case of harbour seals within the Moray Firth, this requires information on both the origin of those seals that may be encountered within the wind farm sites, and the extent to which far-scale effects such as construction noise may overlap with other areas used by harbour seals from the Dornoch Firth and Morrich More SAC.

Over the last 20 years, several different studies have used tracking devices to study the foraging movements of harbour seals from the Dornoch Firth and Loch Fleet (Thompson *et al*., 1996, 1997, 1998; Sharples *et al*., 2008; Cordes *et al*., 2011). Compared with most sites, the foraging areas of harbour seals within the Moray Firth are well characterised, and it was therefore not considered necessary to conduct additional tracking studies. Instead, the key requirement has been to use the different data sets within a common statistical framework that provides an integrated picture of the foraging distribution of harbour seals from these two breeding sites.

The primary challenge in achieving this is that technological developments over the last 20 years mean that different studies have used a variety of techniques (VHF telemetry, satellite telemetry & GPS-GSM technology), each with different levels of accuracy and temporal resolution. In this report, a Bayesian State Space Modelling (SSM) approach is used to integrate tracking data from multiple tag types and standardize position estimates while accounting for location error. The standardized tracking data set is then used to predict habitat usage and estimate the absolute number of harbour seals using different parts of the Moray Firth by scaling by the population size estimated from haul-out counts. As further background for these assessments, the latest information on abundance trends in the Dornoch Firth and Loch Fleet is presented.

3.2 Methodology

3.2.1 Analysis of Telemetry data

Tracking data were available from 37 individual seals that were captured in either Loch Fleet or the Dornoch Firth (Figure 3.1) and tagged between 1989 and 2009 (Table 3.1). Seals were captured under licence using either hand nets or beach seine nets, and then sedated while measurements were taken and tags glued to the hair on the head or neck. Capture and handling techniques are described in Thompson *et al*., 1992.

Table 3.1: Summary of harbour seal telemetry data in the Moray Firth, Scotland.

Tag type	Deployment years	Number of tags	Mean duration (days)	Sex ratio (Male:Female)
VHF	1989-1991	21	58	12:9
Argos satellite	2004-2007	11	109	6:5
GPS GSM	2009	5	95	0:5
Total/Mean		37	87	1:1

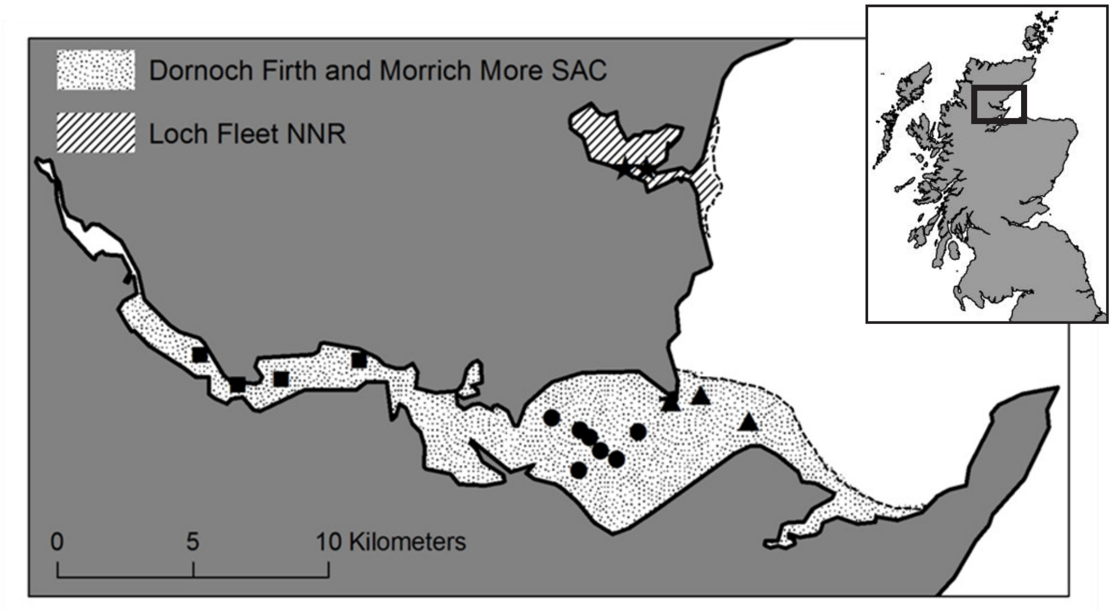

Figure 3.1: A map showing the location of harbour seal haul-out sites in the Dornoch Firth and Loch Fleet (taken from Cordes *et al*., 2011).

VHF telemetry

Between 1989 and 1991, 21 VHF radio tags were attached to harbour seals as part of a Scottish Office funded project on harbour seal foraging ecology (Table 3.1). Subsequent tracking of these individuals was designed to collect one position per day for six days per week. Radio-fixes were made from coastal vantage points with a three-element Yagi aerial using the null average method (Springer, 1979). The accuracy of fixes was estimated using a test transmitter, and the standard deviation of the error between estimated and true bearings used to produce 95% confidence limits for fixes on radio-tagged seals (Thompson & Miller, 1990).

Satellite telemetry

As part of the SEA programme, eleven Sea Mammal Research Unit (SMRU) satellite relay data loggers (SRDLs) were attached to harbour seals in the Moray Firth between 2004 and 2007 (Table 3.1). These SRDLs transmit data via the Argos system (McConnell *et al*., 1999). Service Argos allocates all positions to seven location classes, which describe the quality of those locations. Unfortunately, many marine animal tracking studies typically result in lower accuracy positions, and location errors may be several kilometers (Costa *et al*., 2010).

GPS GSM telemetry

GPS GSM tags combine a global positioning system (GPS) sensor with a mobile phone global system for mobile communications (GSM) modem to relay data ashore (McConnell *et al*., 2004). In 2009, GPS GSM tags were attached to five harbour seals in the Moray Firth as part of a study carried out for Marine Scotland (Cordes *et al*., 2011) (Table 3.1). These tags are able to produce much more frequent locations, providing a mean of 37 GPS positions per day compared to 10 Argos positions per day. They also have higher accuracy than Argos locations (Costa *et al*., 2010). The mean error of GPS positions within a stationary test was 40 m (Hazel, 2009). This is approximately four times greater than the best Argos location quality. Hazel (2009) reported no appreciable directional bias in GPS error, and no significant difference between the latitudinal and longitudinal components of the linear error. Nevertheless, occasional errors may arise, and a 10 km h^{-1} speed filter was therefore applied to the tracks (Costa *et al*., 2010).

3.2.2 State Space Modelling

The state-space modelling (SSM) approach was based on models developed for use with satellite telemetry data (Jonsen *et al*., 2007, Bailey *et al*., 2008). This provides a statistical framework for integrating error in the location estimates with a process model of the movement. For the satellite telemetry data used here, this model was applied to all of the raw Argos satellite positions to obtain daily position estimates (Jonsen *et al*., 2007, Bailey *et al*., 2008).

For the GPS GSM data, since the rare extreme values had been removed using the speed filter, the SSM error structure was modified from the t-distributions that had been used for each Argos location class (Jonsen *et al*., 2005) to a single normal distribution. The accuracy of GPS positions is higher when locations are derived from at least 6 satellites (mean = 32 m, SD = 36.9 m) (Hazel, 2009), which was the case for the majority of locations from the GPS GSM tagged seals. This estimate of error was therefore incorporated into the SSM.

For the VHF telemetry data, the SSM error structure was modified in a similar manner to that for the GPS data. A single normal error distribution was used and the parameters based on the error distribution of the 95% confidence limits for fixes. This resulted in a mean linear error of 1.66 km (SD = 0.93 km). However, the mean number of VHF positions per day was less than one at 0.74. This led to high uncertainty in the output SSM daily positions and therefore only those daily positions that had a corresponding VHF location were retained to ensure that there were no spurious SSM locations.

3.2.3 Habitat association modelling

The 95% credible limits for each SSM position were used to estimate the uncertainty in all positions (Figures 3.2 and 3.3). Characterisation of these uncertainties was important for determining the scale at which movement can be related to underlying habitat variables (Patterson *et al*., 2010). The uncertainty in the SSM positions derived from the GPS tracks was very small because of the high frequency and accuracy of the positions, and was below the resolution of the available environmental data. A suitable grid size for averaging the environmental data was therefore chosen based on the mean width of the 95% credible limits for the Argos and VHF derived SSM positions.

Based upon these criteria, a grid size of 4 x 4 km was applied to the environmental data and associated with the seal positions in the habitat analysis. Grid cells within 2 km of a haul-out site were removed to reduce bias towards locations were hauled out on land or resting in the water in inshore haul-out areas. (Thompson *et al*., 1998).

Two methods were used to model seal occurrence and habitat preference.

Presence-absence approach

The first method used a presence-absence approach within each of the 4 x 4 km grid cells. Any cell that contained at least one seal SSM position was coded as one (1) for seal presence. Based on the average travel speed and foraging trip duration (Thompson *et al*., 1998), all of the grid cells within the Moray Firth were considered available habitat. Cells containing no locations were therefore coded as 0 for seal absence.

A generalised additive model (GAM) was applied with a binomial error distribution and logit link function. The environmental variables considered to be likely explanatory variables of seal occurrence were water depth, seabed slope, distance to the nearest haul-out, and seabed sediment type. The first three of these were treated as continuous variables and the last as a categorical variable, where the most common sediment type (sand, marine sediment) was used as the reference level.

Visual inspection of distributions was used to determine whether transformations of the variables were necessary or supported the removal of any outliers. Variance inflation factors were used to test for collinearity between the explanatory environmental variables. These were all less than three, indicating there was no significant collinearity (Zuur *et al*., 2009).

The smoother terms for the continuous variables were derived using penalized regression splines with a shrinkage term so that, for large levels of smoothing, a smoother could have zero degrees of freedom and be effectively removed from the model (Wood, 2006). The model was applied using the R software package (R Development Core Team, 2008) and contributed package mgcv (Wood, 2006). The GAM output was visually checked for spatial correlation by plotting the residuals against the spatial coordinates. There were no obvious clusters of negative or positive residuals, and no clear clusters of large residuals indicating that spatial correlation was not significant (Zuur *et al*., 2009).

Case/control approach

The second method used a case/control approach where random control points were generated to represent habitat availability. This gave a measure of habitat preference, which was defined as the ratio of the use of a habitat over its availability (Aarts *et al*., 2008). Control points were generated using the equation for accessibility calculated by Matthiopoulos *et al*., (2004) as $d^{-1.98}$, where d is the distance from the haul-out in units of 5 km. Since grid cells of 4 km were used, this was modified accordingly to $(0.8*d)^{-1.98}$.

Twice the number of control points as seal locations were selected so that habitat availability would be sufficiently approximated (Aarts *et al*., 2008). Each seal and control location was associated with environmental data in the nearest 4 x 4 km grid cell, thus taking the uncertainty in the SSM seal positions into account. The same environmental variables were used in this method and the presence-absence GAM.

Initially, a generalized additive mixed model (GAMM) was applied with a binomial error distribution and logit link function. A random effect term was included to account for the correlation within individual tracks. However, the model would not converge, even after increasing the number of iterations and raising the number of control points up to five times the number of seal locations.

A generalized linear mixed model (GLMM) had similar issues and a generalized estimating equation (GEE) model was therefore applied instead. This approach has the advantage that GEEs are less analytically complex and model convergence is more likely. The correlation among pairs of seal locations is also likely to differ from the correlation among available control points (Fieberg *et al*., 2010).

GEEs have the advantage that their parameter estimates and empirical standard errors are robust to misspecification of the correlation structure (Hardin & Hilbe, 2003), and also provide a population averaged inference rather than subject specific (Fieberg *et al*., 2009). A GEE model was therefore applied with five times the number of control points as seal positions to ensure accurate representation of available habitat (Koper & Manseau 2009) and an independence working correlation to avoid biased regression parameter estimators (see Craiu *et al*. 2008).

This GEE model provided an estimate of foraging habitat preference. The model was performed using the contributed R package geepack version 1.0-17 (Yan & Fine, 2004).

Summer only data

Since seal preferences can vary between season and sex, both the GAM and GEE were repeated using only data collected during the summer breeding period (April to July).

Recent reports of "corkscrew deaths" indicate that fatalities are biased towards adult females, and often seem to occur when animals are in late pregnancy or during the pupping/mating season. To assess the area over which females may be ranging at this time of year, additional analysis (GAMs) restricted to adult females during the period 1st May to 31st August was performed.

3.2.4 Harbour Seal Abundance on land and at sea

Estimates of the size of the Moray Firth harbour seal population were taken from Thompson *et al.,* (1997). This population estimate was based upon breeding season counts at haul-out sites which were then scaled to total population size using independently collected data on the proportion of animals that were likely to be in the water at the time of these counts.

Data on trends in abundance at haul-out sites across the Moray Firth were based on recent analysis of the time series of annual surveys conducted in the Dornoch Firth and Loch Fleet (Cordes *et al*., 2011).

To estimate absolute numbers of harbour seals using different parts of the Moray Firth, we combined these data with the output from the presence-absence GAM. Predictions from the presence-absence GAM resulted in a probability of seal occurrence in each of the 4 x 4 km cells across the Moray Firth. The total number of seals in the population was then dispersed across this density surface in relation to the predicted importance of this cell, thereby providing an estimate of the number of seals likely to occur in each cell at any one moment in time.

Currently, uncertainty is not formally incorporate into this estimate. Instead, the estimate is conservative in two ways. First, the average population estimate of 1653 from 1993 (from Thompson *et al*. (1997) is used, when the population was at a peak compared with current numbers (see results). Second, it was assumed that all seals might be foraging at sea at the same time. However, a sub-set of the population will be hauled out on every low tide throughout the year, and many animals typically remain around haul-out sites for several days between offshore foraging trips. As a result it is likely that the number of seals at sea is typically only 60-90% of the total population depending both upon season and the age and status of individual seals (Thompson *et al*., 1998).

3.3 Results

3.3.1 SSM locations

The SSM most probable daily locations derived from the seal telemetry data showed a high degree of overlap between the three tag types (Figure 3.2), indicating consistency in habitat use between tagging methods and over the 20 year period. The majority of locations occurred near the haul-out sites where the seals were tagged in the Dornoch Firth and Loch Fleet. There was also a high number around and to the north of Tarbet Ness (Figure 3.3), which has previously been identified as foraging habitat (Thompson *et al*., 1996, Tollit *et al*., 1998). The greatest dispersion was shown in the Argos satellite positions which extended into the NE part of the Moray Firth.

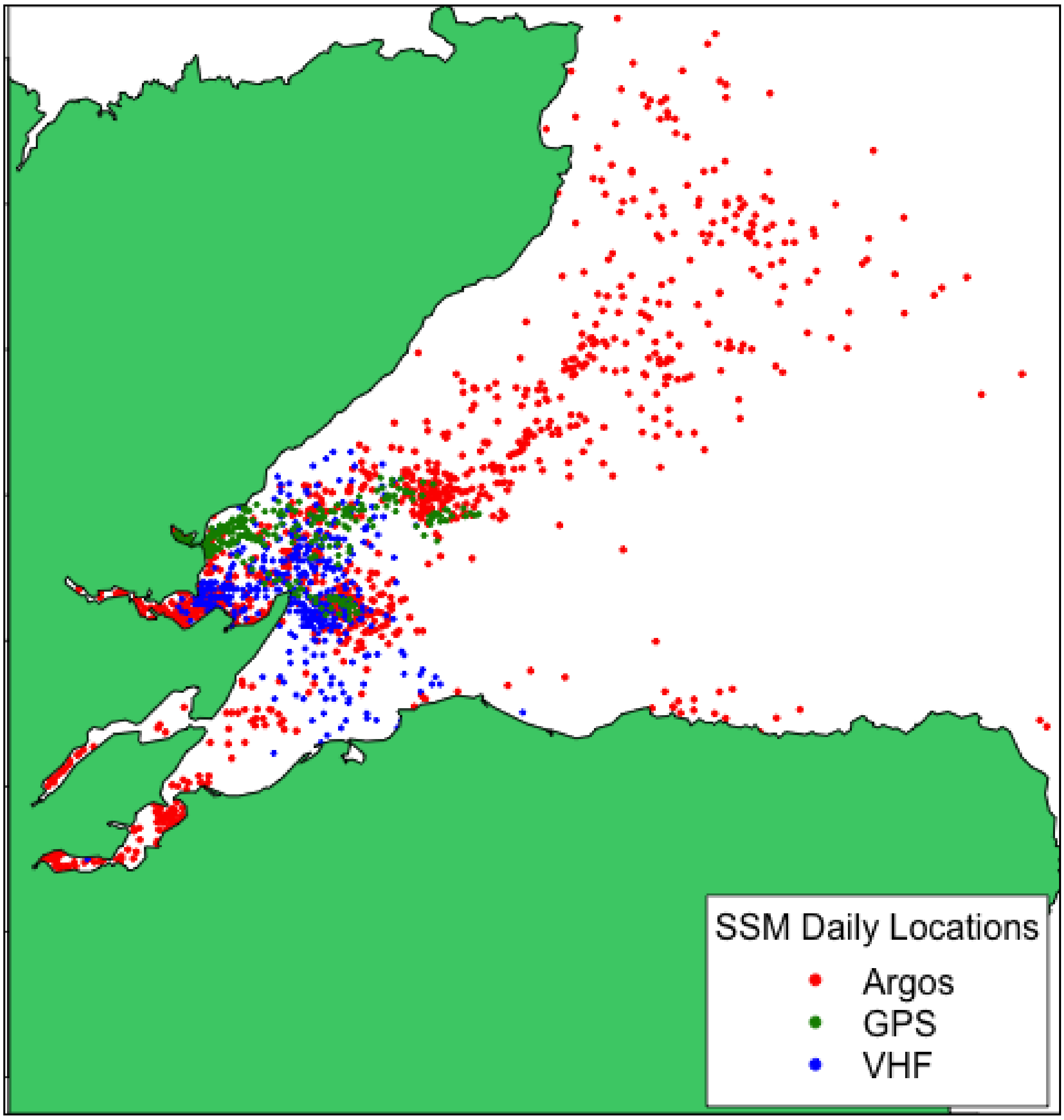

Figure 3.2: a) Daily seal SSM locations derived from Argos satellite (red), GPS GSM (green), and VHF (blue) positions (circles).

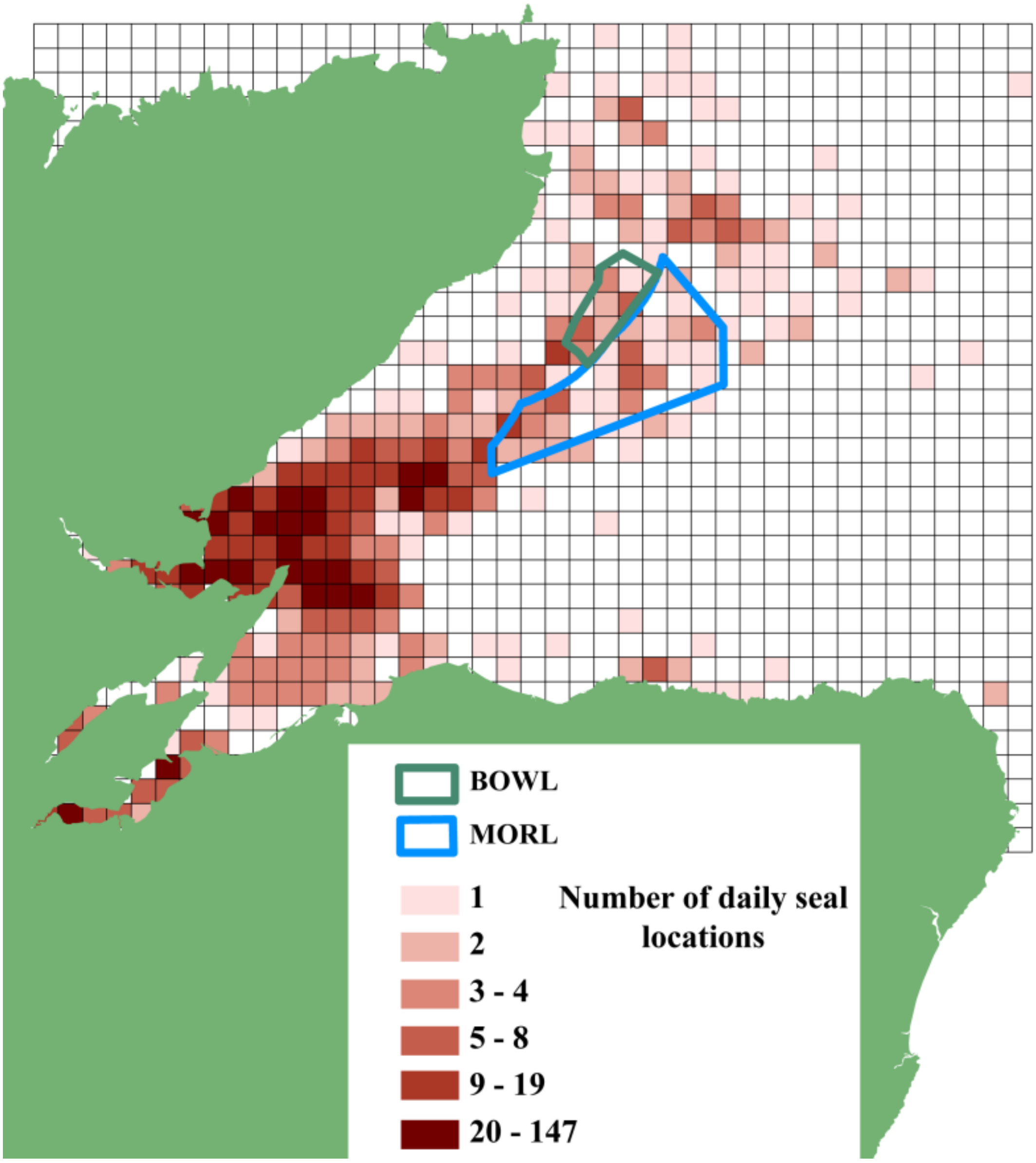

Figure 3.3: Number of daily SSM harbour seal locations within 4 x 4 km grid cells (colour coding based on the quantile distribution) with the proposed BOWL and MORL wind farm sites overlaid.

3.3.2 Presence-absence GAM

The results of the presence-absence GAM showed that depth, slope and distance to nearest haul-out were significantly related to the probability of harbour seal presence, but sediment type was not (Table 3.2). The probability of seal occurrence was highest at intermediate depths (approximately 15-50 m) and decreased with increasing seabed slope (Figure 3.4). The probability of seal presence was highest within 30 km of the nearest haul-out and declined rapidly beyond 100 km distance. Predicted probabilities of seal presence and densities were in the inner Moray Firth, near the coast and in the north-eastern part of the Moray Firth, including the MORL and BOWL sites

(Figure 3.5).

Table 3.2: Results of GAM for probability of seal presence in relation to square root of water depth, square root of seabed slope, distance to nearest haul-out and seabed sediment type (reference level: sand, marine sediment).

<table>
<tr><th>Smoother term:</th><th>edf</th><th>Chi-square</th><th>P value</th><th>Overall deviance explained</th></tr>
<tr><td>Depth</td><td>4.30</td><td>61.06</td><td>< 0.001*</td><td rowspan="8">35.2%</td></tr>
<tr><td>Slope</td><td>1.51</td><td>24.83</td><td>< 0.001*</td></tr>
<tr><td>Distance to nearest haul-out</td><td>6.47</td><td>16.48</td><td>0.021*</td></tr>
<tr><td>Parametric coefficients:</td><td>Estimate</td><td>Z value</td><td>P value</td></tr>
<tr><td>Intercept</td><td>-1.64</td><td>-6.24</td><td>< 0.001*</td></tr>
<tr><td>Sediment – Sand, marine, gravelly</td><td>0.55</td><td>1.96</td><td>0.051</td></tr>
<tr><td>Rock or gravel</td><td>-0.50</td><td>-1.41</td><td>0.160</td></tr>
<tr><td>Sand, marine, muddy or mud, marine, sandy</td><td>0.16</td><td>0.39</td><td>0.693</td></tr>
<tr><td colspan="5">Edf = estimated degrees of freedom. * denotes statistical significance at 5% level.</td></tr>
</table>

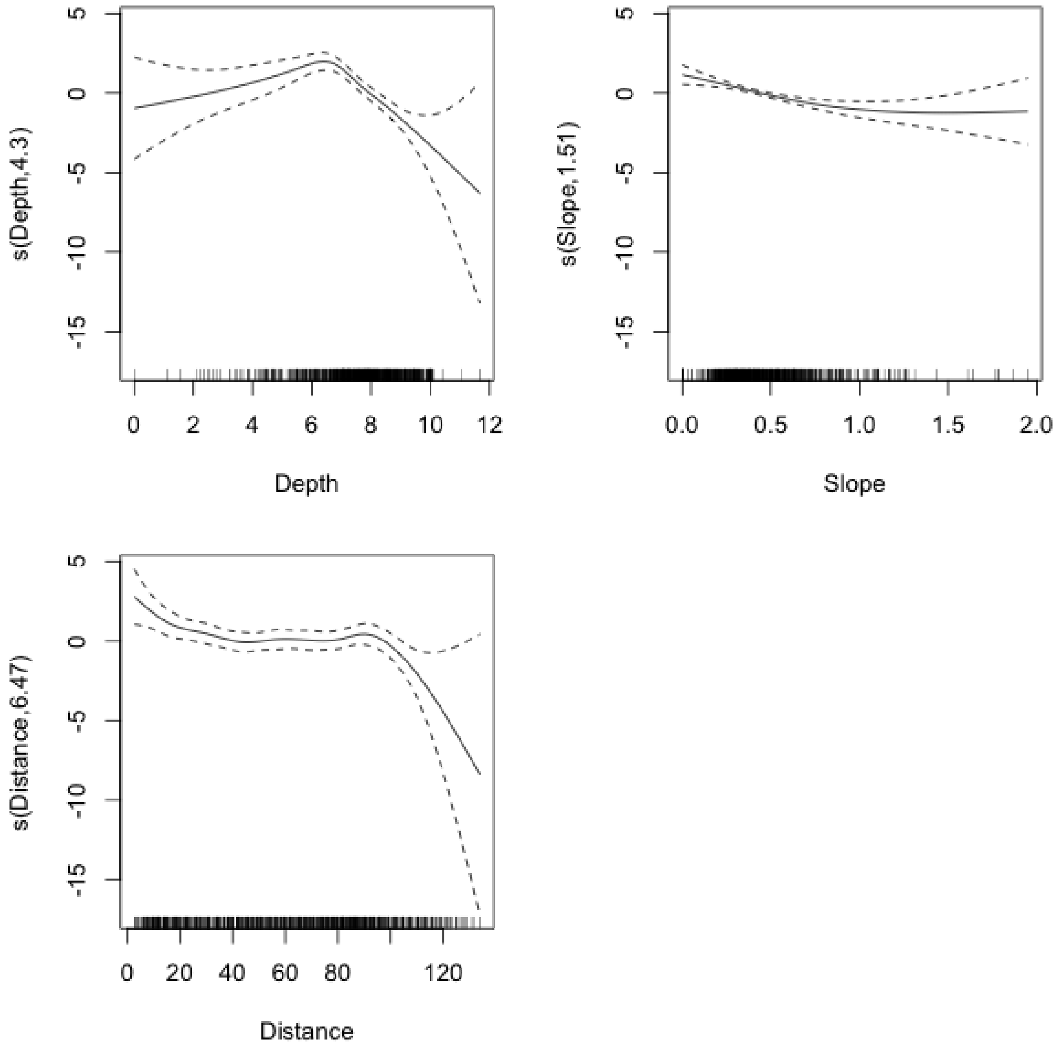

Figure 3.4: GAM smoothing curves for square root of water depth (m), square root of seabed slope (degrees), and distance to nearest haul-out (km) in relation to probability of seal presence.

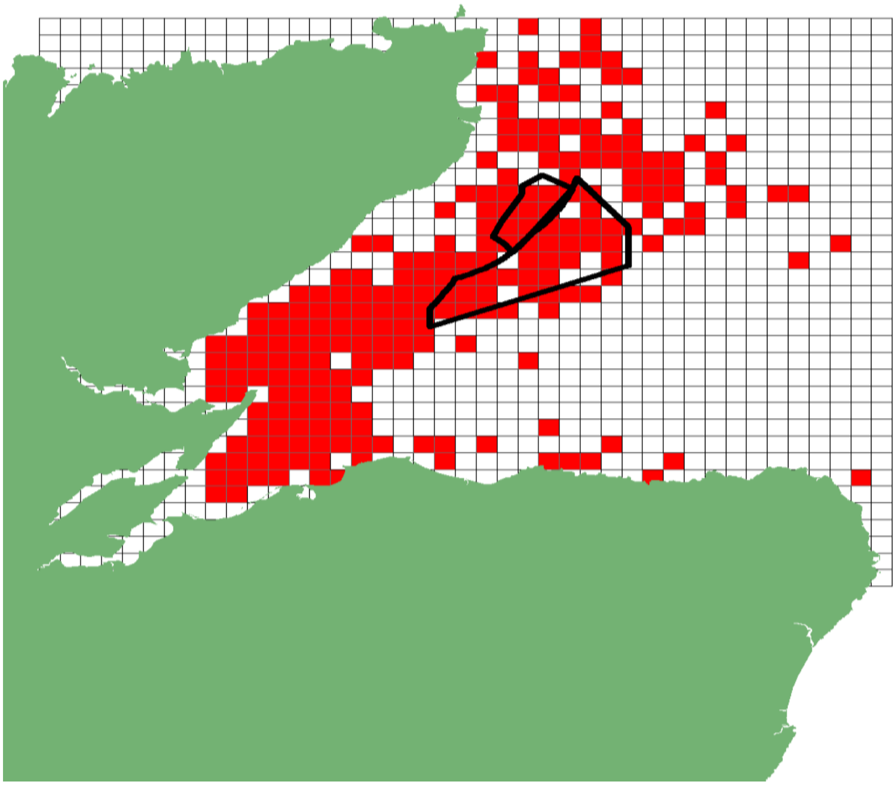

Figure 3.5a: Seal presence from SSM daily positions in 4 x 4 km grid (shown in red).

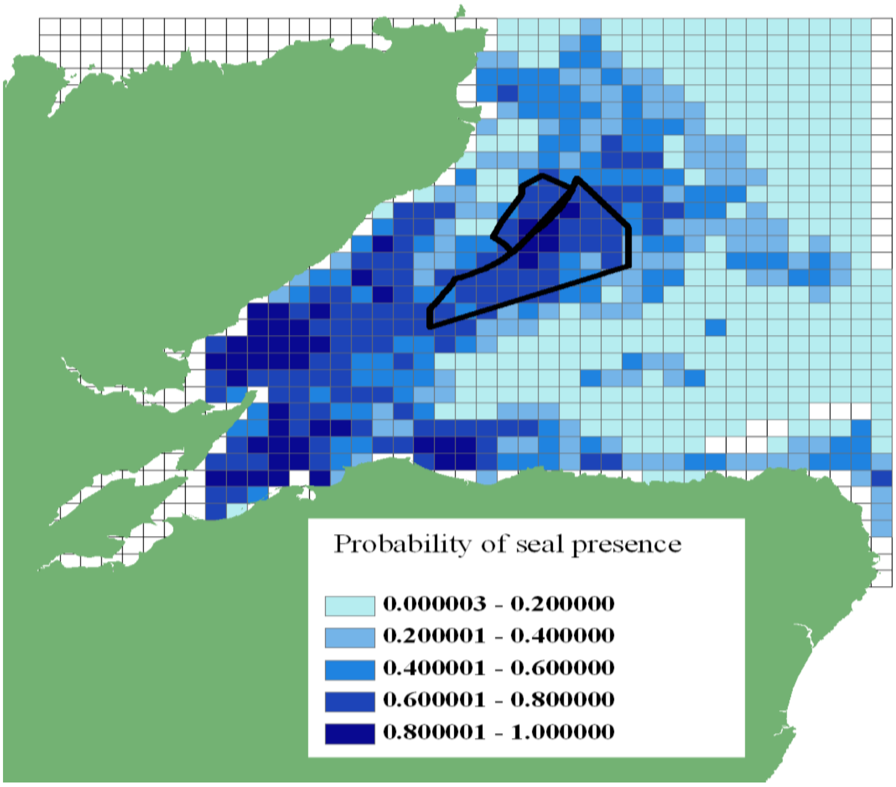

Figure 3.5b: GAM predicted probabilities of seal presence (white cells indicate no data), The BOWL site and MORL R3 zone are overlaid as solid black lines.

3.3.3 Summer only presence/absence GAM

Depth and slope were significantly related to the probability of harbour seal presence, but distance to nearest haul-out site and sediment type were not (Table 3.3). The probability of seal occurrence was highest at intermediate depths (approximately 15-50 m) and decreased with increasing seabed slope (Figure 3.6). The probability of seal presence was highest within 30 km of the nearest haul-out and then remained relatively constant beyond this except for a slight drop at distances greater than 100 km. The predicted probabilities of seal presence and densities were lower in the NE part of the Moray Firth during the summer breeding period (Figure 3.7).

Table 3.3: Results of GAM for summer (April to July) seal presence in relation to square root of water depth, square root of seabed slope, distance to nearest haul-out and seabed sediment type (reference level: sand, marine sediment).

Smoother term:	edf	Chi-square	P value	Overall deviance explained
Depth	4.37	39.86	< 0.001*	37.7%
Slope	2.53	23.01	< 0.001*	
Distance to nearest haul-out	4.68	10.65	0.065	
Parametric coefficients:	**Estimate**	**Z value**	**P value**	
Intercept	-2.82	-7.41	< 0.001*	
Sediment – Sand, marine, gravelly	0.02	-0.06	0.956	
Rock or gravel	-0.79	-1.72	0.086	
Sand, marine, muddy or mud, marine, sandy	-0.15	-0.35	0.729	

edf, estimated degrees of freedom. * denotes statistical significance at 5% level

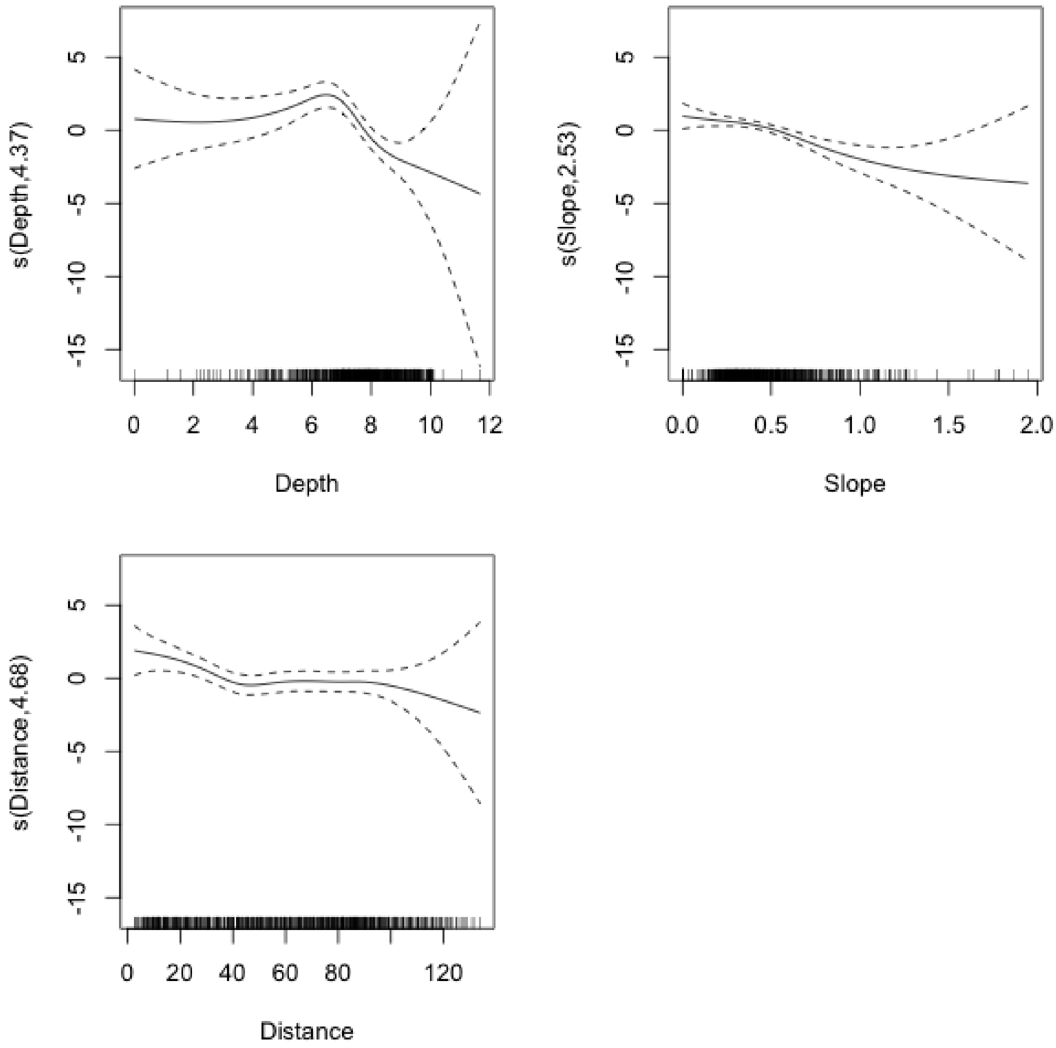

Figure 3.6: GAM smoothing curves for square root of water depth (m), square root of seabed slope (degrees), and distance to nearest haul-out (km) in relation to probability of seal presence during the summer breeding period (April to July).

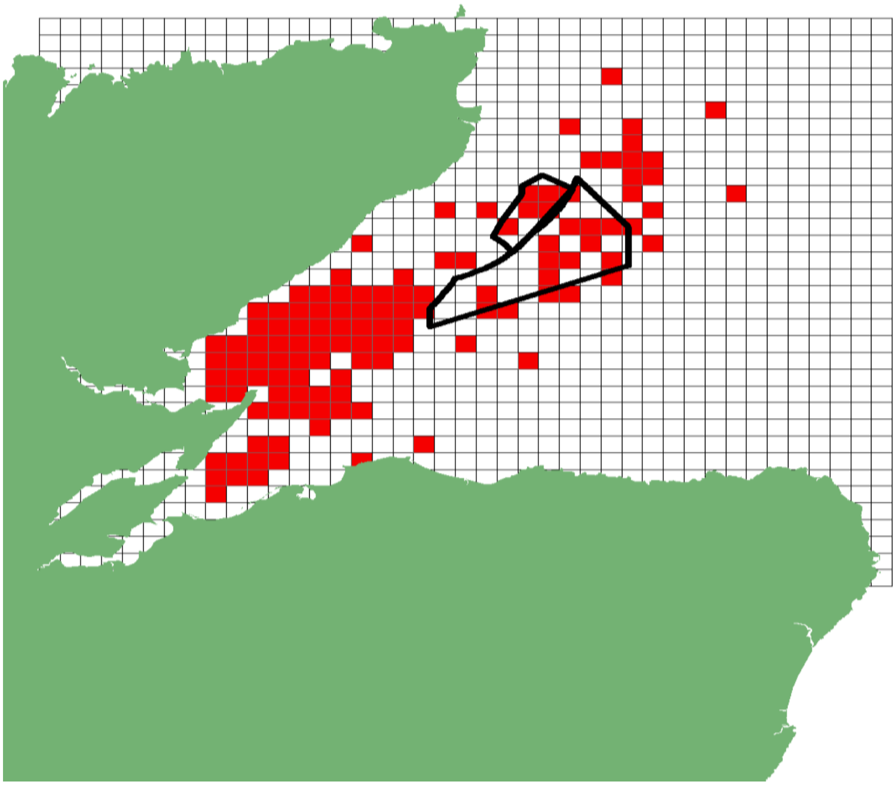

Figure 3.7a: Seal presence from SSM daily positions during summer (April to July) in 4 x 4 km grid (shown in red).

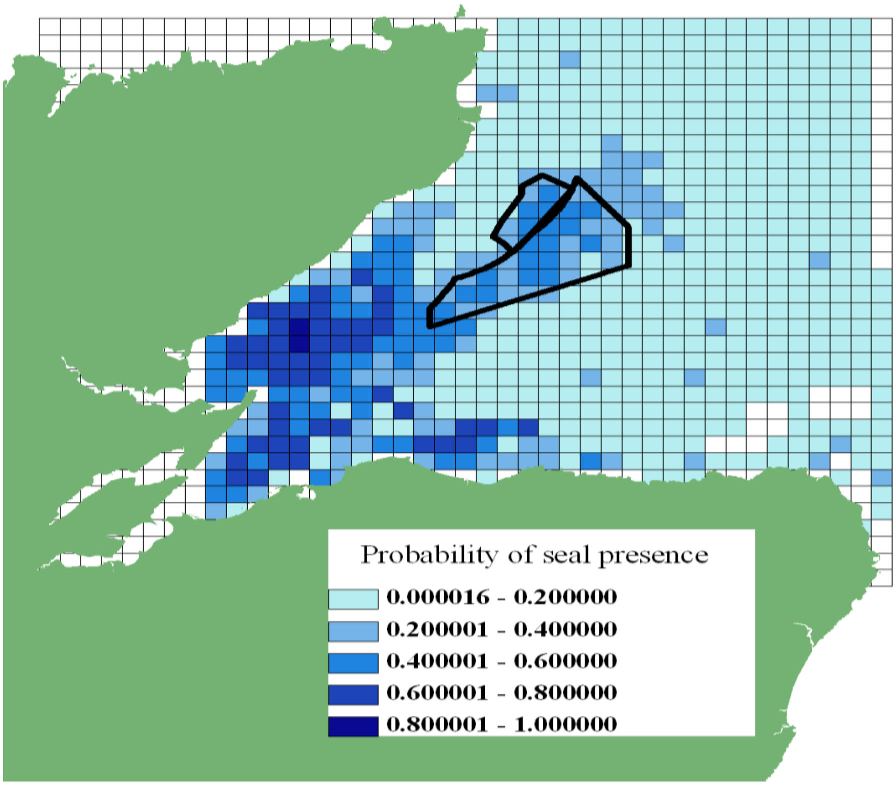

Figure 3.7b: GAM predicted probabilities of seal presence (white cells indicate no data). BOWL site and MORL R3 zone are overlaid as black lines.

3.3.4 Female Breeding season distribution presence/absence GAM

Depth, slope, sediment type and distance to nearest haul-out were all significantly related to the probability of female harbour seal presence during May to August (Table 3.4). The probability of female seal occurrence was highest at intermediate depths (approximately 15-50 m) and decreased with increasing seabed slope (Figure 3.8). The probability of summer female seal presence was highest within 20 km of the nearest haul-out and then remained relatively constant beyond this with a very slight increase. The probability was also significantly lower over rock or gravel than sand, marine sediment. Predicted probabilities of female seal presence during this period were highest in the inner Moray Firth, near the coast and in the vicinity of the MORL and BOWL sites (Figure 3.9).

Table 3.4: Results of GAM for female summer (1st May to 31st August) seal presence in relation to square root of water depth, square root of seabed slope, distance to nearest haul-out and seabed sediment type (reference level: sand, marine sediment).

Smoother term:	edf	Chi-square	P value	Overall deviance explained
Depth	3.85	16.85	0.003*	41.2%
Slope	2.23	8.35	0.031*	
Distance to nearest haul-out	3.16	10.36	0.027*	
Parametric coefficients:	**Estimate**	**Z value**	**P value**	
Intercept	-3.98	-5.48	< 0.001*	
Sediment – Sand, marine, gravelly	-0.08	-0.17	0.867	
Rock or gravel	-1.65	-2.41	0.016*	
Sand, marine, muddy or mud, marine, sandy	0.02	0.05	0.964	

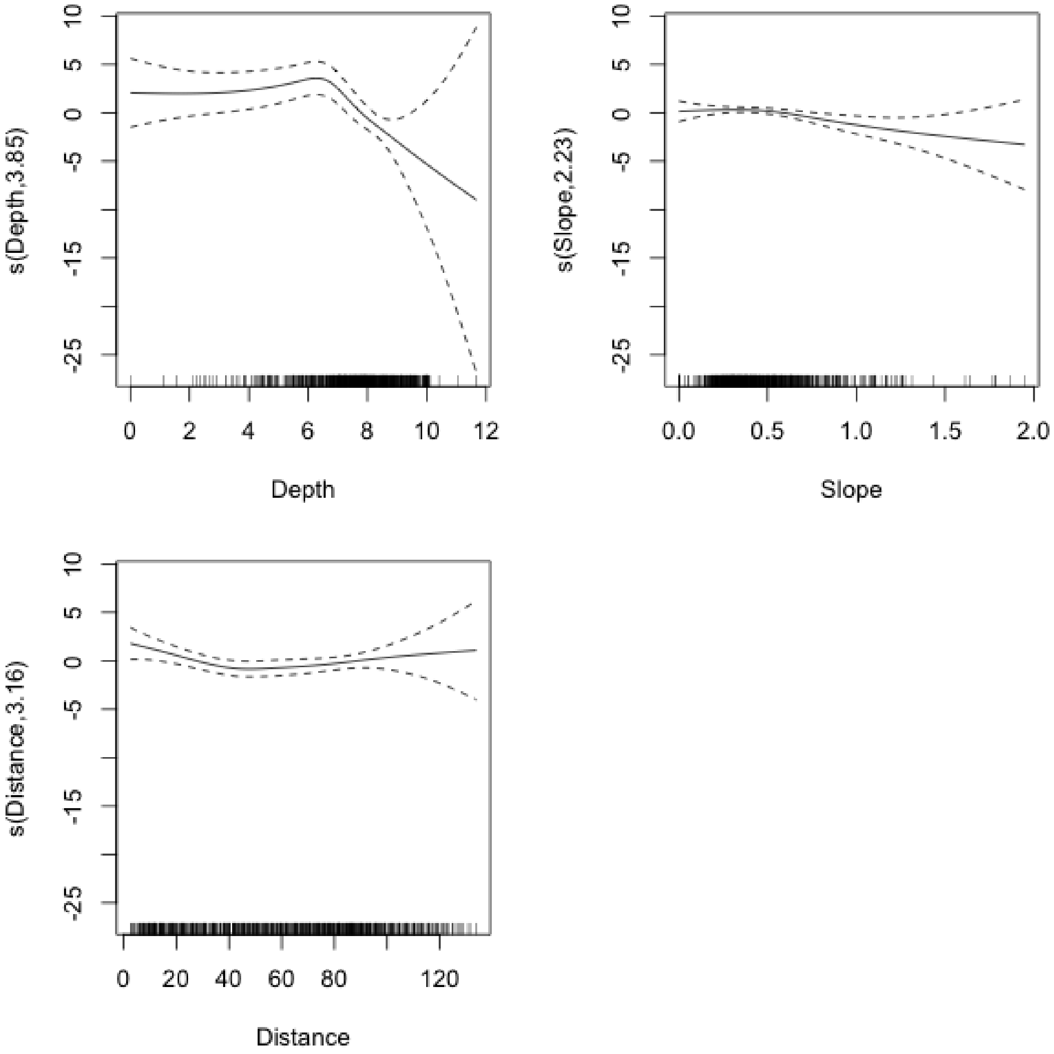

Figure 3.8: GAM smoothing curves for square root of water depth (m), square root of seabed slope (degrees), and distance to nearest haul-out (km) in relation to probability of female seal presence during the summer breeding period (May to August).

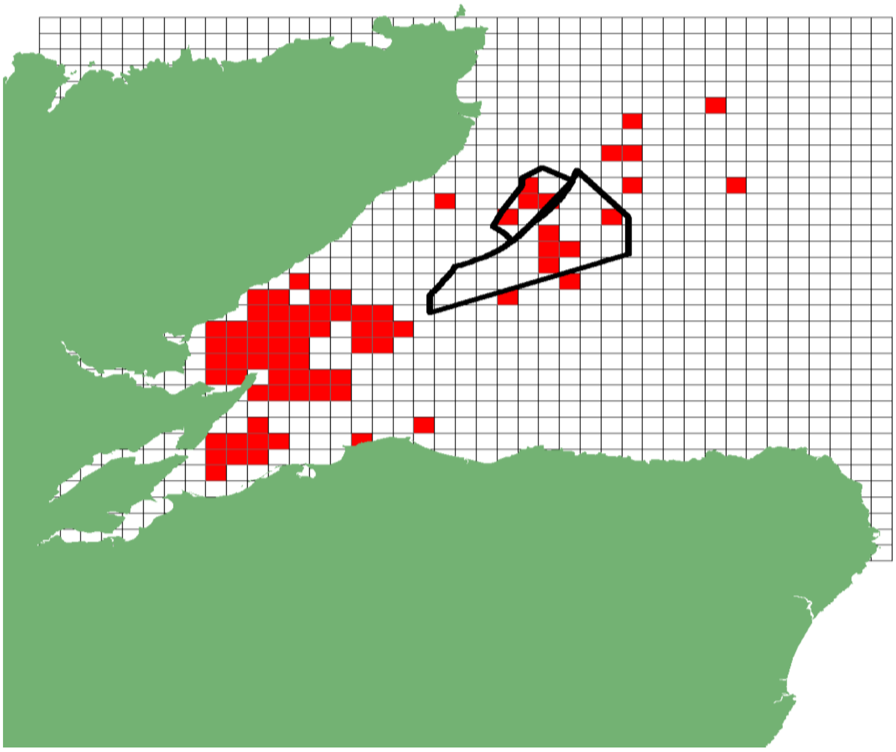

Figure 3.9a: Presence of female seals from SSM daily positions during summer (May to August) in 4 x 4 km grid cells (shown in red).

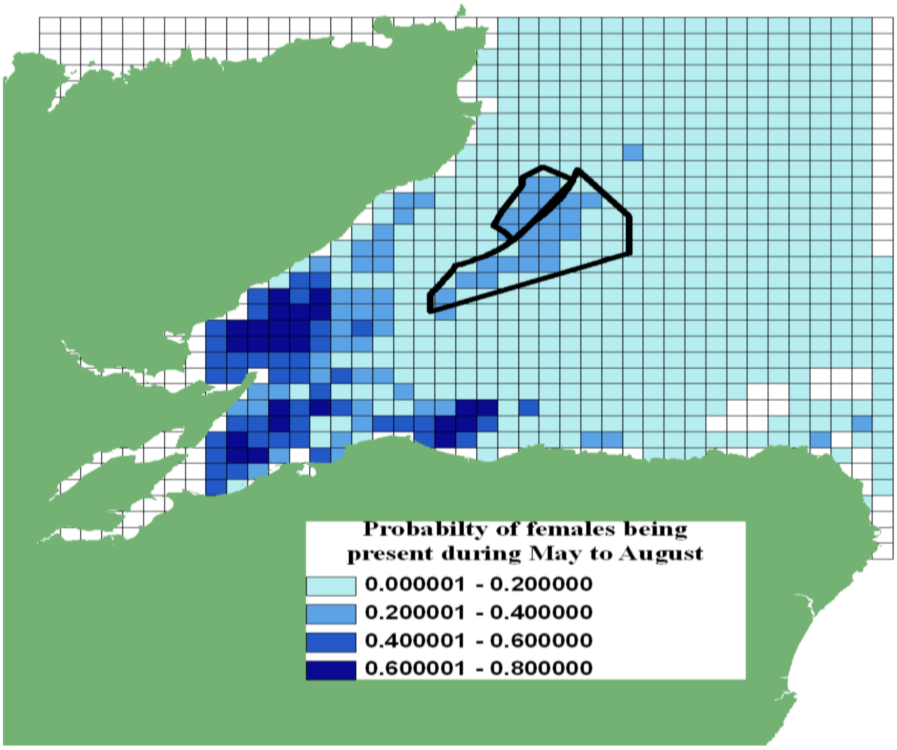

Figure 3.9b: GAM predicted probabilities of summer female seal presence (white cells indicate no data). The BOWL site and MORL R3 zone are overlaid as solid black lines.

3.3.5 Case/control GEE model

The results of the case/control GEE model indicated that seal foraging habitat preference is significantly related to sediment type, depth, slope and distance to nearest haul-out (Table 3.5). Seals significantly preferred sand, marine, muddy sediment over sand, marine sediment and had lower preference for gravel, sandy, marine and gravel marine sediment than sand, marine sediment. Seals preferred mid-water depths, shallow slopes and farther distances from the haul-outs (compared to the distribution of control points). Foraging habitat preference was highest in the north-eastern part of the Moray Firth and also in small areas of the south-eastern part (Figure 3.10).

Table 3.5: Results of GEE for seal habitat preference in relation to square root of water depth, square root of seabed slope, logarithm (to the base 10) of distance to nearest haul-out and seabed sediment type (reference level: sand, marine sediment). * denotes statistical significance at 5% level

Term:	Estimate	Standard Error	Wald Statistic	P-value
Intercept	-9.43	1.41	44.54	< 0.001*
Depth	2.04	0.46	19.22	< 0.001*
Depth^2	-0.21	0.04	29.77	< 0.001*
Slope	-1.43	0.33	18.80	< 0.001*
Distance to nearest haul-out	3.86	0.54	51.27	< 0.001*
Sediment – Sand, marine, gravelly	-0.36	0.23	2.38	0.123
Gravel, sandy marine	-1.31	0.45	8.47	0.004*
Gravel, marine	-0.96	0.31	9.39	0.002*
Sand, marine, muddy	0.56	0.25	5.19	0.023*
Mud, marine, sandy	-0.08	0.72	0.01	0.908

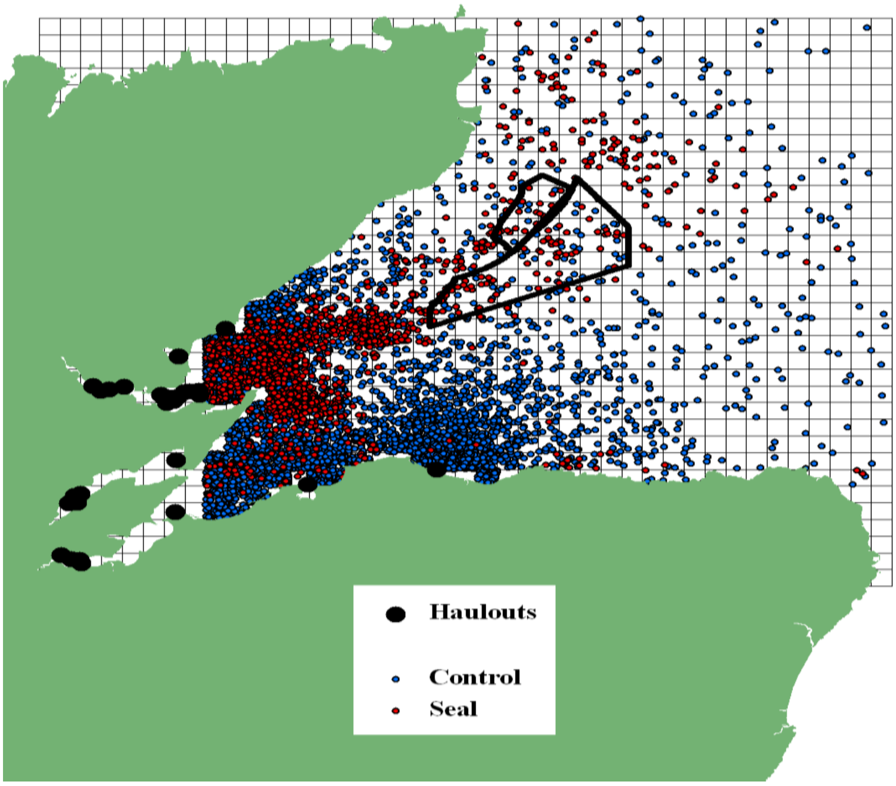

Figure 3.10a: Map of seal SSM daily positions and control points.

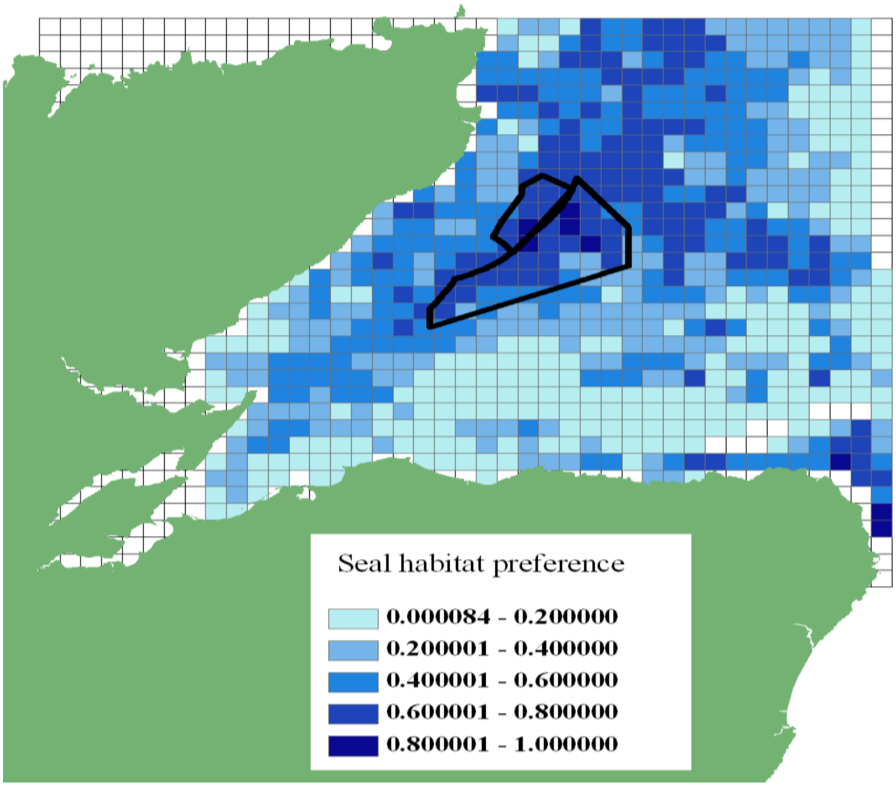

Figure 3.10b: GEE predicted values of seal habitat preference (white cells indicate no data). The BOWL site and MORL R3 zone are overlaid as black lines.

3.3.6 Summer only case/control GEE model

The results of the case/control GEE model for the summer breeding period (April to July) indicated that seal foraging habitat preference is significantly related to sediment type, depth, slope and distance to nearest haul-out (Table 3.6). Seals significantly preferred sand, marine sediment over gravel, sandy, marine, gravel marine sediment and mud, marine, sandy sediment. This difference in sediment type preference may reflect a change in prey preferences during the summer period. Seals preferred mid-water depths and shallow slopes. They also preferred farther distances from the haul-outs (compared to the distribution of control points), although not as great (Figure 3.11).

Table 3.6: Results of GEE for seal habitat preference in relation to square root of water depth, square root of seabed slope, logarithm (to the base 10) of distance to nearest haul-out and seabed sediment type (reference level: sand, marine sediment).

Term:	Estimate	Standard Error	Wald Statistic	P-value
Intercept	-9.79	2.49	15.48	< 0.001*
Depth	2.46	0.80	9.46	0.002*
Depth^2	-0.25	0.07	13.66	< 0.001*
Slope	-1.45	0.51	8.16	0.004*
Distance to nearest haul-out	3.28	0.74	19.91	< 0.001*
Sediment – Sand, marine, gravelly	-0.76	0.42	3.26	0.071
Gravel, sandy marine	-2.04	0.49	17.36	< 0.001*
Gravel, marine	-1.91	0.48	15.85	< 0.001*
Sand, marine, muddy	0.57	0.31	3.36	0.067
Mud, marine, sandy	-39.26	2.79	198.35	< 0.001*
* denotes statistical significance at 5% level				

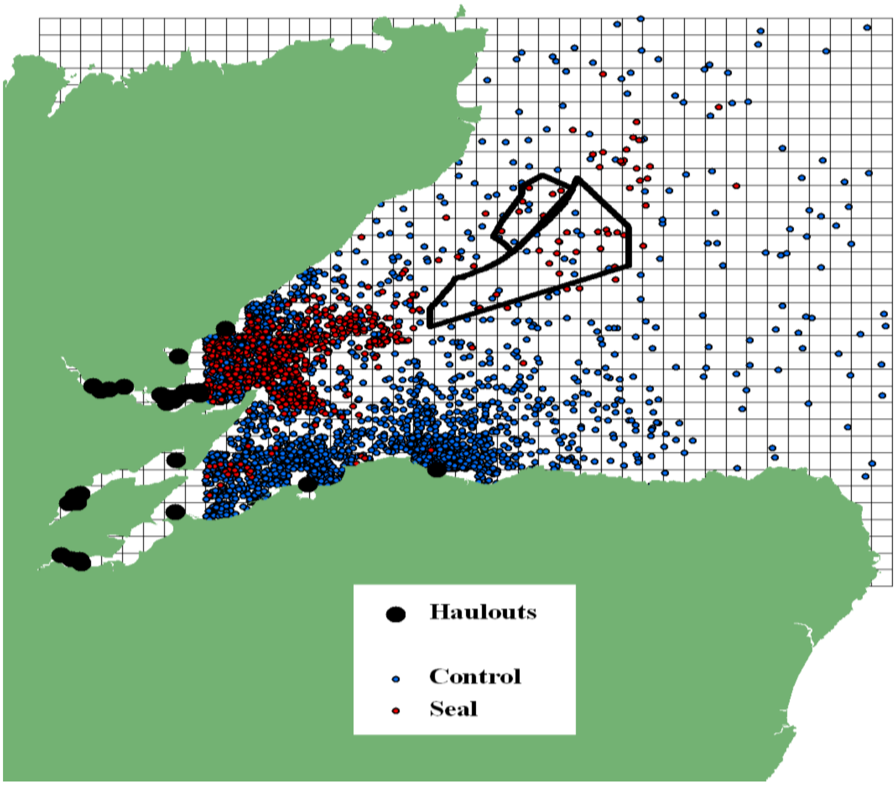

Figure 3.11a: Map of seal SSM summer (April to July) daily positions and control points.

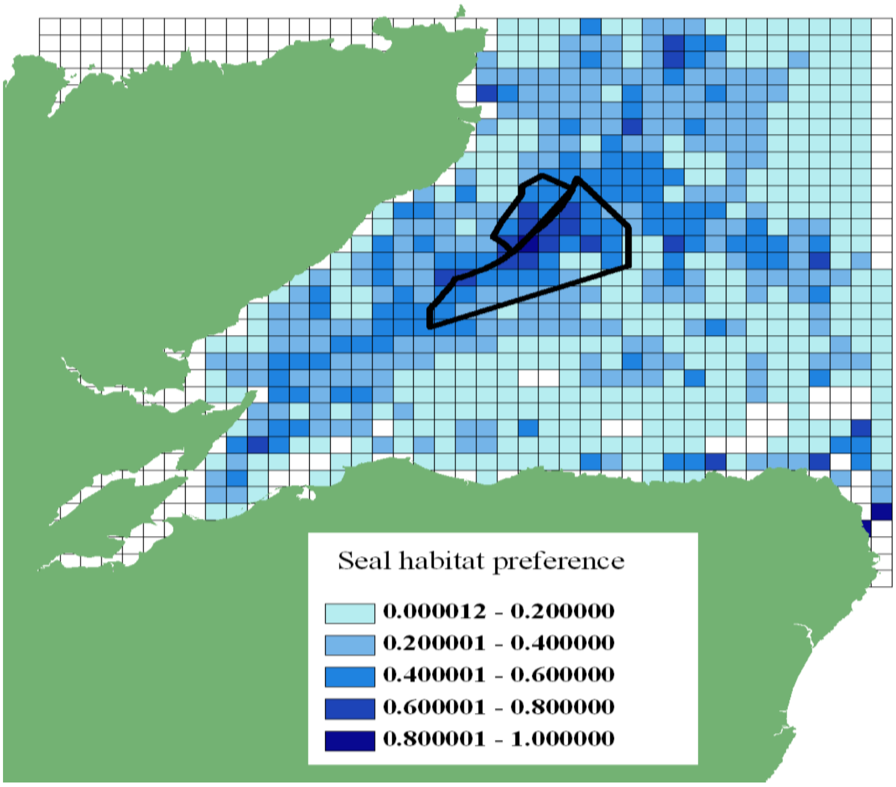

Figure 3.11b: GEE predicted values of seal habitat preference (white cells indicate no data). The BOWL site and MORL R3 zone are overlaid as solid black lines.

3.3.7 Trends in abundance at haul-out sites

Counts made during the breeding season indicate that there has been a steady decline in the number of seals occupying the Dornoch Firth SAC since the mid-1990s (Figure 3.12). Over this same period, numbers in Loch Fleet have gradually increased, and the area has also become established as an important breeding site used by over 70 individually recognisable adult females (Thompson & Wheeler, 2008; Cordes *et al*., 2011; Cordes, Unpublished Data).

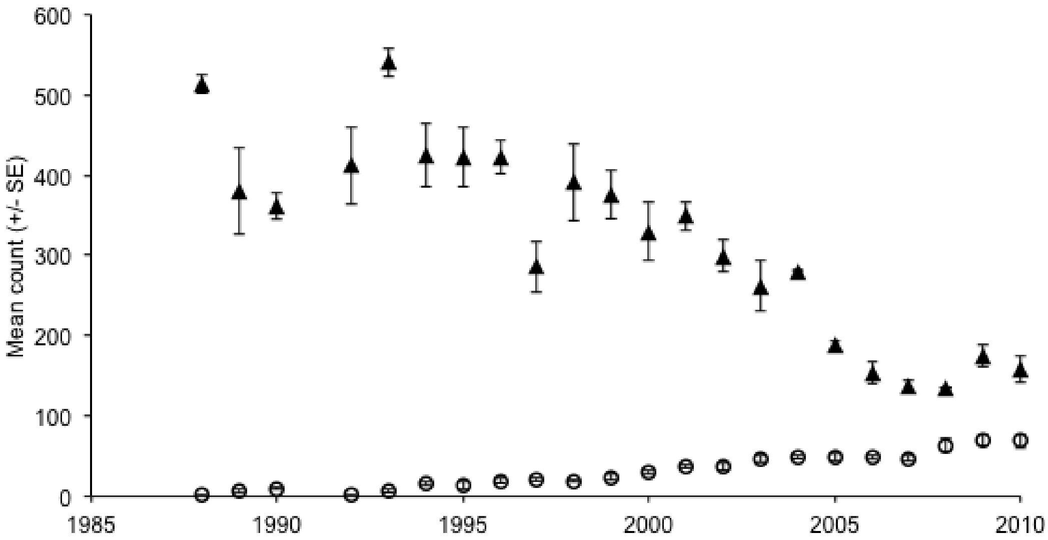

Figure 3.12: Trends in the mean pupping season count of harbour seals (not including pups) at haul-out sites within the Dornoch Firth (closed triangles) and Loch Fleet (open circles). (Adapted from Cordes *et al.*, 2011, with additional unpublished data from SMRU and University of Aberdeen).

3.3.8 Abundance of seals at sea

Based upon the highest levels of abundance seen over the last two decades, the results of the presence-absence GAM indicate that seals from the Moray Firth population may be dispersed widely across the Moray Firth, particularly over offshore sandbanks (Figure 3.13). These data suggest that there is variability in the importance of different parts of the BOWL and MORL development areas, but that some grid squares in this region might be expected to hold up to eight seals, representing a density approaching 0.5 individuals per km^2.

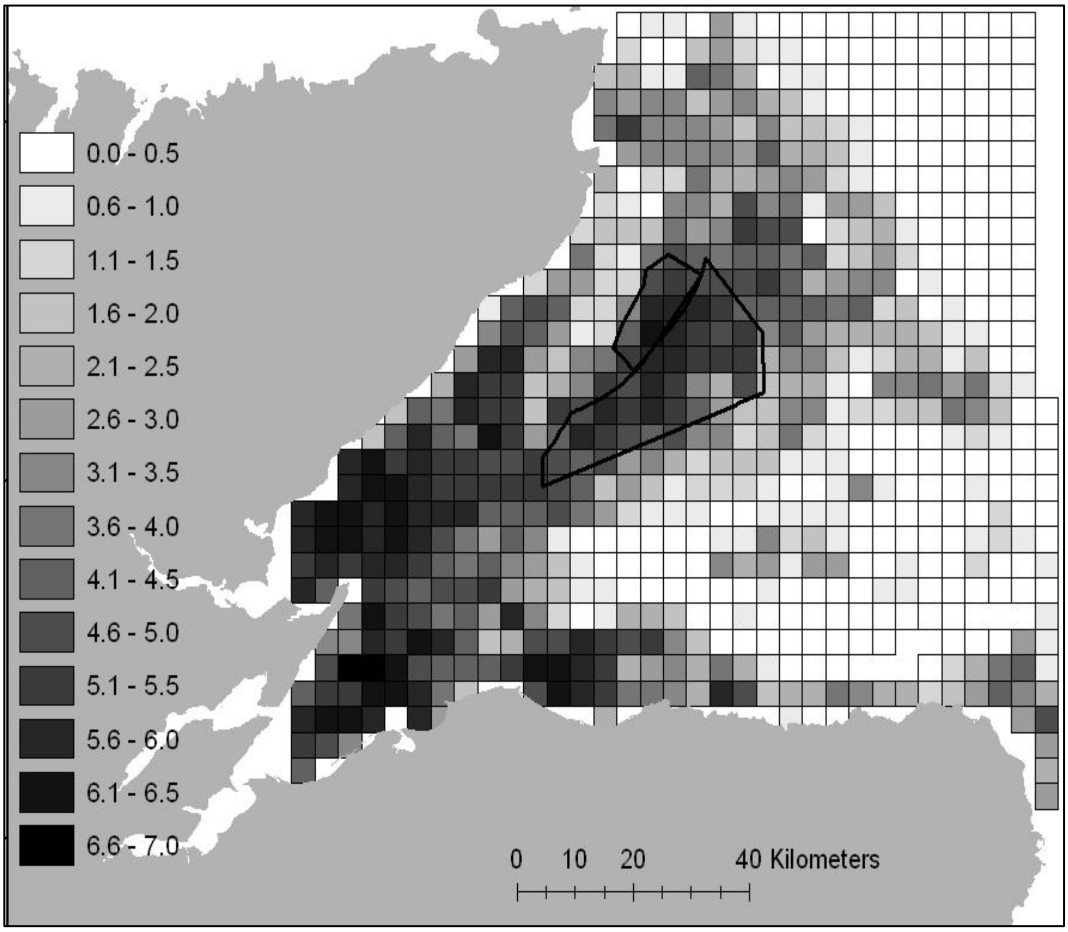

Figure 3.13: Predicted numbers of harbour seals from Moray Firth haul-out sites in different 4 x 4 km grid cells across the Moray Firth.

3.4 Acknowledgements

We would like to think all the funding bodies who supported the collection of data used in this study, and the colleagues who carried out the original capture, tagging and tracking of the seals. A particular thanks to Phillip Hammond, Ruth Sharples, Callan Duck and Line Cordes for access to data and for useful discussion about the work.

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4. Grey seal telemetry and usage maps

4.1 Background

Telemetry allows measurements made remotely (e.g. at sea) to be transmitted and received at a convenient location (e.g. in the lab). Data are typically transferred using satellite systems but more modern systems take advantage of the low cost and ubiquity of GSM networks.

In the UK, the Sea Mammal Research Unit (SMRU) has been deploying telemetry tags on seals since the 1980s. These tags are typically programmed to transmit data about the seal e.g. locations, movements, dive durations and depths but animals equipped with tags have also been used as 'platforms' to collect oceanographic data (temperature, salinity, depth etc.) from inaccessible locations e.g. the Southern Ocean around Antarctica. The duration of each deployment varies depending on the time of year the tag was attached to the animal – depending on the attachment type, tags generally fall off when the animal moults.

For the purpose of this analysis, telemetry data collected by SMRU over the last 20+ years were examined in order to establish the extent of grey seal movement relative to their breeding and haul out sites. Data from any seal which entered a 100 km buffer around the proposed Moray Firth wind farm sites were included regardless of where they were tagged.

Telemetry data were then combined with aerial survey (count) data to produce maps of estimated total, at-sea, and hauled-out density.

4.2 Methods

4.2.1 Grey Seal Tracks

Data from any animal which entered a 100 km buffer zone around the proposed Moray Firth wind farm sites at some point while it was tagged were included regardless of where the animal was tagged. Tags were predominantly satellite relay data loggers (SRDLs) although some GSM 'phone' tags were used in later years.

Grey seal pups are thought to disperse more widely from their natal sites (SMRU, unpublished data) than adults so data were divided into pups and those oldler than one year. Movements made by pups were also examined separately from older animals in order to get an idea of the likely movements made by those animals born along the Helmsdale coast, the closest breeding colony to the proposed wind farm sites.

All locations used were cleaned according to SMRU protocol (Russell *et al.*, 2011). Where appropriate, telemetry locations were then corrected for positional error using a linear Gaussian state space Kalman filter (Royer & Lutcavage, 2008; Jones *et al.*, 2011).

All data filtering and analyses were carried out using the statistical software R (R Development Core Team, 2008). A number of packages were use within R and are listed in Section 4.5. The maps were generated using Manifold. All figures are in the projection Universal Transverse Mercator (UTM) – zone 30 north.

4.2.2 Grey Seal Usage maps

Available data

- *Aerial survey data*

Aerial surveys are conducted each year by the Sea Mammal Research Unit (SMRU) and are funded by Scottish National Heritage (SNH) and the National Environmental Research Council (NERC). They take place throughout August with both grey and harbour seals counted. During August, harbour seals are moulting and are in aggregated groups while grey seals are dispersed at haul-outs along the coast. Over a number of consecutive years the entire Scottish coastline is surveyed and counts are marked using OS Landranger maps (1:50,000) to an accuracy of 50 m. Data from 1996-2009 surveys were used in this analysis.

- *Telemetry data*

Telemetry data from individual grey seals have been collected by SMRU since 1988. These comprise two sources: satellite relay data logger (SRDL) tags developed by SMRU use the Argos satellite system and were deployed between 1988 and 2010. GPS phone tags that use the GSM mobile phone network with a hybrid Fastloc protocol (McConnell *et al*., 2004) have been deployed since 2007.

Telemetry data were selected from the SMRU database by species and processed through a set of data cleansing protocols to remove null and missing values, duplicated records and ineligible data. Tracks were then selected based on the criteria that if any part of a track passed within a 100 km buffer zone of the proposed MORL/BOWL development sites, regardless of where tagging had taken place, that track was included.

Data manipulation

To provide continuity within the EIA, the same 4 km^2 grid was used in the analysis as was used in Section 2. However, the spatial range was extended to incorporate all of a telemetry track if one or more locations in that track were located within 100 km of the boundaries of the proposed offshore wind farm developments.

The statistical package R (R Development Core Team, 2011) was used for analysis and GIS software Manifold version 8.0 was used to produce the maps. Both maps are in Universal projection Transverse Mercator zone 30^0 North (UTM30N), datum World Geodetic System 1984 (WGS84). GSHHS 2.2.0 fine (f) resolution L1 data (Wessel & Smith, 1996) available to download from NOAA was used as the UK coastline layer in the usage maps.

- *Treatment of telemetry positional error*

Positional error, varying from 50 m to over 2.5 km (Argos User's Manual, 2011), affects all Argos telemetry points leading to a loss in fine-scale detail. The range of positional error is defined by the number of uplinks received during a satellite pass. Errors are assigned to six location classes: '0', '1', '2' and '3' indicate four or more uplinks have been received for a location, 'A' denotes three uplinks, and 'B' denotes two uplinks (Vincent *et al*., 2002). Because seals spend the majority of their time underwater, uplink probability is reduced and so over 75% of the telemetry data have location class error 'A' or 'B'.

There are many approaches to addressing the problem ranging from simple moving average smoothers to elaborate state-space models, but none have offered a comprehensive solution combining automation, computational speed, precision and accuracy.

As, for the purpose of this report, are interested in large-scale population-level inferences rather than high-resolution individual-based insights, a Kalman filter was applied (Royer & Lutcavage, 2008; Patterson *et al.*, 2010; Roweis & Ghahramani, 1999) using a linear Gaussian state space model to obtain estimates with error accounted for. This has been developed by SMRU Ltd to give flexibility and fast processing times. Argos data were first speed-filtered (McConnell *et al*., 1992) at 2 $m.s^{-1}$ to eliminate locations that would require an unrealistic travel speed between locations (Russell *et al.*, 2011). Observation model parameters were provided by the location class errors described above, and process model parameters were derived from Vincent *et al*., (2002).

GPS tags are generally more accurate than Argos tags, and 95% of these data have a distance error of less than 50 m. However, occasional errors do arise and these data were excluded from the analysis by removing data with residuals that were either 0 or greater than 25, and removing locations with less than five satellite fixes (Russell *et al.*, 2011).

- *Haul-out detection*

SRDL and GPS telemetry tags record the start of a haul-out event once the tag sensor has been continuously dry for 10 minutes. This event ends when the tag has been continuously wet for 40 seconds. Haul-out event data were combined with positional data and assigned to geographical locations. In the intervening period between successive haul-out events, a tagged animal was assumed to be at sea (if the tag provided such information) or in an unknown state (if the tag did not).

Haul-out sites were defined by the telemetry data as any coastal location where at least one haul-out event had occurred, aggregated into 4 km^2 grid cells. Hauled-out usage was calculated by multiplying the proportion of telemetry points at each haul-out site by the estimated kernel smoothed[2] at-sea density.

- *Information content weighting*

Aerial survey counts were used to scale up the telemetry data. Aerial survey data were weighted linearly, giving increasing importance to more recent data, to produce a single count incorporating all available years for each 4 km^2 grid cell where animals had been counted.

[2] Kernel smoothing is a statistical technique, which fits a smooth spatial usage surface to a set of positional data (Matthiopoulos, 2003). The KS (Chacon & Duong, 2010; Duong & Hazelton, 2003; Wand & Jones, 1994; Wand & Jones, 1995) library in R was used to estimate the spatial bandwidth of the 2D kernel applied to the telemetry data.

To account for individual variation in the telemetry points collected from each animal, indexes of information content were devised from 60 remaining tracks (see Appendix – data waterfall).

Figure 4.1a shows a boxplot of tag type vs. discovery rate for total usage[3]. The mean number of grid cells discovered throughout a tag's lifespan are shown by red triangles (Argos = 163, GPS = 489). A Welch two-sample t-test gave a significant difference between the means at the 90% confidence level. This was driven by a significantly higher tag lifespan (Figure 4.1b; Argos = 2775 hours, GPS = 5474 hours), and higher uplink rate per hour (Figure 4.1c; Argos = 0.194, GPS = 0.484).

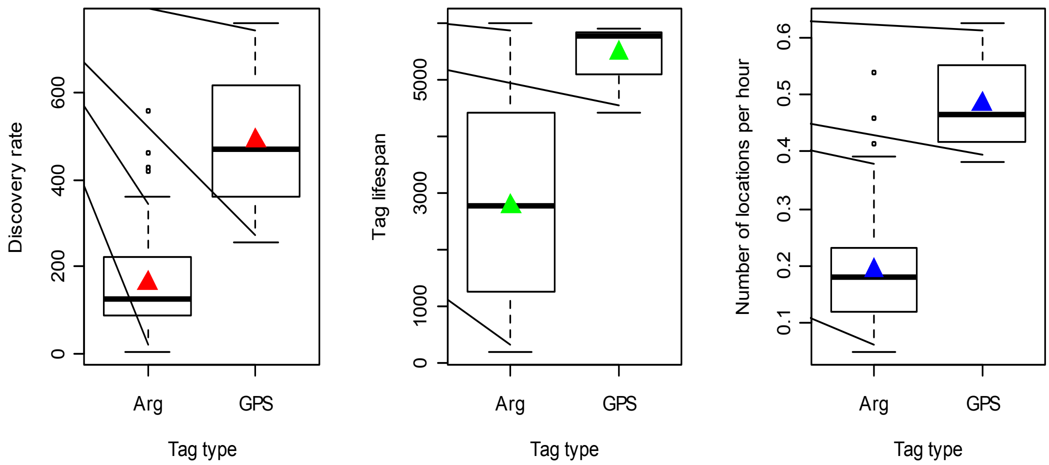

Figure 4.1: Boxplots showing significant differences between tag types. 4.1a (left) = Discovery rate; 4.1b (middle) = tag lifespan; 4.14c (right) = number of locations per hour. Coloured triangles represent mean values, thick black lines are median values, boxes are inter-quartile ranges, and dotted lines show minimum and maximum values.

Generalised additive models (GAMs) using the R library MGCV (Wood, 2011; Wood, 2006) were built separately for total and at-sea usage. The response variable was rate of discovery, defined by the number of new 4 km^2 grid cells an animal 'discovers' in the lifespan of the telemetry tag. This rate was modelled as a function of the number of received telemetry locations for an animal, tag lifespan and whether the tag was Argos or GPS. The intercept was set to zero and a Poisson distribution with a log link function was used.

Number of locations, tag lifespan, and tag type (Argos or GPS) were significant and explained 87.3% and 88.2% of variation in the data for total and at-sea usage models respectively. Figure 4.2a shows total usage fitted values vs. observed discovery rate. Figures 4.2b and 4.2c show the GAM smoothing curves for tag lifespan and number of telemetry locations.

Fitted values were normalised and used to weight the contribution of different animals to estimated usage associated with each haul-out location. This approach reduced the importance of data-poor animals, whilst simultaneously not overstating the contribution of animals with heavily auto-correlated observations.

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[3] At-sea data produced very similar results and is therefore not shown

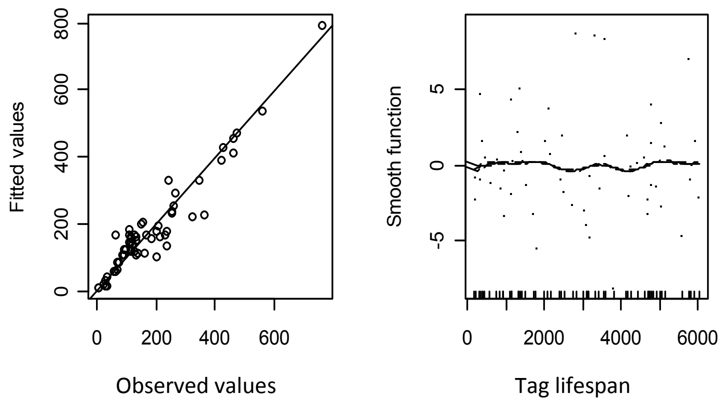

Figure 4.2: GAM model deriving 'information content' by individual. 4.2a (left) = observed vs. fitted values; 4.2b (middle) = tag lifespan smoothing curve; 4.2c (right) = number of locations smoothing curve.

- *Population scaling*

Grey seals haul-out for approximately 35% of their time (95% confidence intervals: 32% to 38%) during the summer irrespective of sex, length (as a proxy to age), region (i.e. location), or survey timing (Lonergan *et al*., 2010). Therefore, to scale the weighted aerial survey counts up to a population estimate, a scalar multiplier of 2.85 (100/35.05) was applied.

- *Null (accessibility) model*

To account for areas in the maps where aerial survey data were present but telemetry data were not, null maps of estimated density were produced. GLMs were used to model the number of telemetry locations associated with each haul-out. This count was modelled using at-sea distance from the haul-out to represent accessibility by animals to each haul-out, and the distance to the shore to represent accessibility to the coast.

A random sub-sample of 25 grey seal tracks was selected. A Poisson distribution with a log link function was used. Figure 4.3 shows the observed vs. fitted number of telemetry locations associated with each haul-out for grey seals.

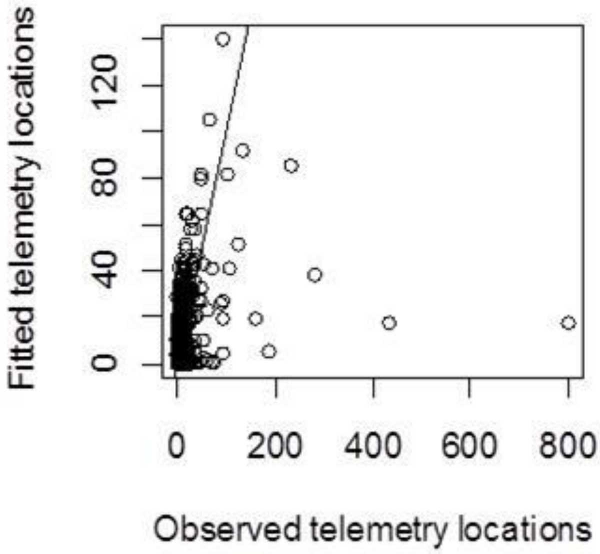

Figure 4.3: GLM model deriving null usage. Observed vs. fitted locations for grey seals.

- *Confidence intervals*

Uncertainty within haul-outs was propagated through the analysis using two sources: (a) by estimating the variability in the telemetry data and (b)using variability in the null usage models:

a) *Telemetry data variance*

Linear Models (LMs) were built to estimate variance. All haul-outs with more than six animals associated with them were used. The response variable was logged variance and covariates were sample size (number of animals associated with a haul-out), logged estimated mean density of seals weighted by information content, and the interaction between them. At-sea kernel smoothed densities were bootstrapped 500 times for each haul-out, and sample size was sampled with replacement and logged, to produce estimated logged variance and logged mean densities.

b) *Null usage variance*

Estimated mean densities in the null maps were produced using a Poisson log link distribution. Therefore, the variance in these maps was equal to the mean.

According to the central limit theorem, the aggregated variance maps were normally distributed and so were scaled up to confidence intervals using a scalar multiplier of 1.96.

Usage Maps

To create single maps of total usage and at-sea usage, all grey seal telemetry data from the SMRU database was put through a series of data cleansing protocols to remove unusable data (Appendix – data waterfall). Argos data were spatially interpolated using a Kalman filter and merged with GPS data. Tracks were then selected based on the criteria that if any part of a track passed within a 100 km buffer zone of the proposed MORL/BOWL development sites, regardless of where tagging had taken place, that track was included.

A 4 km^2 grid was created to extend to the limits of the telemetry tracks and overlaid onto the data. Haul-out detection and aggregation were applied to the data at 4 km resolution. After spending time at sea, an animal could either return to its original haul-out (classifying this part of the data as a return trip), or move to a new haul-out (giving rise to a transition trip). Return trips were attributed to the departure haul-out. Transition trips were divided temporally into two equal parts and the corresponding telemetry data were attributed to departure and termination haul-outs.

At-sea data (i.e. when animals were not hauled-out) were then kernel smoothed. A bandwidth was estimated for each animal. Each animal/haul-out combination was kernel smoothed using the estimated bandwidth to produce separate animal/haul-out association distribution maps.

For total usage, each animal/haul-out map was multiplied by a normalised Information Content Weighting to correct for individual animal bias. All maps connected to each haul-out were aggregated and hauled-out density was added onto each map. Each map was then scaled to the estimated number of animals using that haul-out using the weighted aerial survey counts and then further scaled to the population estimate. A null usage map was derived for each aerial survey site without corresponding telemetry data. Each map was normalised, scaled to aerial survey counts and population estimates, and added to the total usage map.

For at-sea usage, each animal/haul-out map was multiplied by the normalised at-sea Information Content Weighting. Each map was normalised and multiplied by the proportion of telemetry locations not hauled-out. All maps connected to each haul-out were aggregated and scaled to weighted aerial survey counts and then population estimate. Null usage maps were derived using the same process as total usage, but were multiplied by the total proportion of time animals spent not hauled-out (see Population Scaling above) before being added to the at-sea usage map.

Variance in the telemetry data was then estimated for each total and at-sea usage. For total usage, the uncertainty models predicted variance by grid cell for the animals associated with each haul-out, which were then aggregated over all haul-outs. The models were applied in the same way to at-sea usage and both sets of variance maps were scaled to aerial survey counts and population estimates. For the null usage maps, variance was equal to estimated density. Each grid cell was normalised and scaled appropriately to population estimates for total and at-sea usage and added to the telemetry data variance maps. The maps were then scaled up to confidence intervals.

Hauled-out usage and variance was calculated by subtracting the at-sea usage and variance from the total usage and variance.

4.3 Results

4.3.1 Extent of pup movement

The extent of pup movements from the breeding sites where they were tagged (Table 4.1) is shown in Figure 4.4[4]. These movements were typically recorded for a few months but tag duration varied between 17 and 304 days (Table 4.1).

More recently tags have been deployed on pups in Orkney and Wales. These tags are still active and therefore have not been included in this analysis but preliminary results are consistent with the data shown in Figure 4.4 – that grey seal pups show considerable inter-individual variation in the extent of movements they make upon departing from the breeding colony (SMRU unpublished data).

Table 4.1: Details of deployments on grey seal pups in the UK.

Tagging location	Years	Number tagged	Duration (days) [Median range]
Farne Islands, North-East England	1993 - 1994	9	67 [40 – 103]
Monach Islands, Western Isles	1995	9	83 [17 – 187]
Isle of May, East Scotland	2001 - 2002	21	107 [41 – 304]

[4] Only the proposed wind farm sites have been shown – and not the proposed export corridor or cable routes – in each of the Figures because the presence of so many lines when they were included made the maps difficult to interpret.

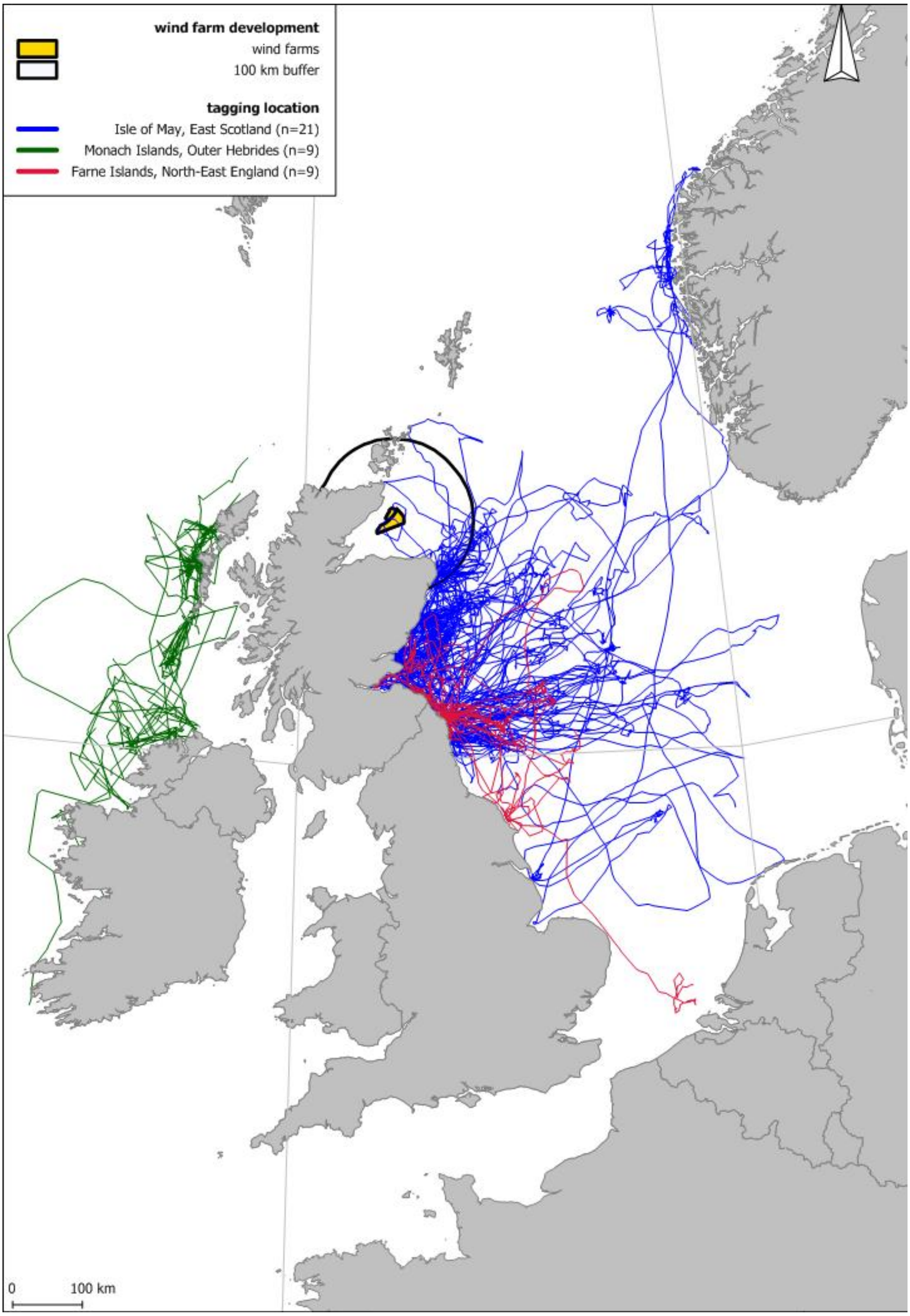

Figure 4.4: The extent of grey seal pup movements from the breeding sites where they were tagged.

4.3.2 Tracks of animals aged 1+

A buffer zone was generated which extended 100 km from the boundary of the potential wind farm development sites. Data from tagged animals (aged one year and above) were presented if a location was recorded inside the buffer zone. The tracks from the resulting 65 animals are shown in Figure 4.5 with each colour representing a different individual. Tags were deployed on these animals in various locations and years (Table 4.2), with median tag duration being 130 days (range: 2 – 253 days). Figure 4.6 shows the same information as Figure 4.5, but in detail for the Moray Firth/100 km buffer.

Table 4.2: The deployments on animals which are presented in Figures 4.2 and 4.3, by year.

Year	Number tagged
1992	6
1993	3
1995	3
1996	11
1997	4
1998	17
2000	1
2003	8
2004	1
2005	3
2006	1
2008	7

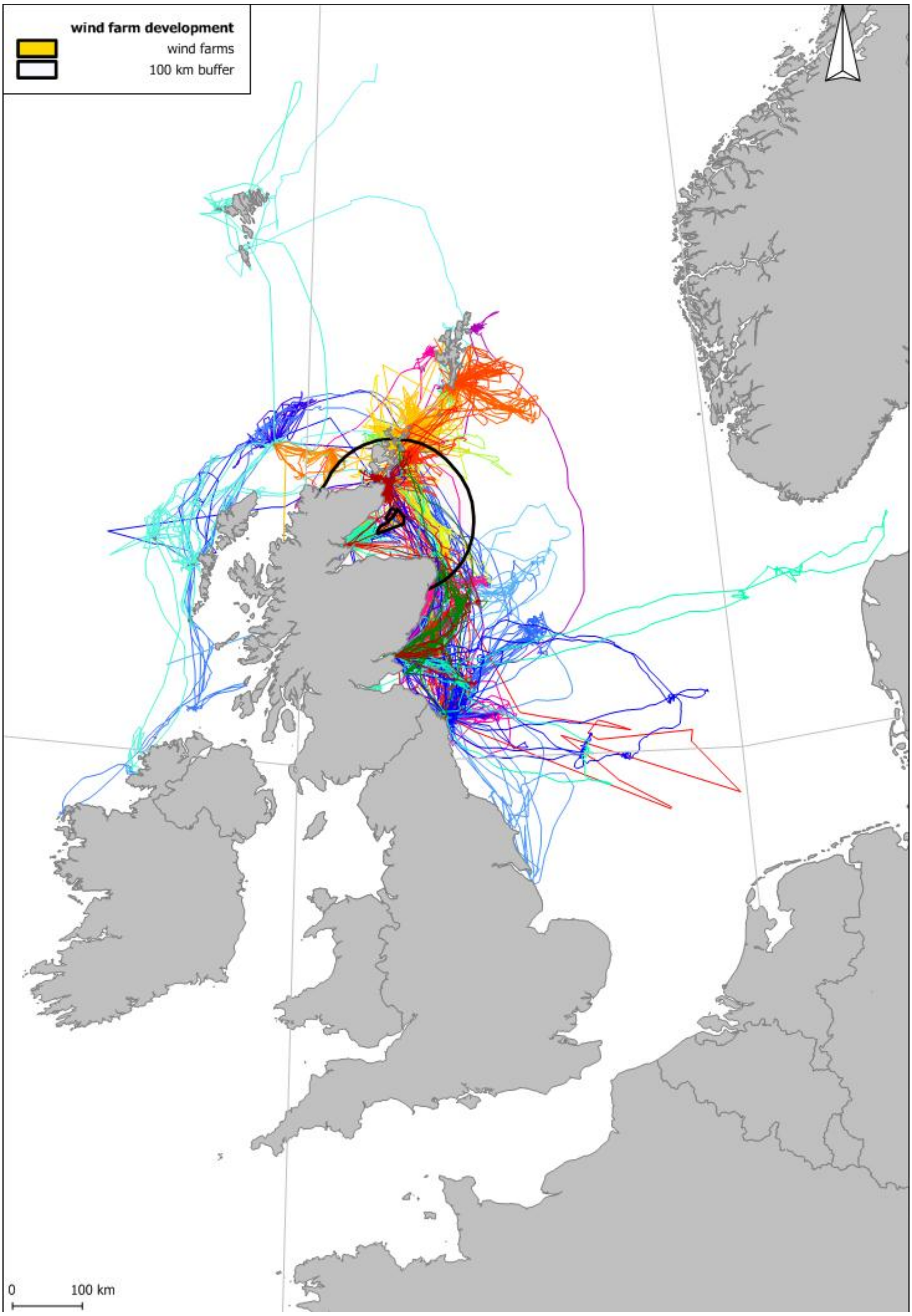

Figure 4.5: Tracks of grey seals (aged one year and above) which, at least once while they were tagged, entered a 100 km buffer zone around the proposed MORL and BOWL wind farm sites. Each colour represents a different individual.

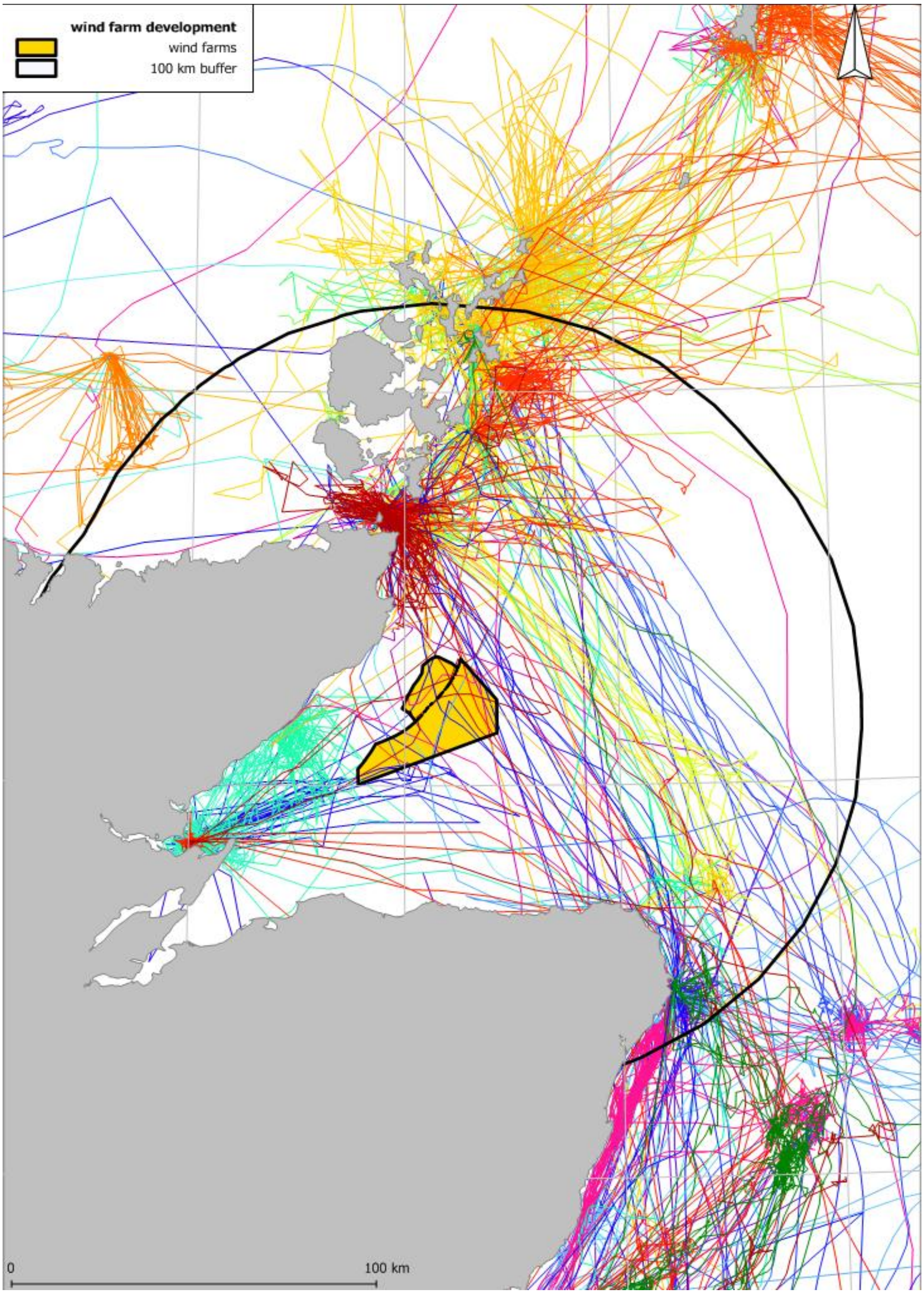

Figure 4.6: Tracks of grey seals (aged one year and above) which, at least once while they were tagged, entered a 100 km buffer zone around the proposed MORL and BOWL wind farm sites. Each colour represents a different individual. This figure shows the same information as the previous one but is magnified to show the Moray Firth in more detail.

4.3.3 Usage maps

Forty four tracks were used in the final analysis (Table 4.3), from seals that were tagged between 1992 and 2008. Thirty seven of the tagged animals were adults, four were juveniles and three were moulted pups. The male to female ratio was 26:18.

Table 4.3: Summary of telemetry tracks used in the final analysis.

Year	Tag type	No. tags	Sex ratio (m:f)	Mean tag lifespan (days)	Mean no. location fixes (per day)
1992	Argos	4	2:2	142	1.9
1995	Argos	2	1:1	111	0.4
1996	Argos	9	5:4	44	1.3
1997	Argos	2	1:1	106	0.8
1998	Argos	16	12:4	160	0.8
2001	Argos	1	0:1	73	0.6
2002	Argos	2	2:0	130	0.5
2003	Argos	1	2:0	215	4.7
2004	Argos	1	1:0	130	7.4
2008	Argos/GPS 6*		2:4	208	2.7
Total		44	**Mean**	134	1.6
*2Argos, 4 GPS.					

Figure 4.7 shows the geographical location of the tracks used in the analysis split by tag. GPS tags have a smaller spatial extent, concentrated in the south of the Moray Firth. Figure 4.8 shows the same tracks split by year of deployment (1995-2008).

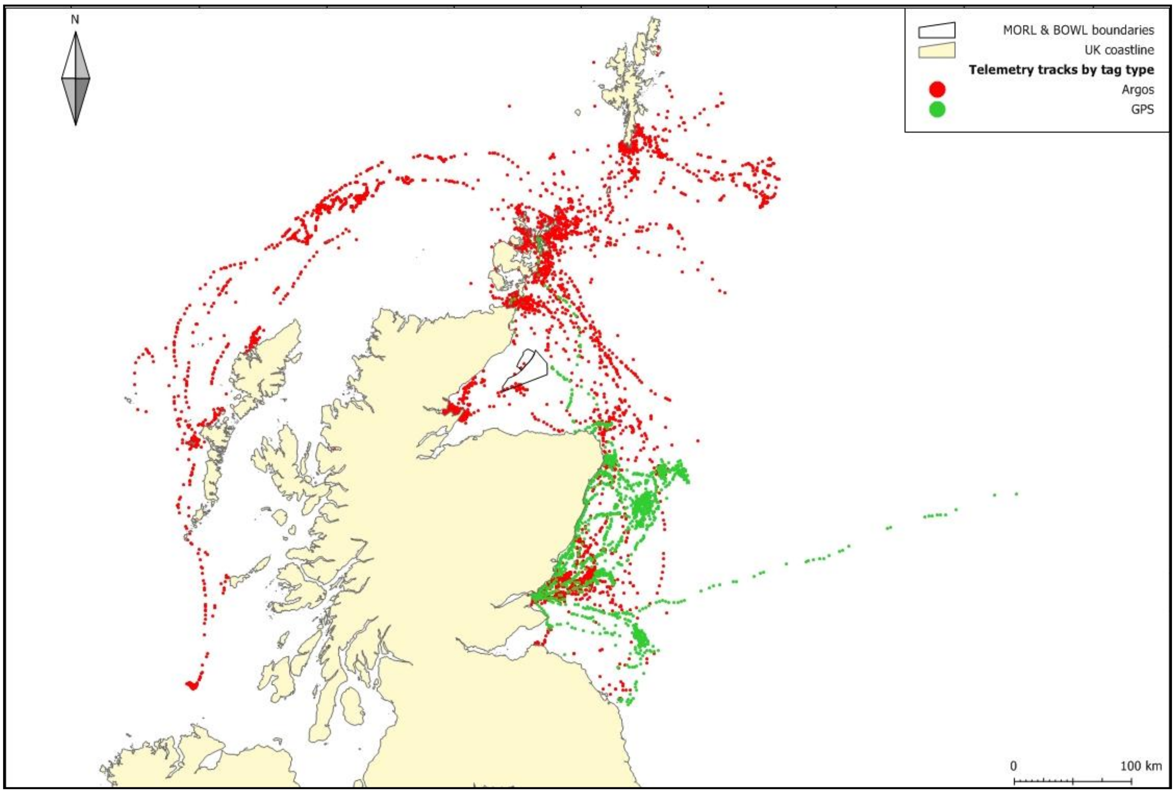

Figure 4.7: Map showing telemetry track locations by tag type.

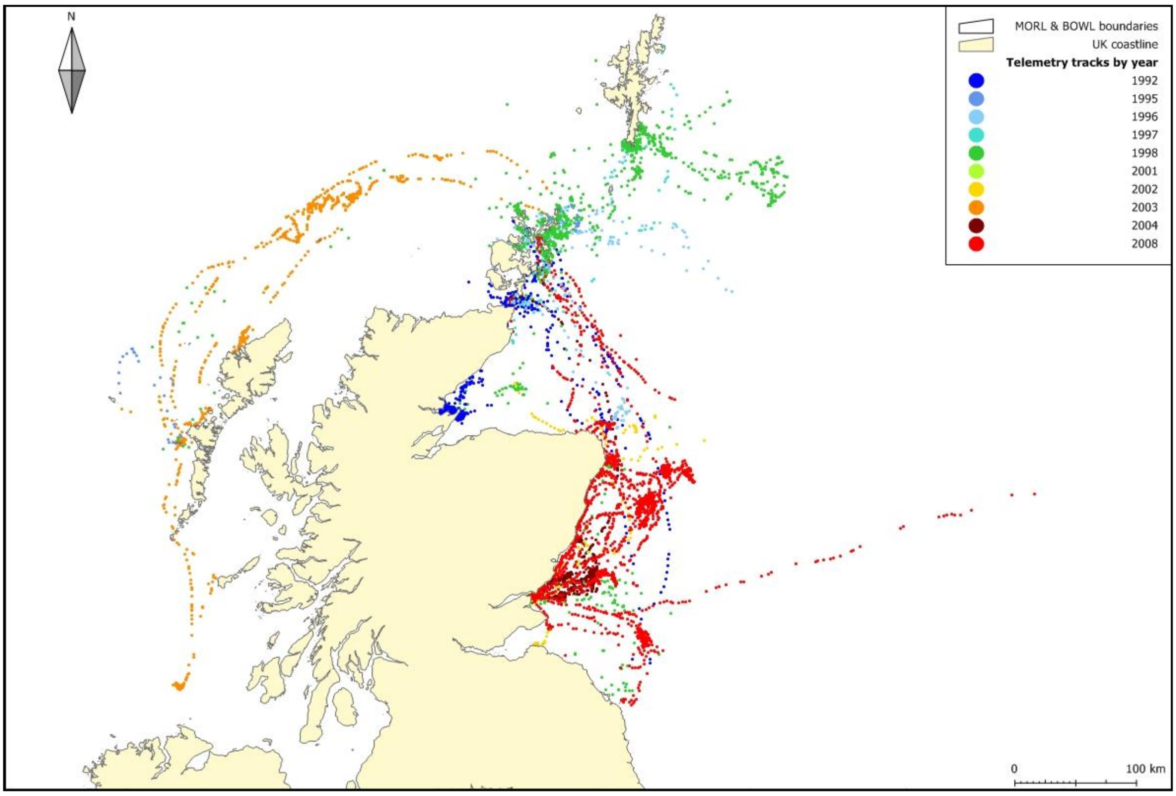

Figure 4.8: Map showing telemetry track locations by year.

Figure 4.9 shows spatial usage of grey seals around the proposed MORL/BOWL development sites. The map can be interpreted as the average number of seals in each 4 km^2 grid cell at any point in time. For example, a green square denotes that, on average, between one and five grey seals will be within that grid square at any point in time. A red square denotes that over 50 animals will be in that grid square at any point in time.

White contour lines denote standard deviation from the mean as a measure of uncertainty magnitude around estimated usage. Labels show the value of standard deviation at each contour as the square root of the estimated variance. This in turn was a combination of two modelling processes: null usage and telemetry data. Variance from the null model was larger than for estimates informed by telemetry data. Therefore, in regions that received considerable usage from haul-outs for which no telemetry data are available, it is often the case that uncertainty contours appear smoother than the usage density map. This is a desirable feature of the model: it inflates uncertainty in regions where the ratio of data/usage is likely to be low.

Within the study area, highest total usage is located in the Inner Moray Firth, the Dornoch Firth, Loch Fleet, the Pentland Firth, and Peterhead Bay. Possible offshore foraging patches can also be seen throughout the study area, mostly denoted in orange.

Figure 4.10 shows estimated grey seal at-sea usage with white contour lines denoting standard deviation. Total and at-sea usage display similar characteristics, although at-sea usage is 27% lower due to the removal of hauled-out usage.

Figure 4.11 shows estimated grey seal hauled-out usage with white contour lines denoting standard deviation. The highest hauled-out usage occurs in the Dornoch Firth and Pentland Firth.

The standard deviation for each of these figures can be found in Figure 4.12.

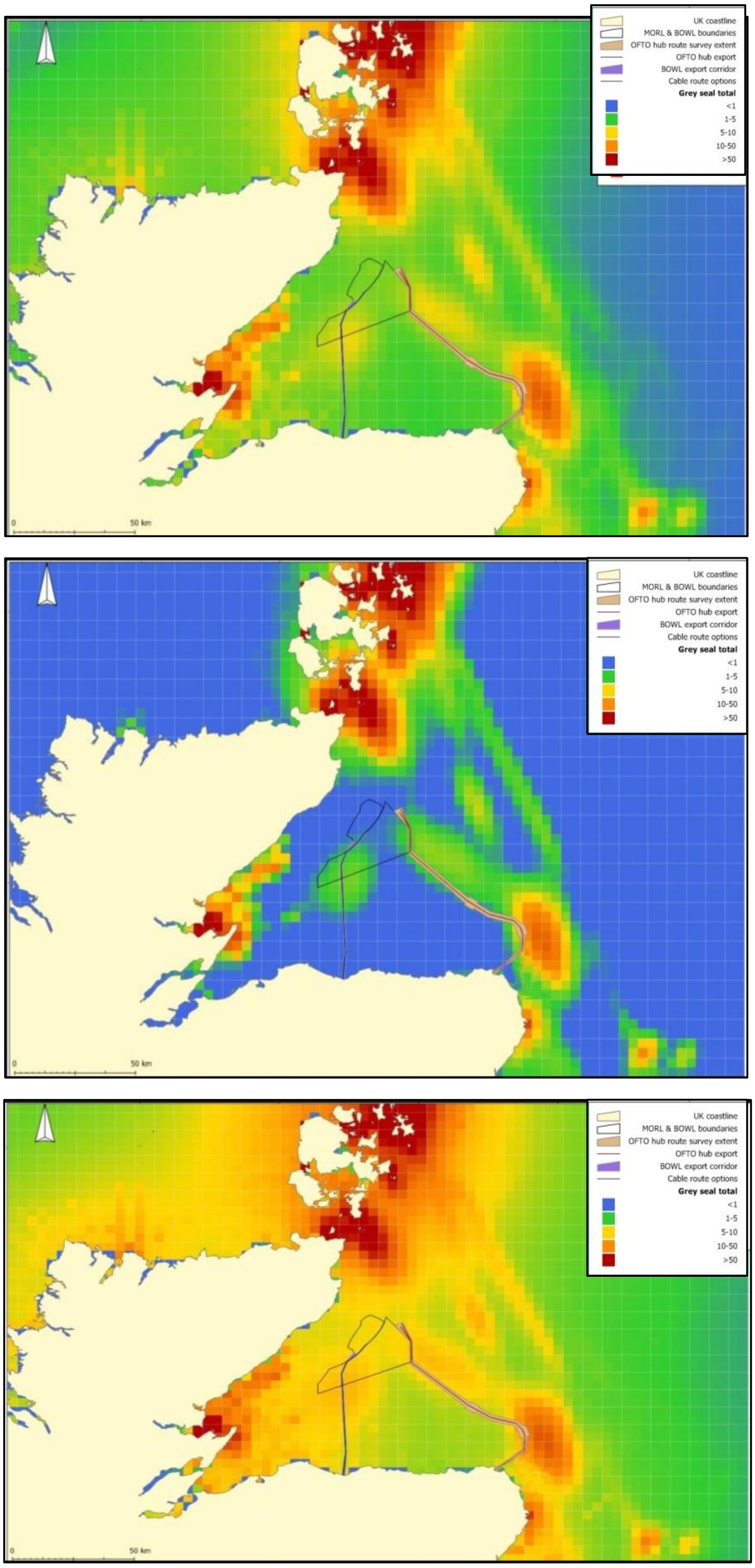

Figure 4.9 Top: Estimated grey seal total (at-sea and hauled-out) usage around the proposed MORL/BOWL development sites. Middle = lower 95% CI; Bottom = upper 95% CI.

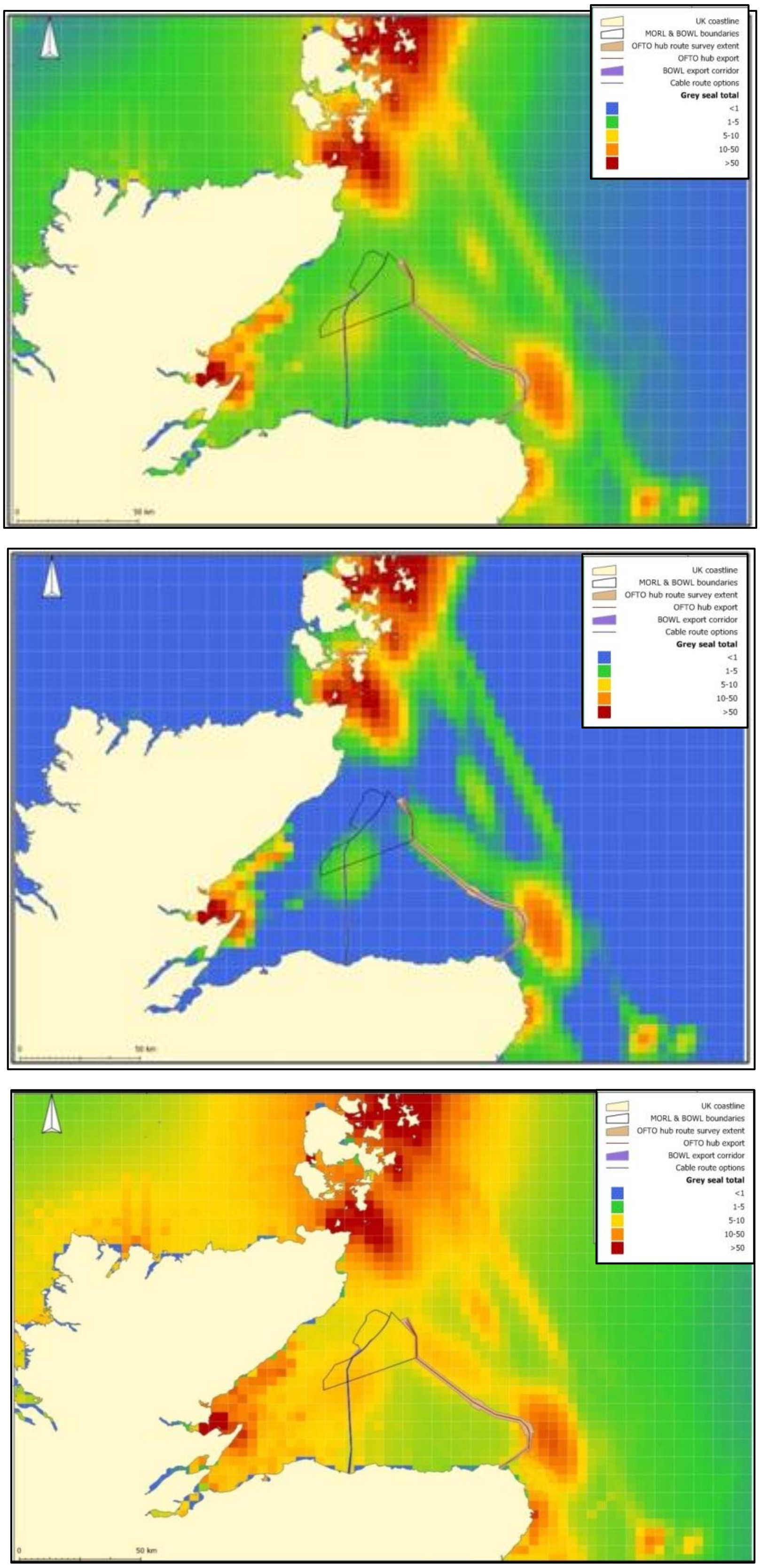

Figure 4.10 Top: Estimated grey seal at-sea usage around the proposed MORL/BOWL development sites. Middle = lower 95% CI; Bottom = upper 95% CI.

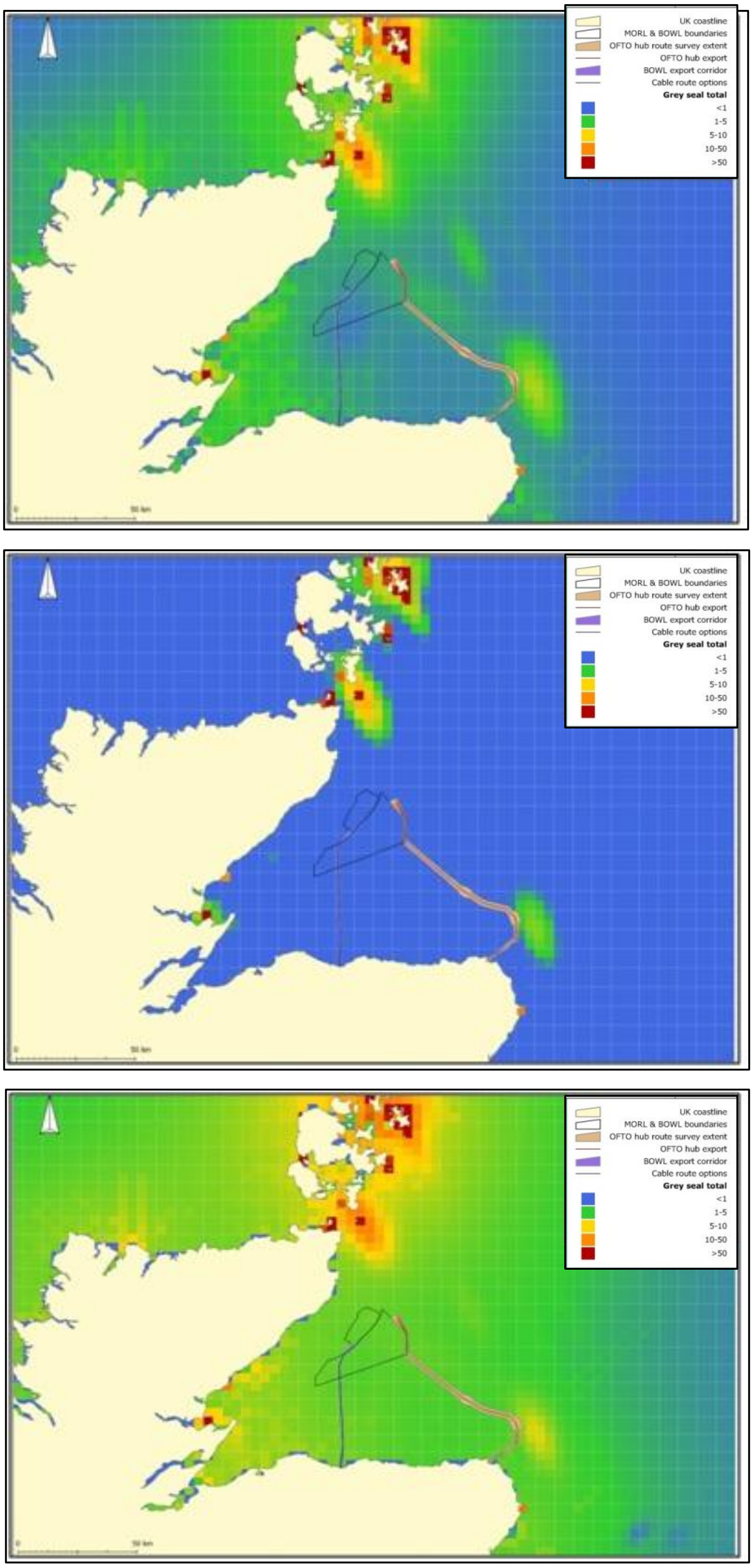

Figure 4.11: Estimated grey seal hauled-out usage around the proposed MORL/BOWL development sites. Middle = lower 95% CI; Bottom = upper 95% CI.

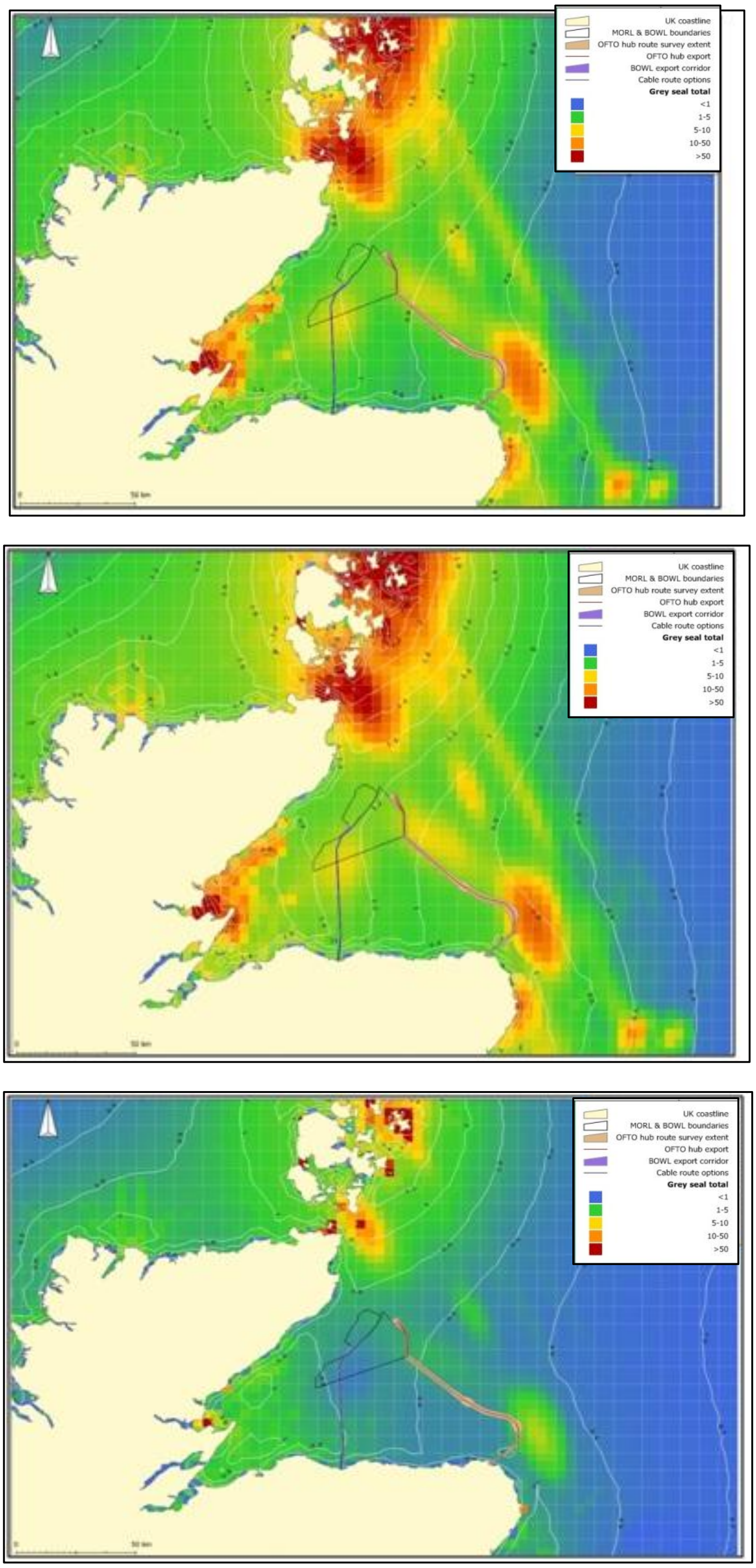

Figure 4.12: Standard deviation for (top) total usage; middle = at sea usage and bottom = hauled out usage.

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4.6 Appendix – Data waterfall

Description	Counts	Drop-off#	Drop-off%	#Animal tracks
Haul-out				
Species = grey or harbour seal	96,949			650
Remove missing/null values	96,934	15	100%	650
GPS				
Species = grey or harbour seal	507,300			603
Remove missing/null values	507,283	17	0%	603
Merging biological information	331,649	175,634	35%	434
Remove invalid/duplicate records	331,127	522	0%	428
Deduplication for Kalman filtering	236,264	94,863	29%	427
Merge telemetry data				
Merge Argos & GPS	364,766	0	0%	181
Retain grey seals	155,250	209,516	57%	262
Retain animals whose tracks appear at least once within 100 km buffer of MORL/BOWL sites	47,572	107,678	69%	76
Haul-out detection				
Assign haul-out events	47,572	0	0%	76
Only retain animals that have at least one haul-out event associated with them	39,805	7,767	16%	69
Trip detection				
Assign trip & grid cell Ids to each animal/location	39,805	0	0%	60
Remove observations out with location range of overlying grid cells	39,524	281	1%	60
Kernel smoothing				
Remove haul-out events	32,341	7,183	18%	60

NULL usage				219
Information content weighting				
Total usage information content weighting	39,524	0	0%	60
At-sea information content weighting	32,341	0	0%	60
Usage maps				
(Total usage) Match haul-outs with aerial survey data	9,379	30,145	76%	44
(At sea) Match haul-outs with aerial survey data	7,570	24,771	77%	44
(Hauled-out) Match haul-outs with aerial survey data	1,809	1,809		44

5. Cetacean density estimates and habitat modelling

5.1 Background

Appropriate Assessment for oil and gas activities within the Moray Firth has highlighted a lack in available data on cetacean abundance and behaviour in the offshore areas of the Moray Firth. In response to this, a scope of work was developed to aid characterisation of the proposed development areas and connectivity with local SACs.

5.2 Visual survey methods

5.2.1 Data sources

Primary data sets for this part of the study were collected by the University of Aberdeen (AU) through previous and ongoing surveys carried out in relation to the Beatrice Demonstrator Project and assessment of the impact of seismic surveys. These included two data sets that were collected using boat-based line transect surveys, and one that was collected using aerial line-transect survey. All these data were collected during the summer months (April-October).

Additional data on sightings of harbour porpoises and dolphins of all species were also made available from the boat-based seabird and marine mammal surveys that were carried out during April to October 2010 by Natural Power Consultants (NPC) on behalf of MORL and the Institute of Estuarine and Coastal Sciences (IECS) on behalf of BOWL.

Each of the datasets used broadly similar survey methods. All used line-transect methods and collected effort data in the format of transect distance surveyed. All recorded the location, species and number of animals sighted, although the number and experience of observers varied between surveys. No deviation from the survey track line was made when animals were sighted.

AU Boat surveys within the Moray Firth SAC (2004, 2005)

These surveys were carried out to provide baseline data from the Moray Firth SAC for the Beatrice Demonstrator project. As outlined in Bailey & Thompson (2009), the aim was to assess habitat associations of bottlenose dolphins and harbour porpoises along the survey route and model their relative abundance across the Moray Firth SAC to identify hotspot areas for these species.

Line transect surveys were designed to provide representative coverage across the Moray Firth SAC during the summers of 2004 and 2005 (Figure 5.1 and Table 5.1). Surveys were conducted using a 8.5 m Newhaven Sea Warrior, and the single observer recorded sightings of any marine mammals from the top of the wheelhouse at approximately 3.5 m above sea level. Total survey distance was 1628 km, and survey speed was approximately 7 knots.

Table 5.1: Days of survey effort carried out during the University of Aberdeen's boat-based surveys within the Moray Firth SAC.

Year	Month	No. Survey Days
2004	August	2
2004	September	5
2004	October	3
2005	April	5
2005	May	4
2005	June	5
2005	July	1

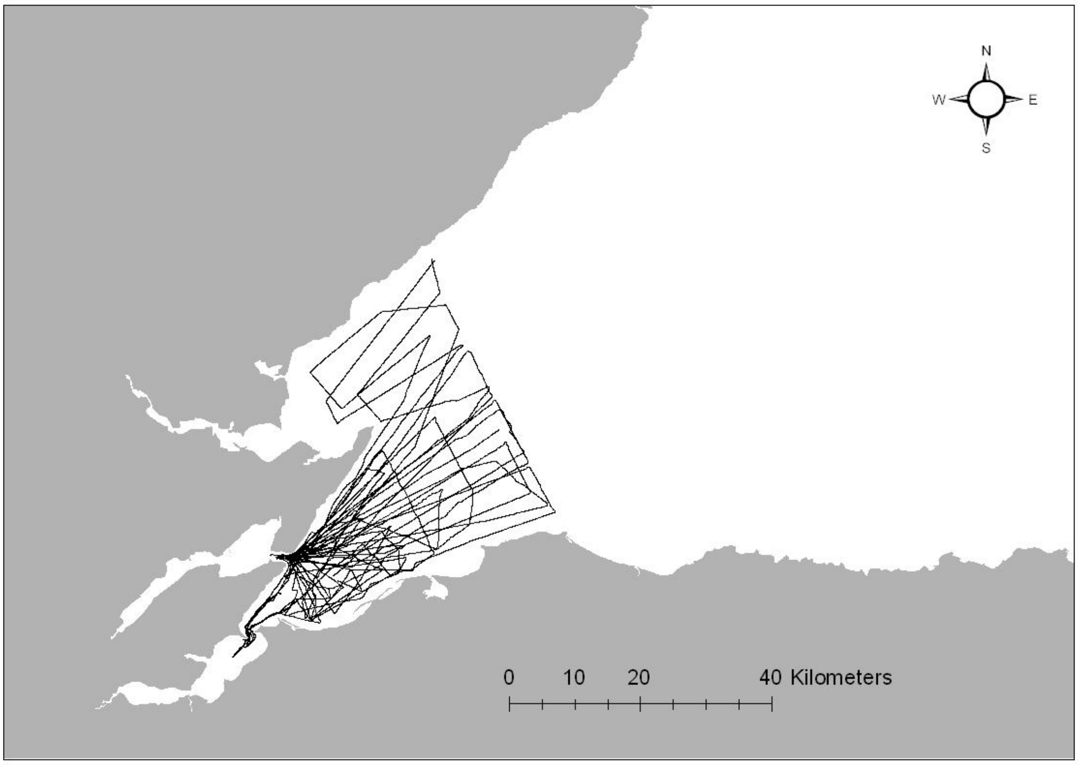

Figure 5.1: Map of the survey tracks used during the University of Aberdeen's boat-based surveys within the Moray Firth SAC.

AU Boat surveys in Outer Moray Firth (2009)

These surveys were carried out in the summer of 2009, to collect data for DECC to support their assessment of proposed oil and gas exploration within the Moray Firth (Thompson *et al.*, 2010a). Surveys covered a large geographical area at relatively low resolution, with the aim of determining which species were present within the offshore waters of the Moray Firth at a broad scale (Table 5.2 and Figure 5.2). Three different vessels were used; two fishing vessels and a converted lifeboat. Observation height varied between vessels, but was at least 5 m above sea level. Survey speed was approximately 8 knots. Two observers were on watch at all times, each scanning one half of a 180° arc ahead of the boat. Total survey distance was 1671 km.

Table 5.2: Days of survey effort carried out during the 2009 boat-based surveys.

Year	Month	No. Survey Days
2009	June	5
2009	August	4
2009	September	3
2009	October	2

Figure 5.2: Map of total effort during the 2009 University of Aberdeen boat based surveys.

AU Aerial surveys in Outer Moray Firth (2010)

Aerial surveys were carried out in the summer of 2010 by the University of Aberdeen. The primary reason for these surveys was to estimate the density of harbour porpoises in two 25 x 25 km survey blocks as part of a programme of work investigating impacts of seismic surveys on cetaceans. In addition, surveys were designed to compare the occurrence of different dolphin species along the north and south coasts of the Moray Firth to support assessments of connectivity with the Moray Firth SAC (Figure 5.3).

Surveys followed the line-transect procedures used for SCANS and SCANS-II (Hammond *et al*., 2002; Hammond, 2007) and used experienced aerial surveyors from NERI and WWT Consulting Ltd. A Partenavia 68 aircraft, fitted with bubble windows was flown at a speed of 100 knots, at 600 ft above sea level. Two observers scanned the area on either side of the aircraft. A total of 5664 km of transect were surveyed during five survey days in August and eight in September 2010. Incomplete surveys or those carried out in poor sighting conditions were excluded from analysis, giving a final total effort of 4784 km. Further details of survey protocols are given in Section 5.2.3.

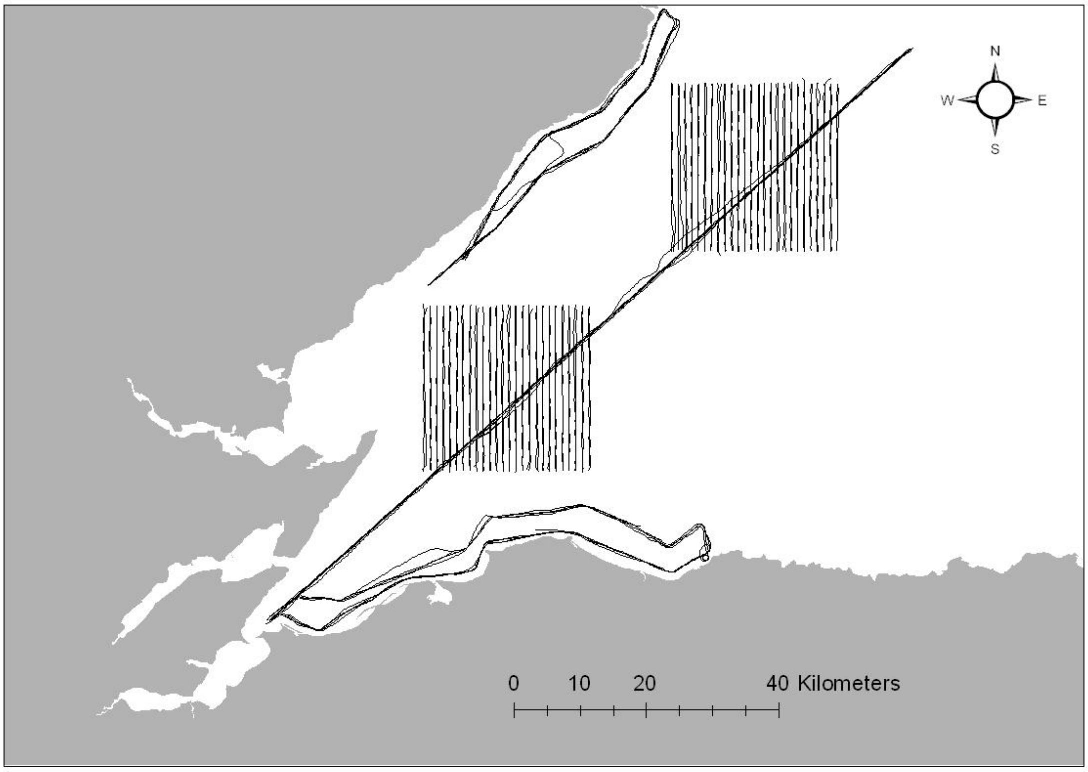

Figure 5.3: Map of survey tracks used during the 2010 aerial surveys

NPC surveys of proposed MORL sites (Telford, Stevenson and MacColl: 2010)

These surveys were carried out in 2010 as part of a two year programme of bird and marine mammal surveys to support the MORL ES. Monthly surveys began in April 2010 (Table 5.3). Only data collected up to October 2010 are presented here to allow comparison with University of Aberdeen data.

In total, 3015 km of survey effort was carried out during this period. A variety of survey vessels were used, but all had survey platforms at least 5 m above sea level and travelled at approximately 10 knots on a series of standard transects (Figure 5.4).

Table 5.3: Days of survey effort carried out during the 2010 Natural Power surveys

Year	Month	No. Survey Days
2010	April	3
2010	May	3
2010	June	3
2010	July	3
2010	August	6
2010	September	2
2010	October	4

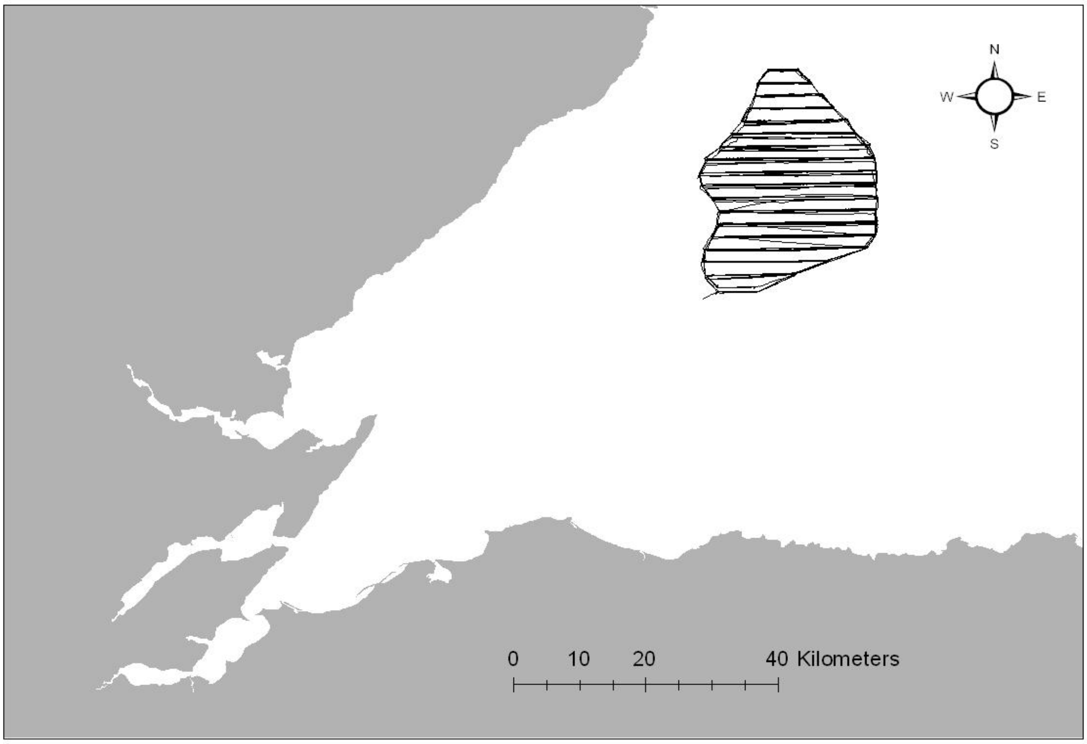

Figure 5.4: Map of survey tracks conducted by NPC, April to October 2010 surveys.

IECS Boat surveys of proposed BOWL site (2010)

These surveys were carried out in 2010 as part of a two year programme of bird and marine mammal surveys to support the BOWL ES. Monthly surveys began in November 2009 (Table 5.4), but only data collected between April and October 2010 are incorporated into this analysis to allow comparison with University of Aberdeen data.

Total survey effort during this period was 1390 km (Figure 5.5). The survey vessel was a converted lifeboat, with an observation height of approximately 5 m above sea level.

Table 5.4: Days of survey effort carried out at during the 2010 IECS surveys

Year	Month	No. Survey Days
2010	April	4
2010	May	2
2010	June	2
2010	July	2
2010	August	2
2010	September	2
2010	October	0

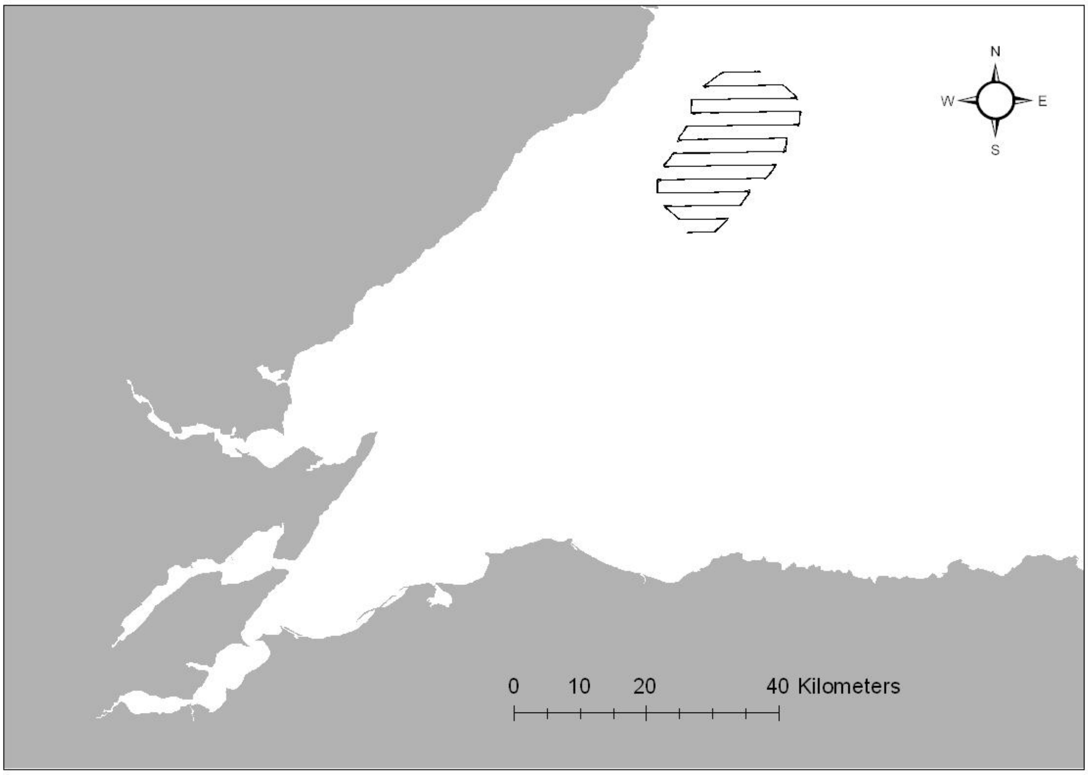

Figure 5.5: Map of survey tracks conducted by IECS April to October 2010 surveys

5.2.2 Habitat association modelling

To assess habitat association of cetaceans in the Moray Firth, survey and habitat data were summarised across a 4 x 4 km grid.

Based upon earlier analyses of data from within the SAC (Bailey & Thompson, 2009), four habitat variables were assessed: depth, sediment type, slope and distance to the coast (Figure 5.6a to d). For depth, slope and distance to the coast, a mean value for every 4 x 4 km grid cell was calculated using BGS data available through SeaZone.

Sediment was processed to give the proportion of sand and gravelly sand sediments within each cell, on the basis that sand eels prefer habitat with high proportions of these sediments (Holland *et al*., 2005) and it is reasonable to assume that porpoises would seek out these areas when foraging.

For some cells that were surveyed in the inner Moray Firth, BGS habitat data were not available, and data from these cells were therefore removed from the analysis. To ensure a good estimate of the proportion of sand and gravelly sand within the cell, any cell with less than 50% data coverage was removed.

The slope variable was highly right skewed, the result of a single observation much larger than the others. This observation was removed, giving a range of slopes between 0° and 1.583°. Some coastal cells had mean depth values that were above sea level; therefore a minimum mean depth of 5 m was used to ensure that most of the cell was available to porpoises. Depth was also right skewed, so a maximum depth of 73.5 m was used.

Survey effort and sightings data were also split into the same 4 x 4 km grid cells. Where multiple surveys covered the same cells, the data were treated separately, leading to some cells being included in the analysis up to four times. Cells were not included if they contained less than 1 km of effort. In total 429 cell observations were included in the model, from 241 unique cells (Figure 5.7).

Each observation was coded to reflect the data collection method; either aerial or boat based, to allow models to account for the potential difference in sighting rate between these methods.

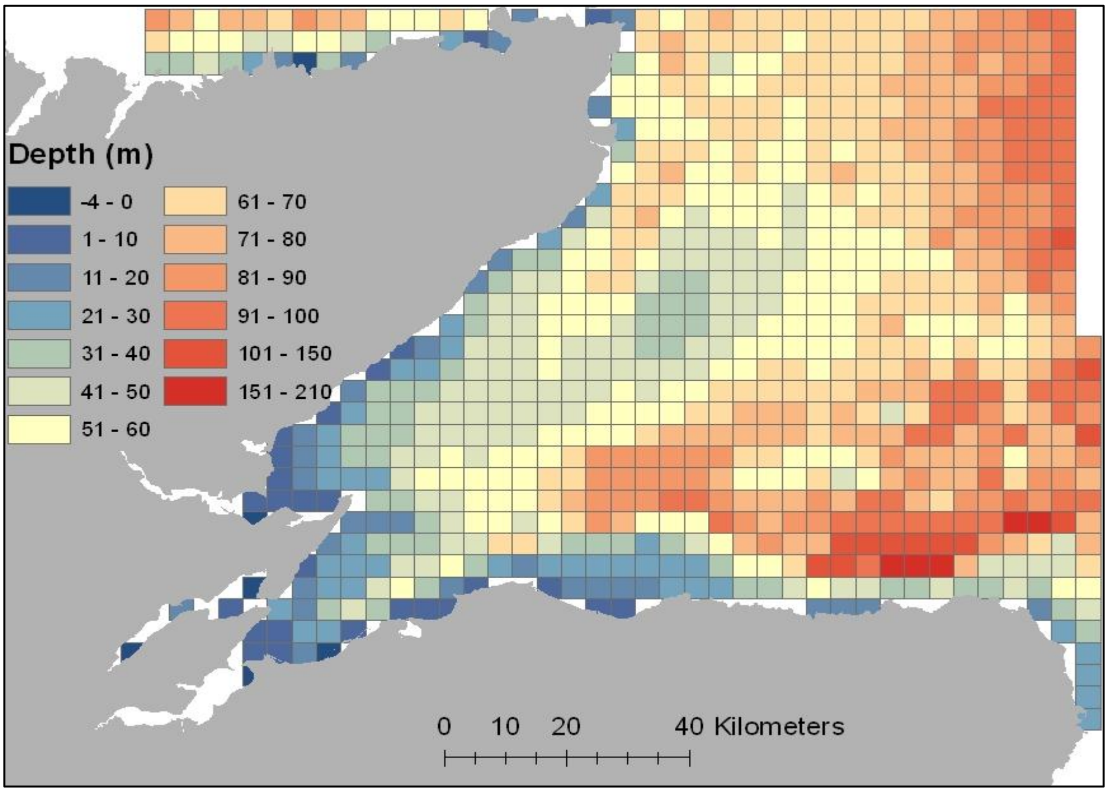

Figure 5.6a: Depth summarised over a 4 x 4 km grid.

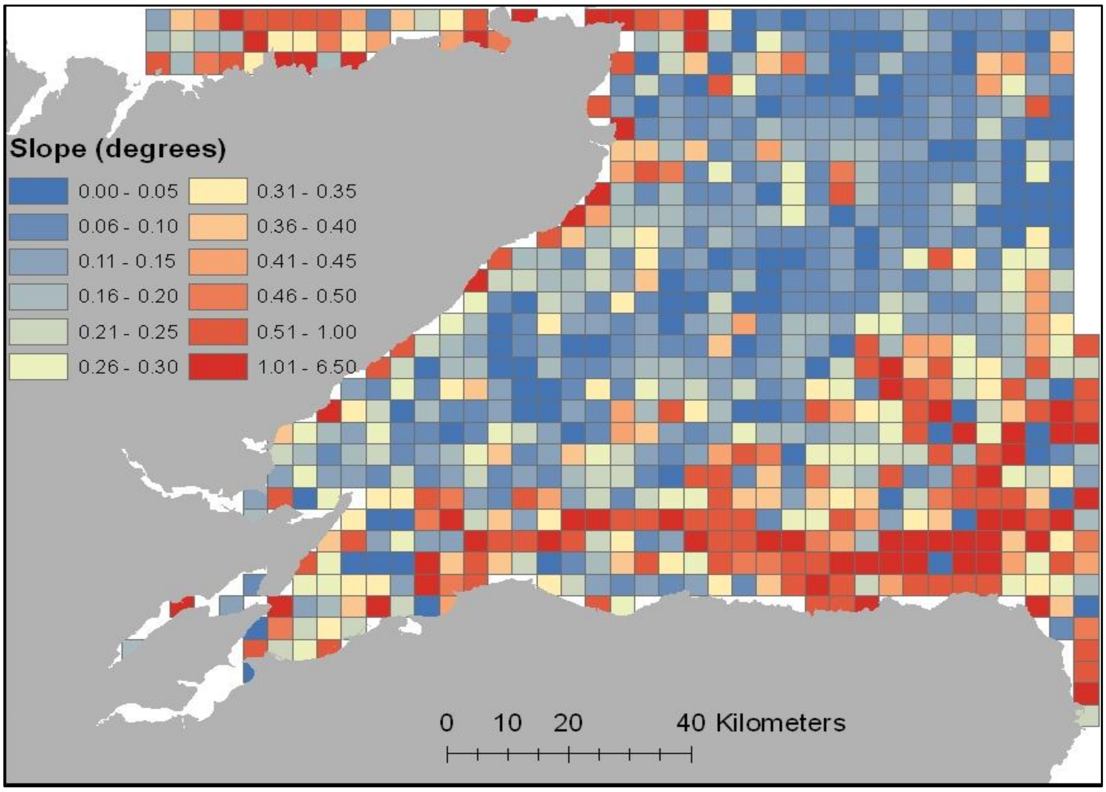

Figure 5.6b: Slope summarised over a 4 x 4 km grid.

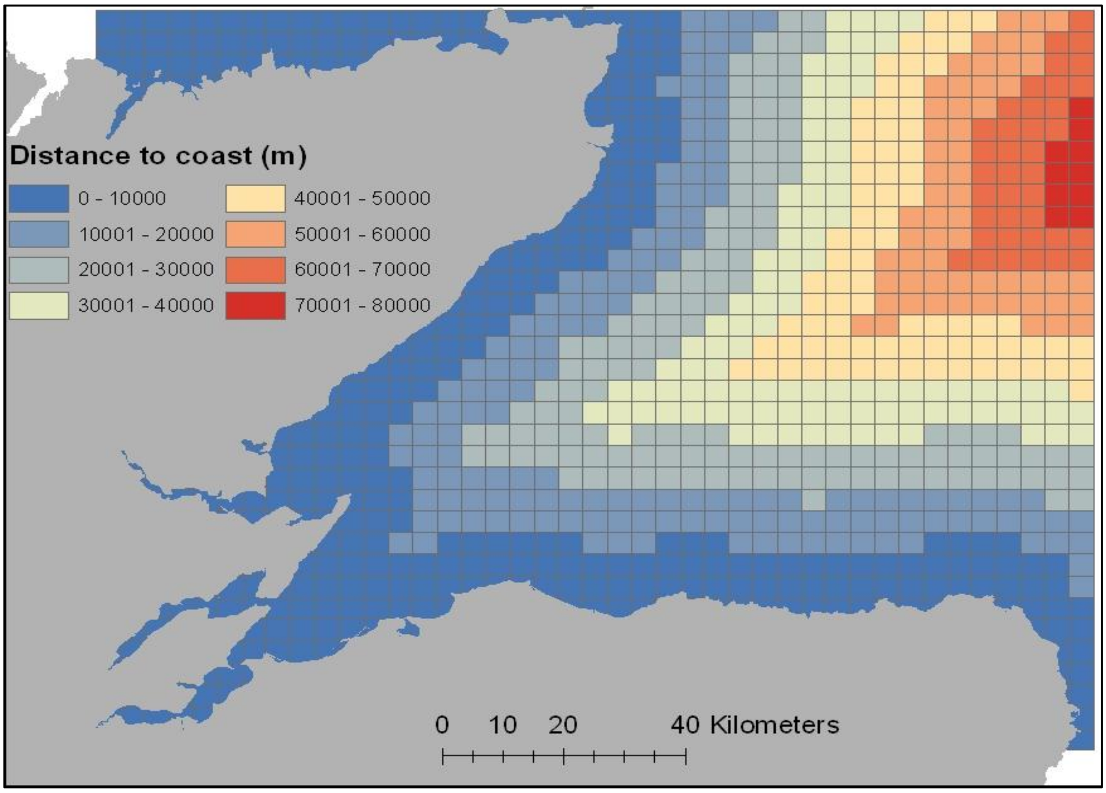

Figure 5.6c: Distance to coast summarised over a 4 x 4 km grid.

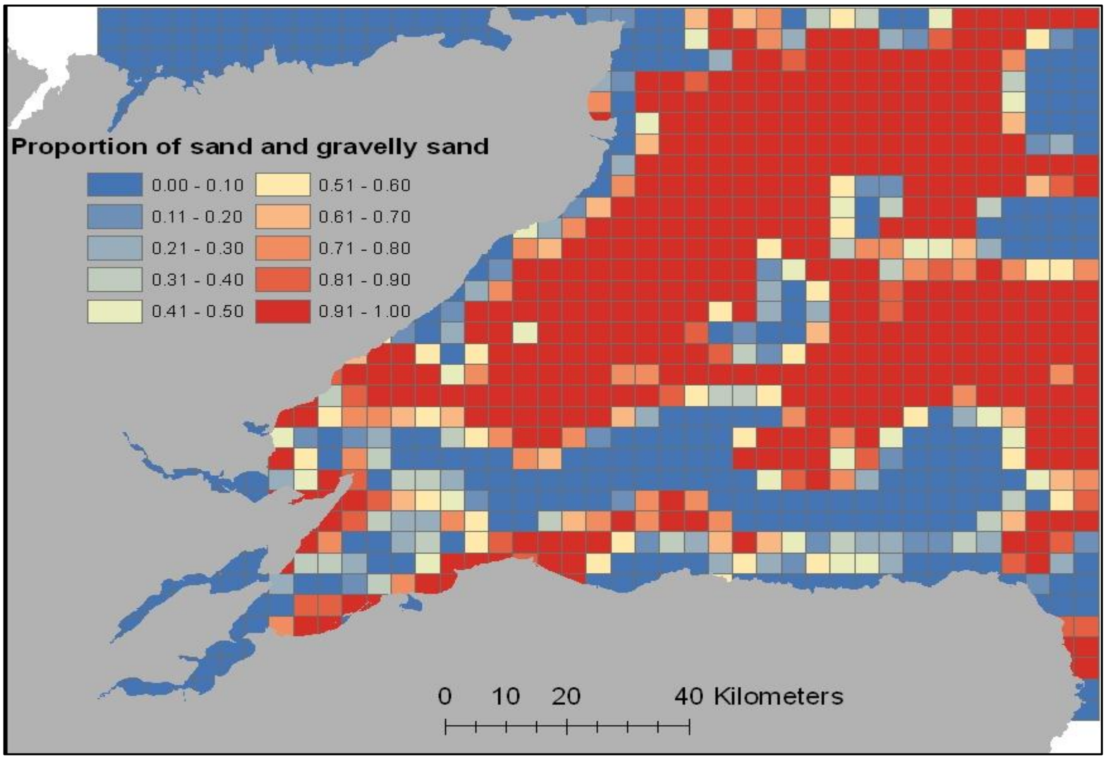

Figure 5.6d: Sediment type summarised over a 4 x 4 km grid.

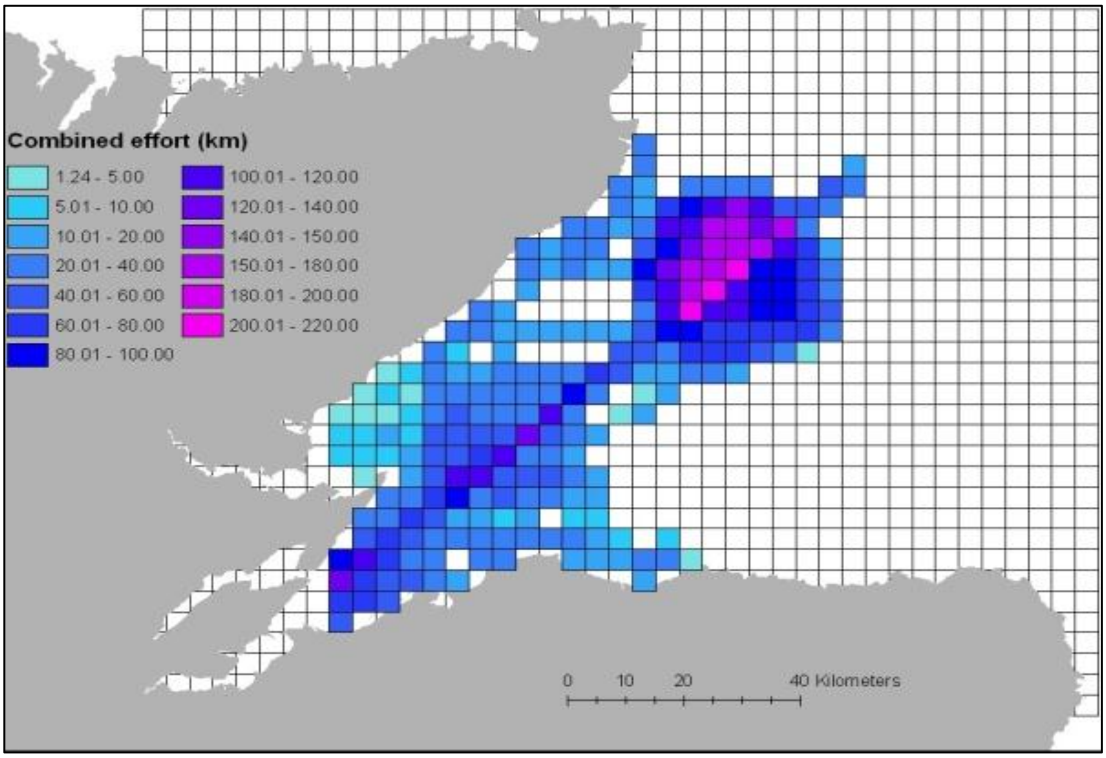

Figure 5.7: The total amount of survey effort in each 4 x 4 km cell.

- Harbour porpoise model

There were over 1000 sightings of harbour porpoises from the combined surveys, but relatively few sightings of different dolphin species (see results). Whilst this provided good opportunities for modelling harbour porpoise habitat associations, there were insufficient data to model individual species distribution for other species.

For the porpoise models, data exploration indicated that depth and distance from the coast were highly collinear, so distance from the coast was removed from the model. Porpoises are known to occur at a large range of distances from the coast, and it is more likely that they respond to depth in terms of available food.

Models were constructed with a count of animals in each 4 x 4 km grid cell for each dataset, along with a value for each habitat variable. The log of the total transect length within each grid cell was used as an offset variable.

The relationship between porpoise numbers and depth was non-linear, so generalised additive mixed models (GAMM) were used. These models allow non-linear relationships and also account for the pseudo-replication caused by including some cells more than once. The initial model included depth, the proportion of sediment that was sand or gravelly sand, slope and the log of effort as an offset. Cell identity was included as a random effect. Models were weighted by the ratio of effort to the maximum value of effort, thereby allowing cells with more effort to have more influence on the estimated values from the model.

Initial models were found to be over-dispersed when using a Poisson distribution and the final models therefore used a negative binomial distribution. Model selection was based on AIC (Akaike, 1974), which gives information on the accuracy of the model, taking into account its complexity. Model selection aims to minimise the AIC score. Analysis was carried out in R version 2.12.1 and the mgcv package (Wood, 2008) was used for GAMM analyses.

- Dolphin model

Although there were insufficient data to produce habitat association models for individual dolphin species, it was possible to use the available survey data in classification trees (De'ath & Fabricius, 2000) to assess the likely species identify of dolphins that may be encountered in different parts of the Moray Firth. In particular, this analysis was developed to assess the likelihood that any dolphins encountered in offshore areas (see results in Section 5.6) were bottlenose dolphins.

Available sightings of dolphins that were identified to species within the Moray Firth between 1982 and 2010 were used for this analysis. Several datasets described in Thompson *et al*., (2010a) were used, in combination with the four datasets described in Section 5.1.1. Datasets without counts of animals or with poor locational precision were excluded from the analysis. In total, eight datasets were included (Table 5.5).

Habitat and other spatial variables (e.g. distance to coast) were calculated for each of the locations where a visual sighting of different dolphin species had been made. Classification trees were then developed by repeatedly splitting the dataset in two, until most animals were assigned to a unique species group on the basis of these different spatial variables. The resulting tree could then be used to predict the proportion of each species that might be expected in an area given its habitat characteristics.

These presence only methods do not account for effort so, used alone, they cannot provide a prediction of the number of animals that might be found in an area. However, this approach does tell us that, if dolphins were present, this is the likely species composition that we would find in different areas.

Individual dolphin sightings were used in the classification tree. Each sighting was assigned the habitat values averaged over the 4 x 4 km grid cell that it was seen within. These were the same habitat values used in the porpoise model. The tree was built using R version 2.12.1 and the tree package (Ripley, 2010). Four habitat variables; depth, distance to coast, slope and sediment type, were included, as well as the X and Y coordinates of the middle of the grid cell. The tree was weighted by the count of animals in each sighting.

The analysis was run twice, once with all of the data, and once excluding data collected by IECS over the BOWL site which, given its offshore location, contained an atypically large number of bottlenose dolphin sightings relative to sightings of other species (see results). Predictions were then made from the output of each analysis, on the basis of the habitat characteristics of cells.

Table 5.5: The number of sightings and count of dolphins used from each of the datasets included in the analysis. JNCC Seabirds at Sea data include data from the RSPB surveys in 1982 and 1983.

Dataset	Year	Number of dolphin sightings	Number of animals recorded
BOWL	2010	5	28
JNCC Seabirds at Sea	1980-1998	45	146
JNCC seismic MMO	1998-2006	23	94
MORL	2010	8	72
Crown Estate	2009-2010	4	15
UoA AFEN	2001	4	43
UoA 2009 boat	2009	1	3
UoA 2010 aerial	2010	29	87
UoA SAC	2004-2005	41	143
UoA Photo-ID	1990-2010	828	7267

5.2.3 Estimation of density from line-transect aerial surveys

A key part of the DECC funded assessment of the impacts of seismic exploration involved an estimation of changes in cetacean density (primarily harbour porpoises) at an impact and control site, before and during a proposed seismic survey in September 2010. These two survey blocks were both 25 x 25 km, with the control block (Figure 5.8, Block B) covering a large part of the MORL and BOWL development areas.

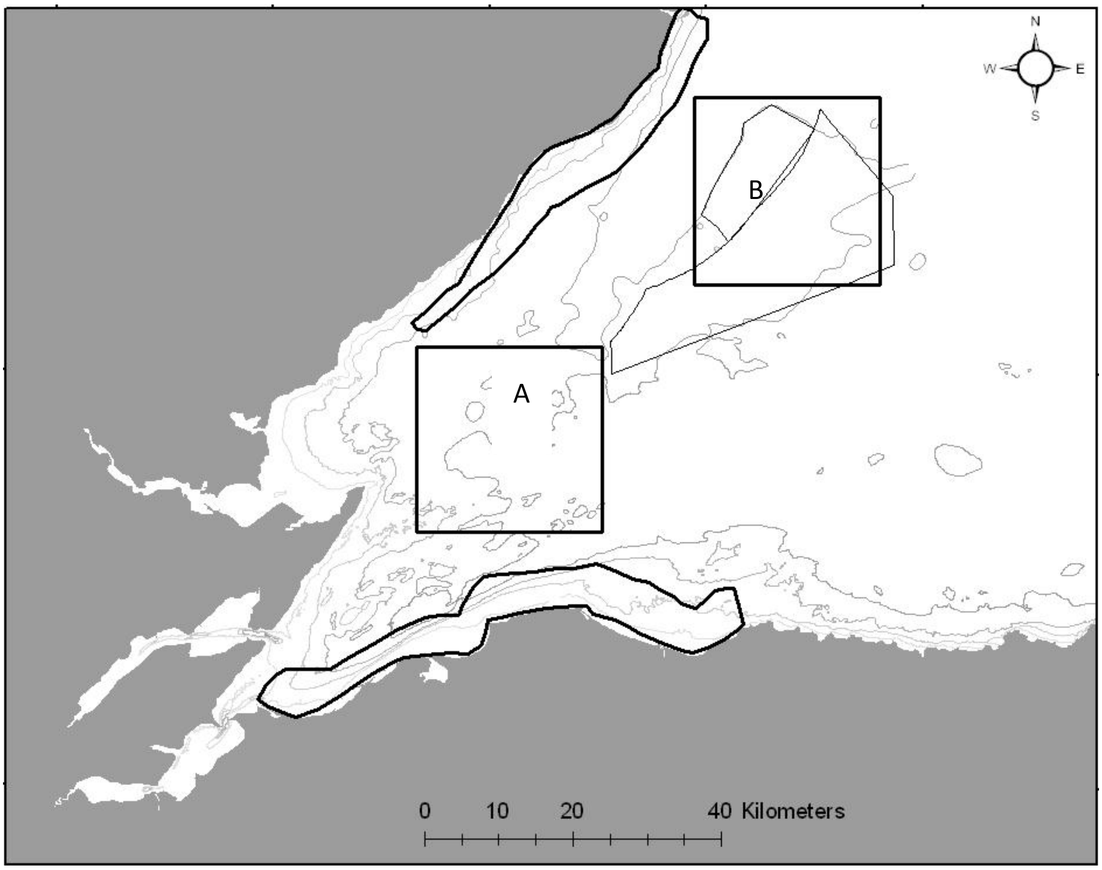

Figure 5.8: A map of the Moray Firth showing the position of the aerial survey blocks in relation to the location of the MORL and BOWL sites.

Aerial surveys (Section 5.1.1) were carried out during August and September of 2010, from a Partenavia 68 aircraft fitted with observer bubble windows. Within the two offshore blocks, parallel north/south transect lines spaced at 4 km were flown on each survey. An offset of 1 km was used and the starting position was selected randomly so that during the course of the survey period, the blocks were covered at 1 km spacing (Figure 5.9). On the coastal transects, the aeroplane flew parallel to the coast at a distance of 1 km offshore, returning on a parallel transect 5 km offshore. The two blocks and transect were surveyed a total of nine times, the north coast route six times and the south coast survey route five times.

The aim of these surveys was to use standard procedures available in the program Distance (Thomas *et al*., 2009) to calculate density and abundance. Data from the whole 45-day survey period were pooled to provide estimates of density both across the entire survey area and in different sub-areas.

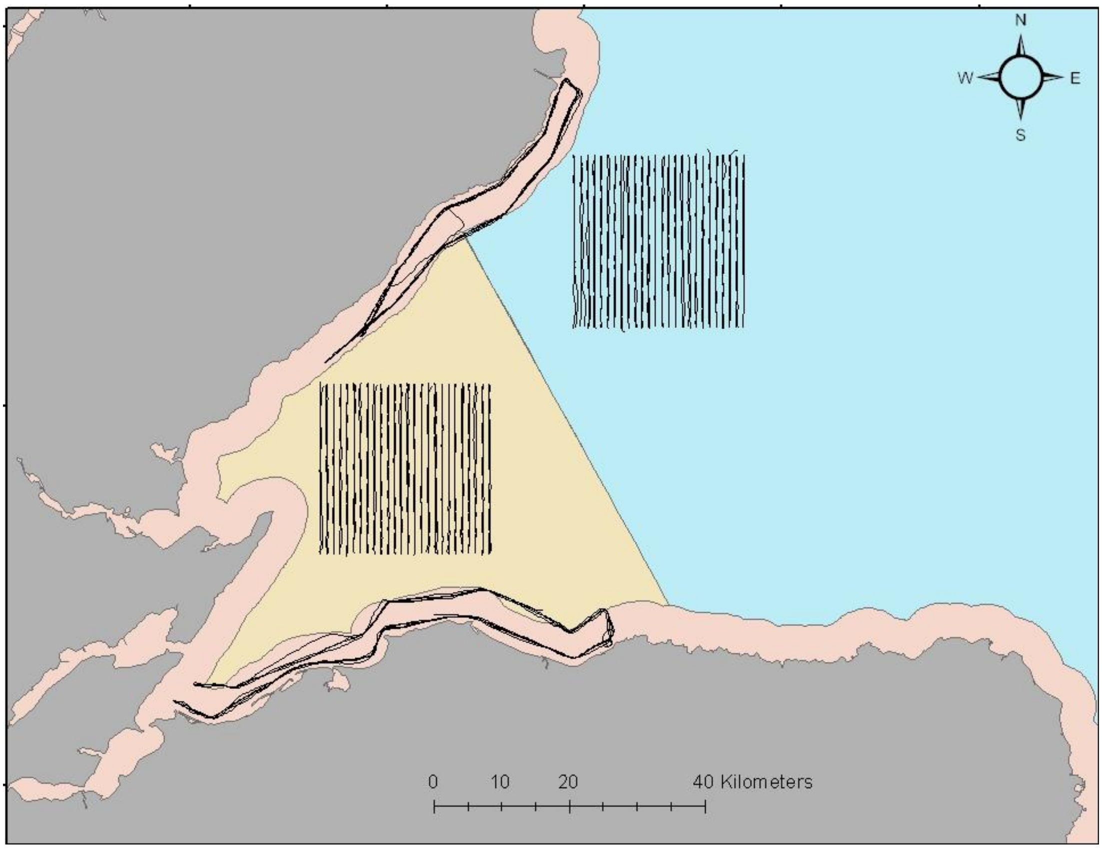

Figure 5.9: Map showing the total aerial survey effort used in the calculations of density and the regions used to estimate abundance (peach = coastal; yellow = central Moray Firth; blue = outer Moray Firth).

Observers followed protocols developed for SCANS and SCANS-II aerial surveys to collect data (SCANS II, Appendix A3.2). Observations were made out of different sides of the aeroplane, and the two observers each recorded sightings into separate voice recorders. Time, species, number of animals and the declination angle to the sighting were recorded as a minimum. GPS data were recorded automatically every five seconds and these data were subsequently interpolated to give the location of the aeroplane when the sighting was made. The horizontal distance from the track-line to the sighting was later calculated from the declination angle and used to calculate the position of each animal seen.

Environmental variables were recorded by a third observer and included Beaufort sea state and glare intensity. A subjective measure of sighting conditions was recorded as four levels; poor, moderate, good and excellent.

These levels related to the likelihood that a porpoise would be observed if it were present, and took into consideration all variables that might influence observers' ability to detect animals. All data collected under poor sighting conditions were removed prior to analysis using Distance.

One of the key assumptions of distance analysis is that all animals on the track line are detected i.e. the detection probability on the track line, g(0), is equal to 1 (Thomas *et al*., 2009). Data collected in studies such as those discussed here fail to meet this assumption in two ways, and this must therefore be accounted for when fitting a detection function to the data.

The first problem is that observers were unable to view the sea areas directly below the aeroplane. This blind sector extended through the closest 20°, which is equivalent to the closest 66 m to the aeroplane. To account for this, data were left truncated at 66 m, meaning that the program did not try to fit a detection function to this area.

The second failure of this assumption occurs because marine mammals spend a proportion of their time under water, and are therefore not available for detection at all times, even when they are within the area being surveyed. To account for this, the probability of detecting an animal on the track line, g(0) is estimated and used as a multiplier when estimating density and abundance. Given the much larger dataset available from the SCANS-II aerial surveys of the North Sea in 2005, we used their value of 0.45 for g(0) for harbour porpoises (Hammond *et al*., In prep). This value was calculated using the racetrack method where the aeroplane circles back around a sighting to determine the re-sighting rate (Hiby, 1999).

Environmental covariates that may have affected detection were included when modelling the detection function. Four covariates were tested; observer identity, sea state, sighting conditions and glare intensity. These were added using a forward stepwise selection procedure based on AIC. Observer identity and sighting conditions were retained in the detection function as they contributed to a lower AIC.

For porpoises, the same detection function was used throughout all analyses and was estimated using the entire dataset.

There were insufficient sightings to estimate detection functions for different dolphin species. On the assumption that the detection of the different dolphin species likely to occur in this region is similar, a single detection function was produced for all dolphins and used to provide an estimate of density and abundance for all dolphins of all species combined. The output from the classification tree analysis provides an indication of the likely species composition of dolphins in different parts of the Moray Firth.

Density estimates for porpoises and dolphins were calculated both for the entire survey area and for the sub-areas areas separately. To provide an estimate of the total number of individual porpoises and dolphins in the region, we stratified the region into three areas each represented by one of the main sampling areas used for our aerial surveys; a coastal strip within 5 km of land, a central Moray zone and an outer Moray Firth zone (see Figure 5.9).

5.2.4 Abundance and distribution of bottlenose dolphins

The most recent estimate of the abundance of bottlenose dolphins along the whole of the east coast of Scotland is based on co-ordinated photo-identification studies in 2006 and 2007, which produced an estimate of 195 (95% highest posterior density intervals (HPDI): 162-253) (Cheney *et al*., In Press a).

More detailed annual surveys within the Moray Firth SAC between 2002 and 2010, indicate that around 50% of these animals use the SAC in each year, with estimates ranging from 68 to 114 individuals; (mean = 93.3) but with overlapping confidence limits (Cheney *et al*., In Press b). Overall, the number of dolphins using the SAC between 1990 and 2010 appears to be stable (Cheney *et al*., In Press b).

Annual estimates of the east coast bottlenose dolphin population were also made for the period 1990-2010 by updating the Bayesian capture-recapture model developed in Corkrey *et al*., (2008). A Bayesian linear regression suggested that there is a >80% probability that the bottlenose dolphin population on the east coast of Scotland is either stable or increasing (Cheney *et al*., In Press b).

Repeat observations of these individually recognisable dolphins have demonstrated that dolphins off the east coast of Scotland are highly mobile, with individuals ranging from the inner Moray Firth to Fife. Some individuals that have been regular sighted within the Moray Firth have occasionally ranged further south with one confirmed sighting in 2007 of a group near Whitley Bay and the Tyne river mouth (Thompson *et al*., 2011b).

Longer range movements have also been recorded (between the Moray Firth and both the West coast of Scotland and SW Ireland), but these have involved individuals that have only ever been observed within the Moray Firth for a very short period (Robinson *et al*., In Press).

Consequently, whilst the Moray Firth is clearly an important area for this population, they are not restricted to the either the Moray Firth SAC or its immediate surrounding waters. Instead, these animals are highly mobile, and appear to have a broad potential range around the UK coast and possibly beyond.

Much of this research into bottlenose dolphins within the Moray Firth have concentrated on the inner waters. In recent years, effort has been put into collecting data and developing new approaches for providing a robust description of broad-scale distribution across the Moray Firth. Ongoing work for DECC, with additional support from MORL and BOWL, is now using a combination of broad-scale passive acoustic monitoring and classification analysis of visual sighting data to predict bottlenose dolphin distribution across the Moray Firth. The approach integrates three sets of data:

- C-POD data from 2009 and 2010 (Figure 5.23) were used to model spatial variation in the probabaility of encountering "dolphins" across the Moray Firth.

- The classification tree analyses of available visual sightings (see Figure 5.30) were then used to determine the probability that "dolphin" detections are bottlenose dolphins, and to provide a density surface representing spatial variation in the probabaility of encountering bottlenose dolphins across the Moray Firth (See Figure 5.32 below).
- The most recent photo-ID based estimate of the East coast bottlenose dolphin population (Cheney *et al*., In Press) was then used to provide an estimate of the total number of animals present in the Moray Firth, and these animals were dispersed across the density surface produced in previously to estimate the number of individuals in each 4 x 4 km square. Based upon a qualitative assessment of photo-ID sighting in different parts of the population's range, we assume that 50% of the estimated population of are within the Moray Firth at any one time.

5.3 Passive acoustic monitoring methods

As highlighted previously, cetaceans spend most of their time underwater, and are often difficult to detect even when at the surface. They do, however, regularly vocalise, and this has meant that passive acoustic monitoring studies have been increasingly used to provide fine-scale spatial data on cetacean distribution and temporal trends in occurrence within key areas (Clark & Clapham, 2004; Verfuss *et al.*, 2007; Van Parijs *et al*. 2009).

The development of automated devices that can remotely record cetacean echolocation clicks for periods of up to six months has proved particularly important for supporting assessments of the impact of different anthropogenic activities including fisheries by-catch and marine renewables (Thompson *et al*., 2010b). These Timing POrpoise Detectors (T-PODS) were originally designed to study harbour porpoises (Thomsen *et al.*, 2005), but can be programmed to detect echolocation clicks from a range of other species (Philpott *et al.*, 2007). For harbour porpoises, it has been estimated that animals can be detected within a distance of approximately 200 m around the T-POD (Tougaard *et al.*, 2006), whereas field studies indicate that bottlenose dolphins can be detected at distances up to 1200 m (Philpott *et al.*, 2007; Bailey *et al*., 2010). In 2009, production of T-PODs ceased, and these were replaced with a new digital device, the C-POD (http://www.chelonia.co.uk/).

The University of Aberdeen have been conducting passive acoustic studies of cetaceans in the Moray Firth since 2005. This has involved studies using both T-PODs and C-PODs, in both coastal and offshore waters. Whilst some data from the Smith Bank have been published (eg. Bailey *et al*., 2010; Thompson *et al*., 2010b), integration of these data with additional unpublished and new data now provides an opportunity to explore temporal patterns of occurrence of harbour porpoises and dolphins on the Smith Bank over the last 5 years.

The following sections outline the different data sets available for these analyses, and describe the device characteristics and analysis methods for T-PODs and C-PODs.

5.3.1 Data sources

Beatrice Demonstrator study (2005-2007)

A key objective of the Beatrice Demonstrator project was to develop and/or validate methods that could be used for assessing changes in the occurrence of cetaceans in response to offshore wind turbine construction. As a result, some studies were conducted in inshore waters, where visual observations could be used to validate acoustic detections on T-PODs (Bailey *et al*., 2010).

In addition, data were collected at other sites in the Moray Firth between August 2005 and December 2007; at a site near the Beatrice Demonstrator turbines and at a site 40 km to the south near Lossiemouth (Figure 5.10). The original aim was to use this second location as a control site. In practice, the identification of suitable control sites was constrained by the limited information available at this time on cetacean distribution in the Outer Moray Firth, and uncertainties over the scale of the potential impact (see discussion in Thompson *et al*., 2010b).

Data from August to October of 2005, 2006 and 2007 have previously been published in Thompson *et al*., (2010b) but, until the present study, there has been no analysis of the full dataset to explore long-term variation in acoustic detections at this site. Because earlier studies during the Beatrice Demonstrator project were based upon T-PODS (Bailey *et al*., 2010), and more recent work has been conducted using C-PODS (Thompson *et al.,* 2010b), any investigation of these long-term patterns first required a comparison of performance of these two different devices. To address this, both a C-POD and a T-POD were deployed at 14 of the moorings used during the 2010 field season. In each case, the two devices were cable tied side by side at the same position on the mooring.

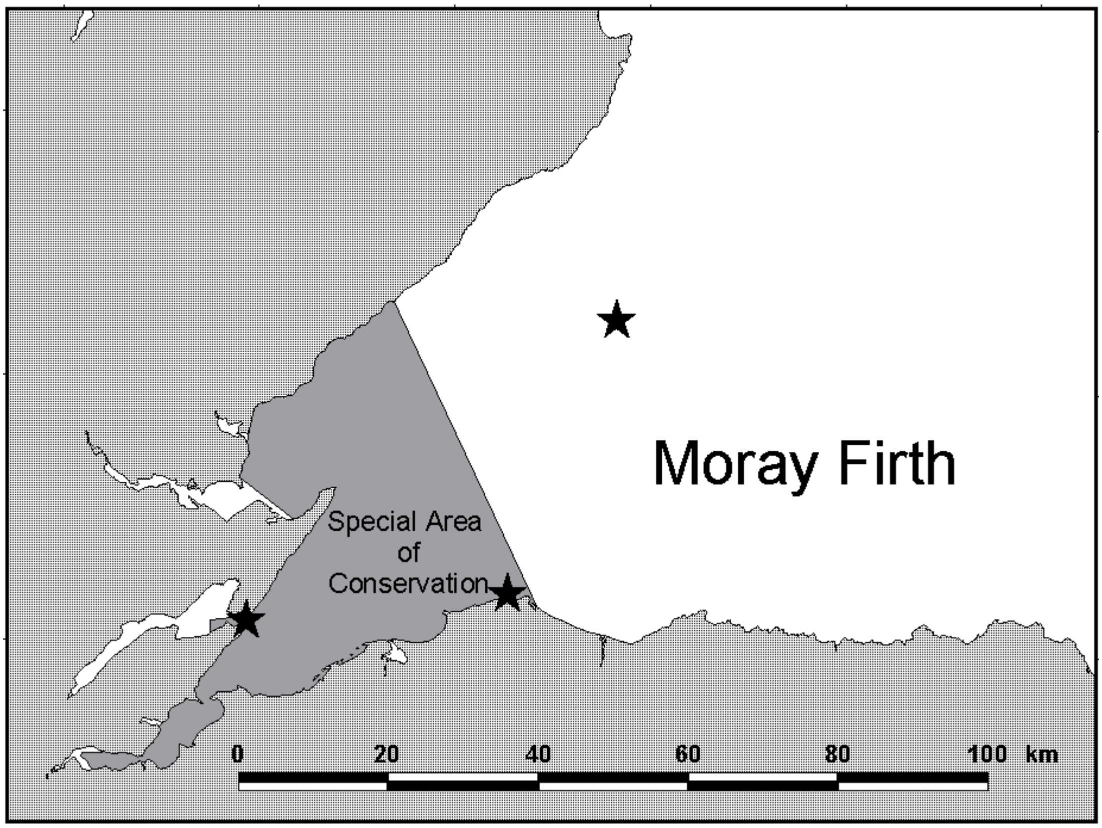

Figure 5.10. Sites used for passive acoustic monitoring during the Beatrice Demonstrator study, 2005-2007. Reproduced from Bailey *et al.*, 2010.

SNH & SEERAD Studies (2006-2008)

Following the Beatrice Demonstrator Project, further passive acoustic monitoring in the Moray Firth was conducted as part of a broader scale SNH and SEERAD funded study of the distribution and abundance of bottlenose dolphins in Scottish coastal waters (Thompson *et al*., 2011b). No additional data were collected from the wind farm development areas. Nevertheless, these studies continued the time-series of data at the Lossiemouth site, and extended this to other sites along the southern Moray Firth coast (Figure 5.11) which could potentially support ES work related to cable installations. Almost all of these data were collected using T-PODs, but the newly developed C-PODs were deployed at three sites in the final year of the study.

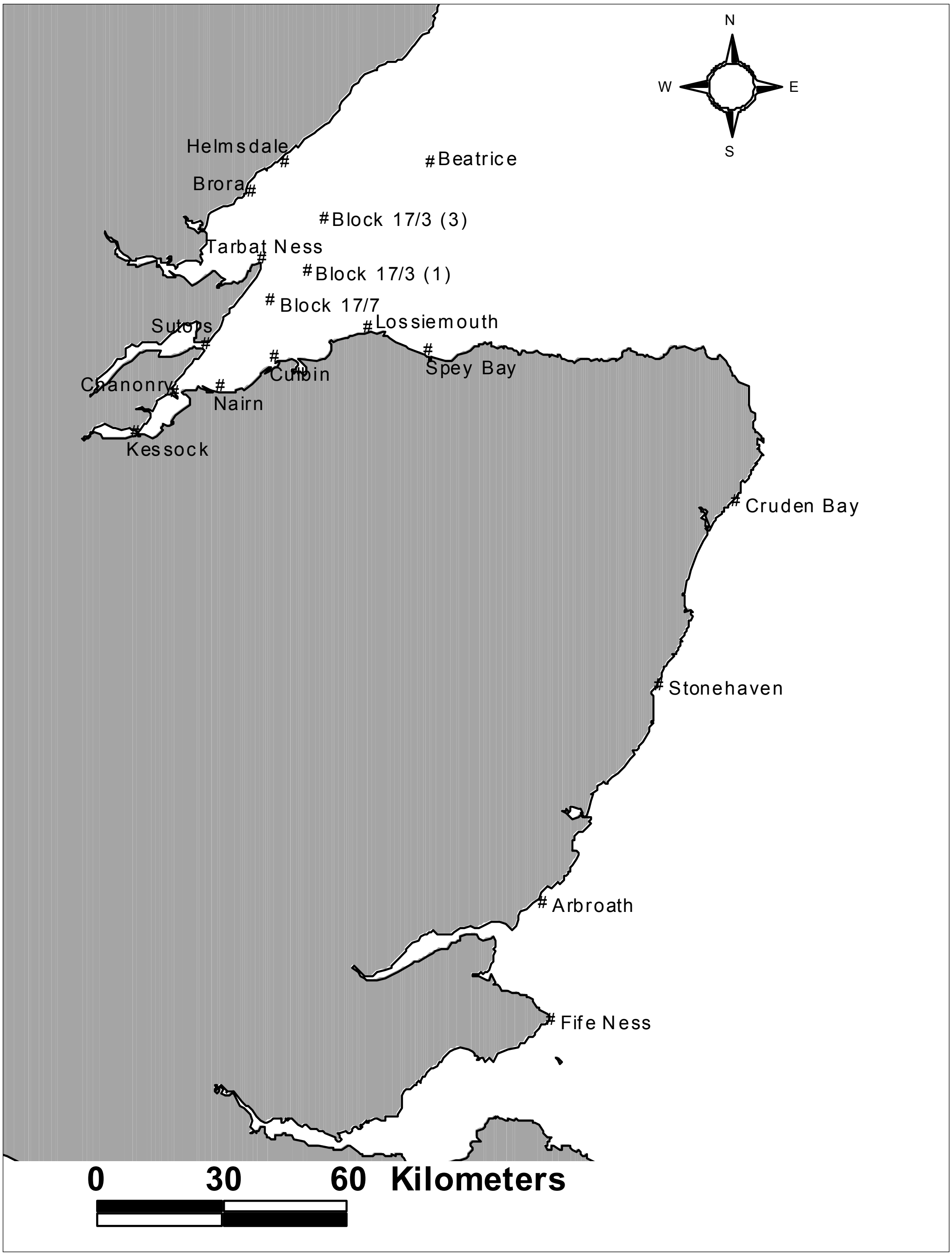

Figure 5.11: Sites used for passive acoustic monitoring during SNH and SEERAD funded studies 2006-2009. Reproduced from Thompson *et al.*, 2011b

DECC Study (2009-2010)

DECC funded studies in the 2009 and 2010 led to the deployment of an extensive array of C-POD monitoring across the Moray Firth. In 2009, deployments were made for the period May-Nov (Thompson *et al*., 2010a). In 2010, deployments were made for the period July-Dec.

In both years, these studies involved deployments at multiple sites within both the BOWL and MORL development areas (Figure 5.12a and b). All primary deployments were made using C-PODs. For a subset of moorings in 2010, C-PODs were paired with T-PODs to provide data for comparison of detection rates between the two devices.

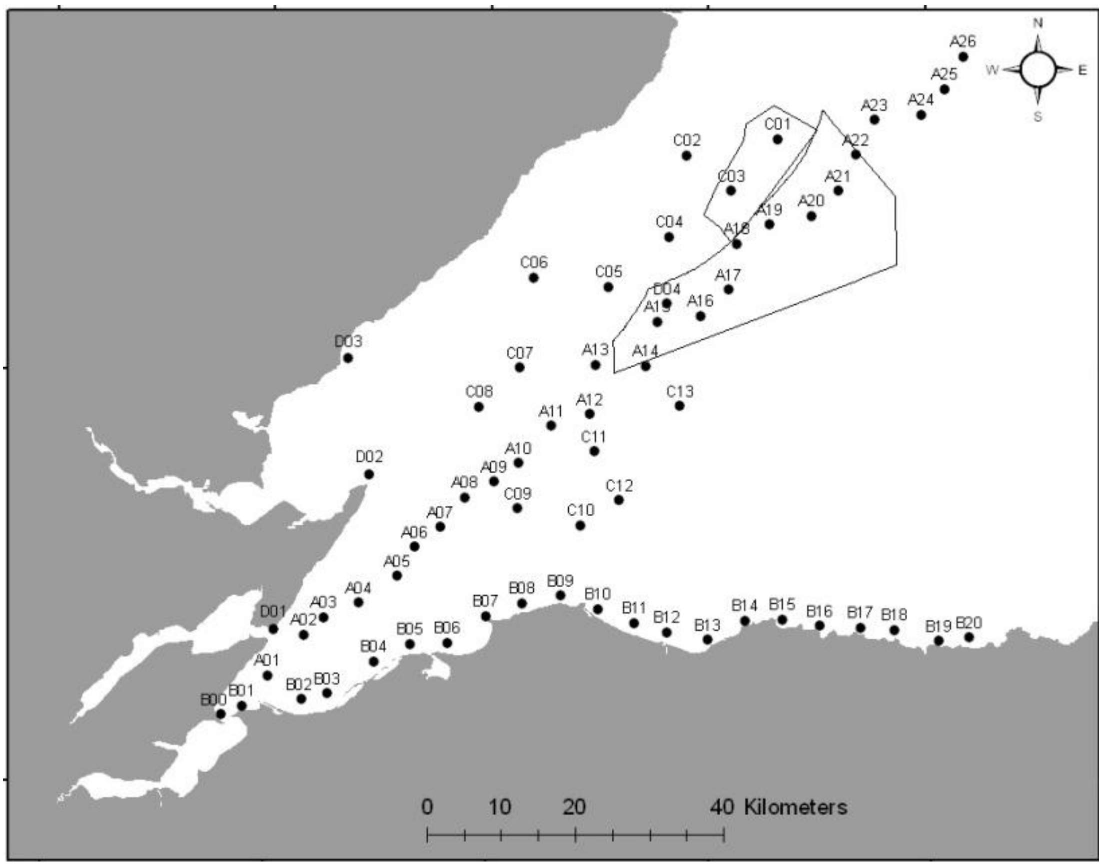

Figure 5.12a: Sites used for passive acoustic monitoring during DECC funded studies in 2009.

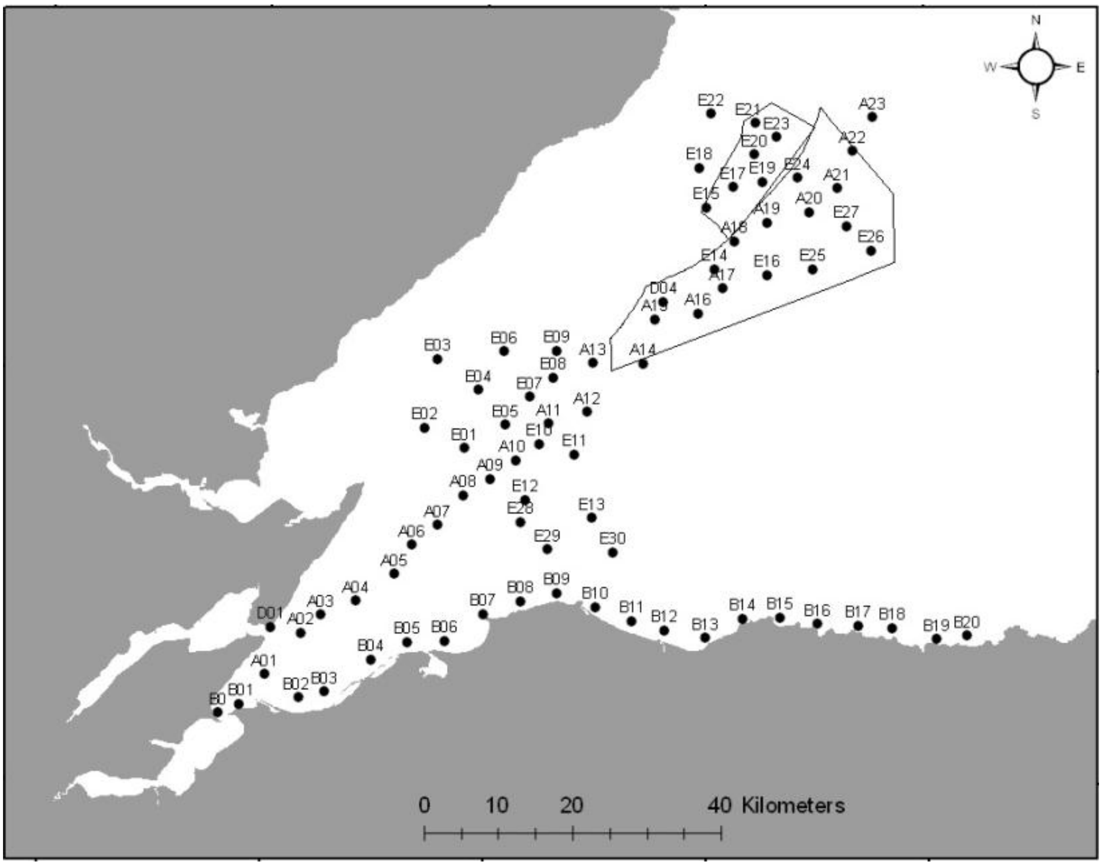

Figure 5.12b: Sites used for passive acoustic monitoring during DECC funded studies in 2010.

MORL/BOWL funded studies (2010-2011)

Between 2009 and 2011, most acoustic data collected through these other studies were collected during the period July-November. To complement these data and assess seasonal patterns of occurrence, MORL and BOWL contracted the University of Aberdeen to make additional deployments within their development areas at other times of year.

In the first of these winters (2009/10), deployments were made at two sites within both the MORL and BOWL area, although one device from the MORL area was lost. In the second winter (2010/11), deployments were made at 15 sites within the MORL area and six sites within the BOWL area. Locations of all the PAM sites within and in the vicinity of the MORL and BOWL development areas are shown in Figure 5.13.

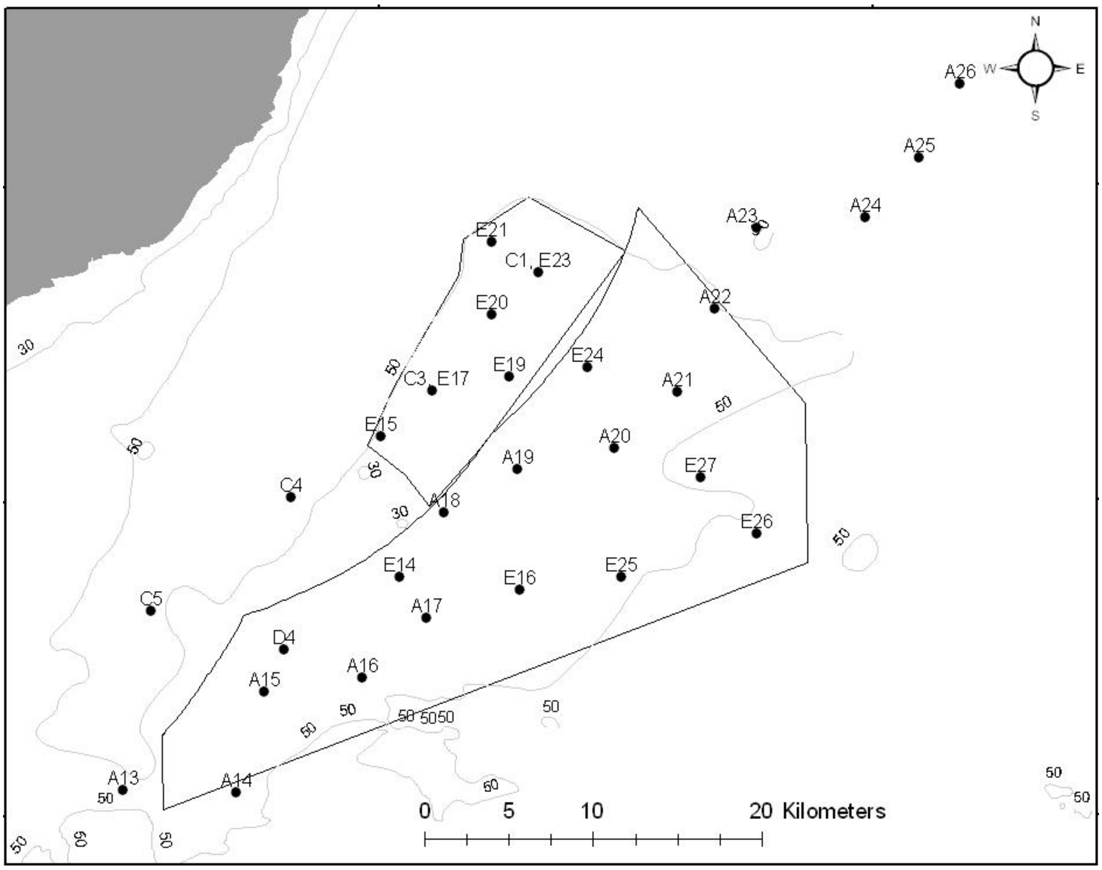

Figure 5.13: Sites at which T-PODs or C-PODs have been deployed within or close to the MORL and BOWL development areas.

5.3.2 Equipment

T-PODs

T-PODs incorporate a hydrophone, analogue processor and digital timing system that automatically logs the start and end of each echolocation click to 10 μs resolution. In every minute, the T-POD runs six successive scans within different user-defined frequencies, logging detections for periods of up to five months. An accompanying software program is used to post-process the recovered data, detect characteristic click trains, and remove noises from other sources such as boat sonar (see www.chelonia.co.uk for details). Resulting data on the number of cetacean click trains recorded in each minute can be used to determine the presence or absence of target species in different time periods, or to identify the timing and duration of encounters with target species.

In these studies, Version 4 and Version 5 T-PODs were used to detect echolocation click trains. Following guidelines for use in areas where both harbour porpoises and bottlenose dolphins might be detected, T-PODs were configured to detect clicks from dolphins and porpoises on alternate channels.

For dolphins, a target frequency of 50 kHz and a reference frequency of 70 kHz on three of the channels were used. For porpoises, a target frequency of 130 kHz and reference of 92 kHz on the three other channels were used.

All data were processed using version 8.24 of the manufacturer's software (version 4.1 train filter). This train detection algorithm in the T-POD software assigns trains into several different categories. The category "*CET ALL*" was used, which combined both the high probability click trains (CET HI) and less distinctive trains (CET LO), following the recommendation of the manufacturer (www.chelonia.co.uk) and previous assessments of performance for detecting harbour porpoises (Thomsen *et al*., 2005). T-POD data were subsequently used to determine those hours in which dolphins and porpoises had been detected at each site on each day.

Validation studies in the inner Moray Firth had previously shown that false porpoise detections sometimes occurred within a series of dolphin detections, even when dolphins were confirmed to be the only cetacean present in the area. In areas where dolphins are common and porpoises are rare, this can artificially inflate the occurrence of porpoises. In such areas, this problem can be avoided by only considering porpoise detections as positive if they occurred during a sampling period in which no dolphin clicks were detected. In practice, this was not an issue in the Outer Moray Firth as dolphin detections were extremely rare.

C-PODs

In 2008, production of the T-POD ceased following the development of a digital echolocation detector, the C-POD (www.chelonia.co.uk). A V.0 C-POD was produced during 2008, and the first V.1 C-POD units were available in June 2009. The C-POD continuously monitors within the range of 20-160 kHz for possible cetacean clicks, and records the centre frequency, frequency trend, duration, intensity, and bandwidth of each click.

As with T-PODs, these data are then post-processed to differentiate between dolphins, porpoises and other high frequency sounds such as boat sonar. The output indicates the level of confidence in classification of the detection as a cetacean echolocation click by classing each as CetHi, CetMod or CetLow.

Prior to deployment in the Outer Moray Firth, all new C-PODs were first bench tested using an artificial high frequency noise source. Short trial deployments of one to two days were then made in the mouth of the Cromarty Firth, an area which is used by bottlenose dolphins on a daily basis during summer, to ensure that they were detecting dolphin echolocation clicks. Once recovered, data were downloaded and analysed using V1.054 of the C-POD train filter to identify detections of harbour porpoises and dolphins. In these analyses, only CetHi and CetMod detections were used to estimate the number of hours that either porpoises or dolphins were detected at each sampling site on each day.

Deployment

Because of greater levels of fishing effort in the outer Moray Firth, the mooring design used previously in inshore areas was modified. In this study, moorings with a single riser from a 100 kg or 150 kg weight were used, and a larger surface Dhan buoy with radar reflector and flag (Figure 5.14). As in previous studies, PODs were attached to the riser at a height of approximately 2-6 m above the seabed. In 2009, offshore deployments were made from FV Rois Mhairi and some recoveries were made from FV Alba, MV Topcat and MV Solstice. In 2010 and 2011 all deployments and recoveries were made from MV Solstice.

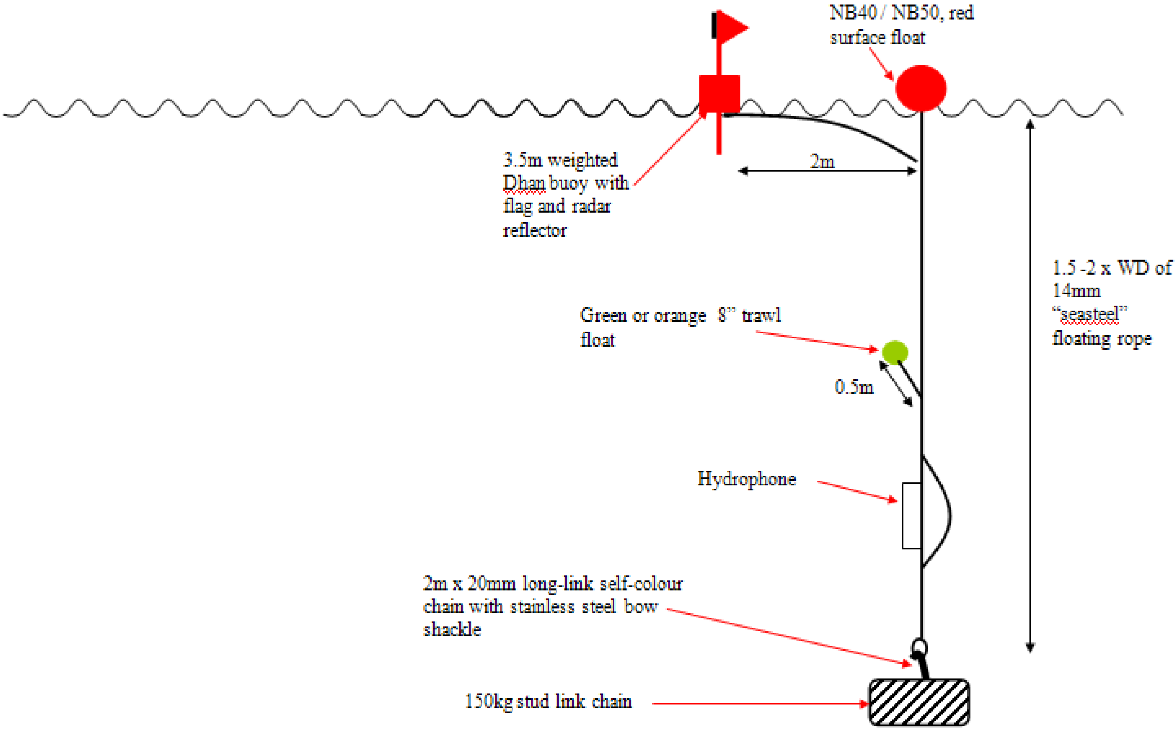

Figure 5.14: Single riser mooring design with Dhan buoy used to suspend PoDs in the water column.

5.4 Results

5.4.1 Cetacean sightings during different visual survey programmes

Overall, there were over 1000 encounters with a total of seven different species of cetacean during the visual survey programmes outlined in Section 5.1 (Table 5.6).

Maps presenting raw data on the distribution of all sightings of harbour porpoises and dolphins are shown in sections in Figures 5.15 – 5.19. In all these figures and in Table 5.6, only those sightings where the different survey teams were confident about species identification are included.

Table 5.6: Number of sightings of cetaceans recorded during each of the different visual survey programmes.

Species	AU SAC	AU Boat	AU Aerial	MORL	BOWL
Harbour porpoise	54	71	230	190	114
Bottlenose Dolphin	56	1	26	1	4
White-beaked dolphin	0	0	2	3	0
Risso's Dolphin	0	0	1	1	0
Common Dolphin	0	0	6	3	1
Unidentified Dolphin	0	1	4	4	6
Killer Whale	0	0	0	2	0
Minke Whale	10	34	13	24	43

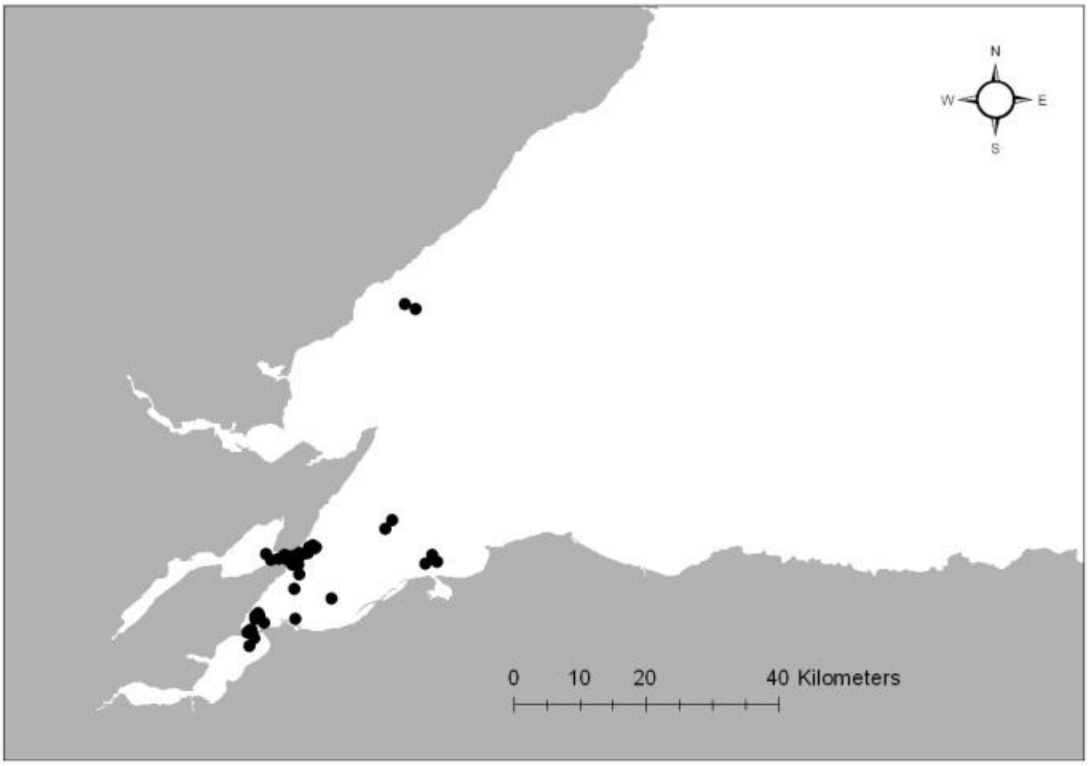

Figure 5.15a: Sightings of dolphins made during the University of Aberdeen surveys within the Moray Firth SAC. All sightings of dolphins on these surveys were reported as bottlenose dolphins.

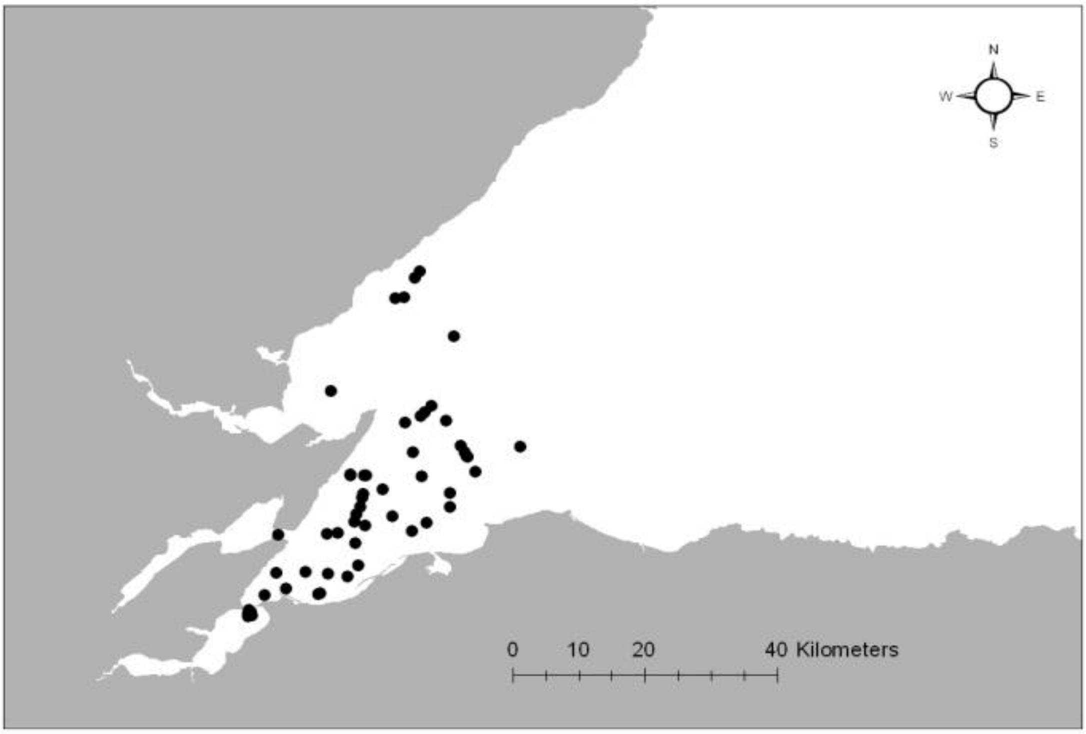

Figure 5.15b: Sightings of harbour porpoises made during the University of Aberdeen surveys within the Moray Firth SAC. All sightings of dolphins on these surveys were reported as bottlenose dolphins.

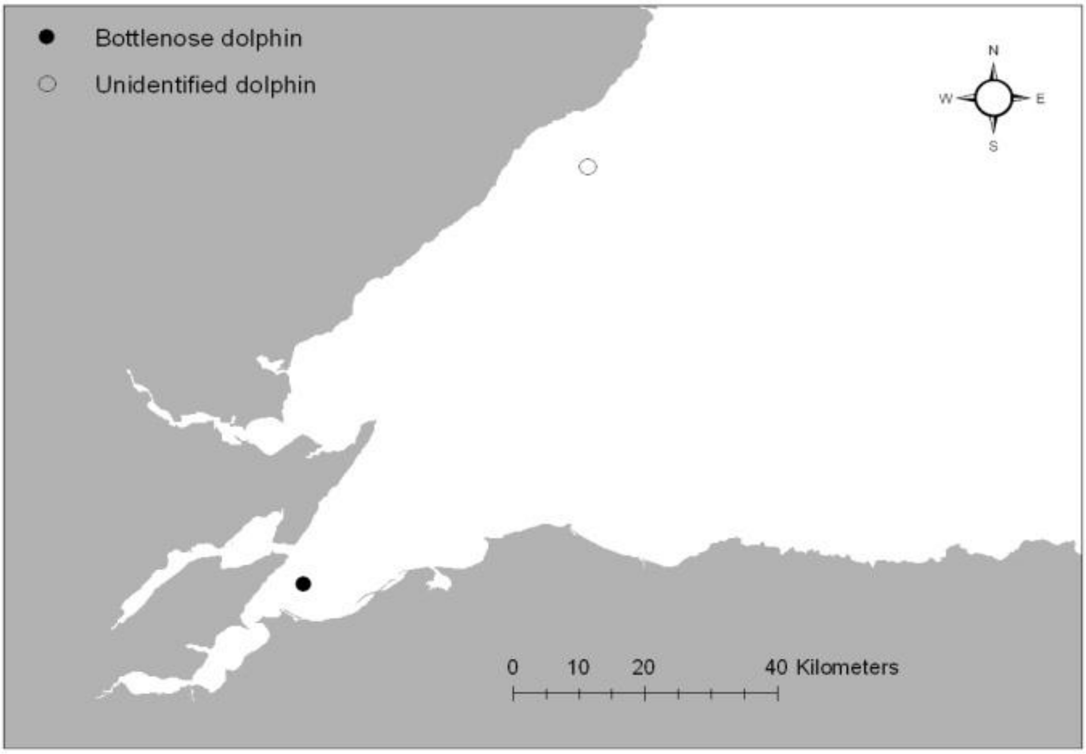

Figure 5.16a: Sightings of dolphins made during the University of Aberdeen's 2009 boat based surveys in the Outer Moray Firth.

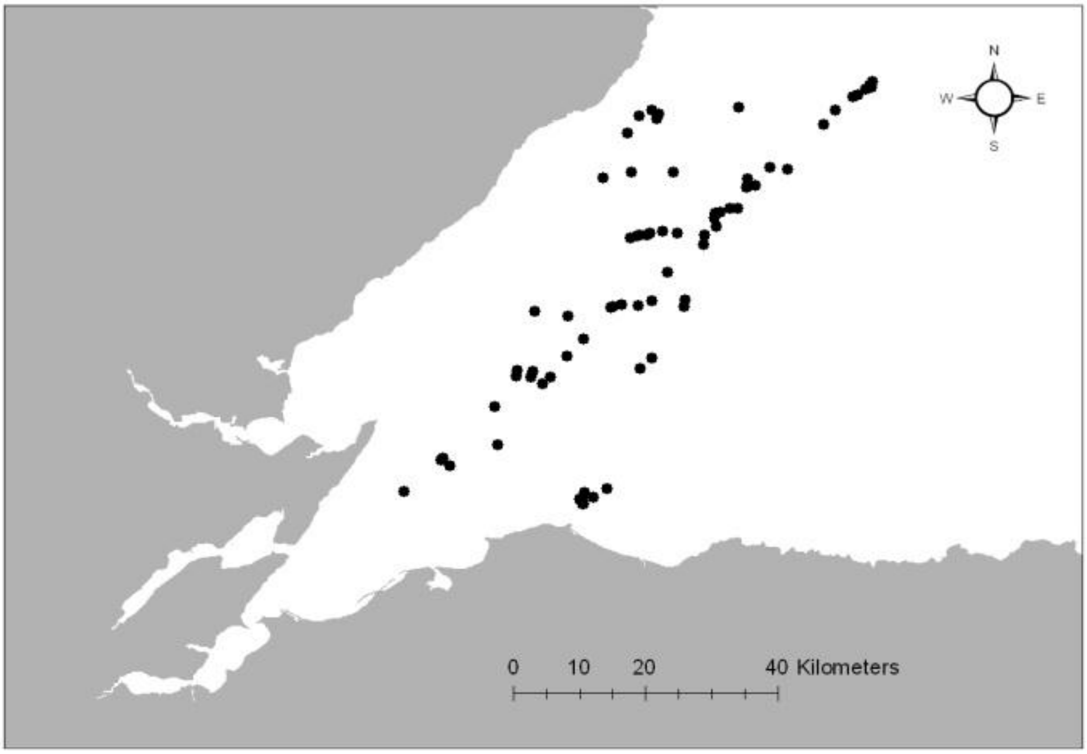

Figure 5.16b: Sightings of harbour porpoises made during the University of Aberdeen's 2009 boat based surveys in the Outer Moray Firth.

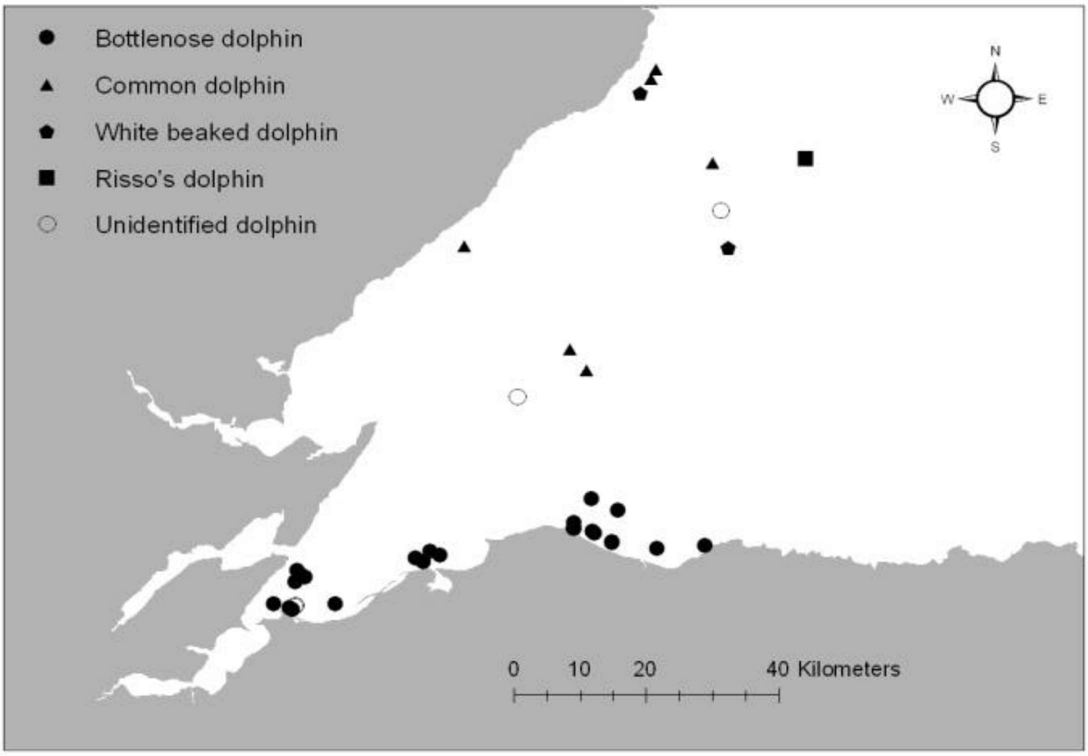

Figure 5.17a: Sightings of dolphins made during the University of Aberdeen's 2010 aerial surveys of the Outer Moray Firth.

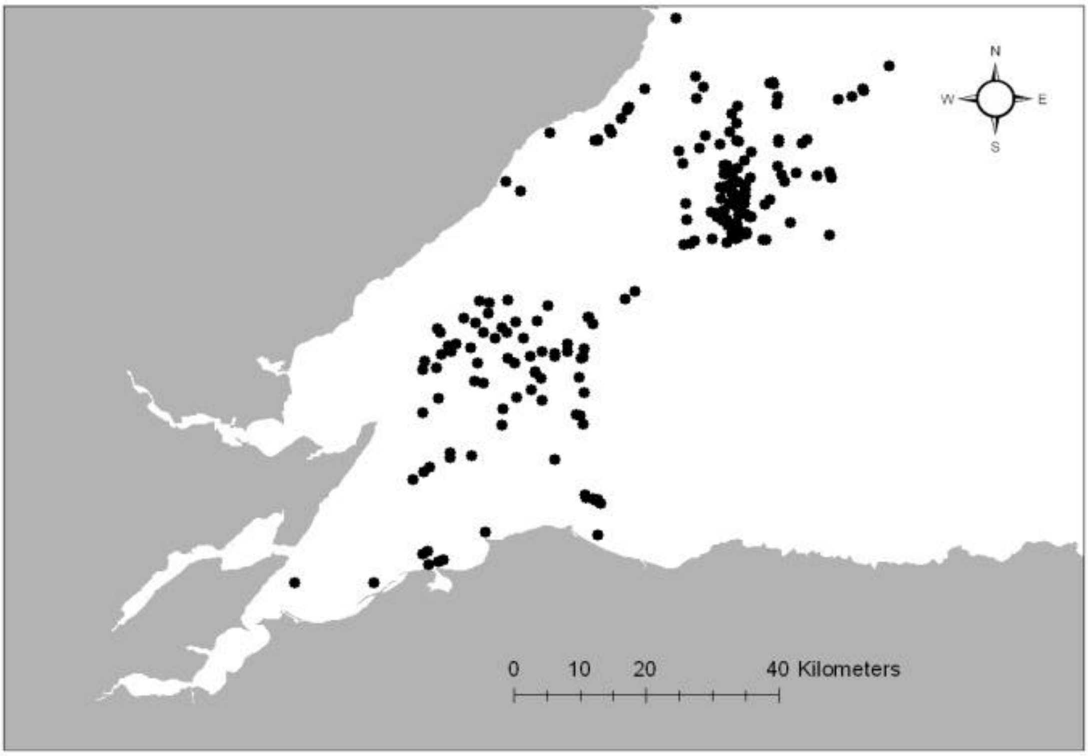

Figure 5.17b: Sightings of harbour porpoises made during the University of Aberdeen's 2010 aerial surveys of the Outer Moray Firth.

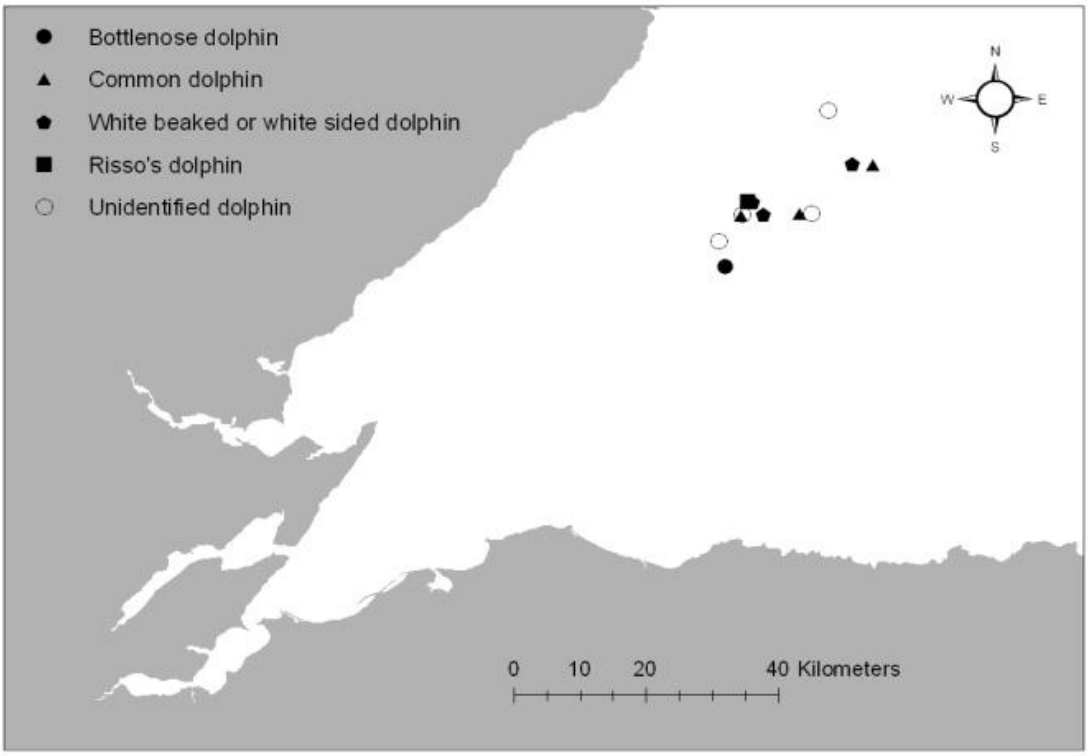

Figure 5.18a: Sightings of dolphins made during Natural Power boat surveys of the MORL sites (Telford, Stevenson and MacColl) between April and October of 2010.

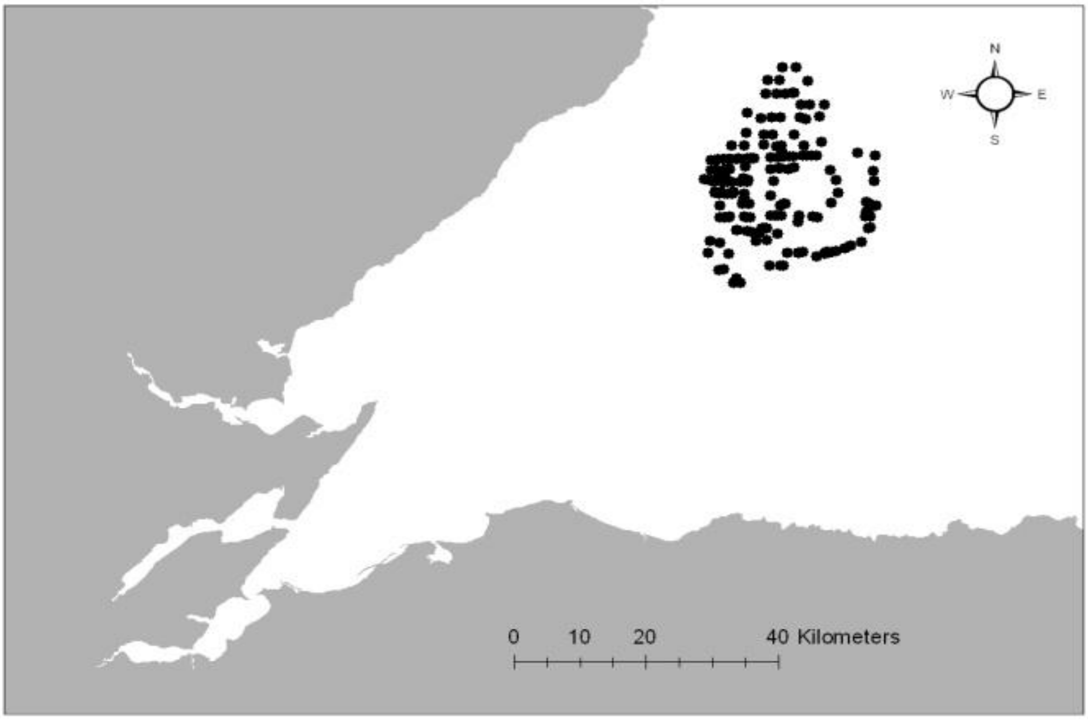

Figure 5.18b: Sightings of harbour porpoises made during Natural Power boat surveys of the MORL sites (Telford, Stevenson and MacColl) between April and October of 2010.

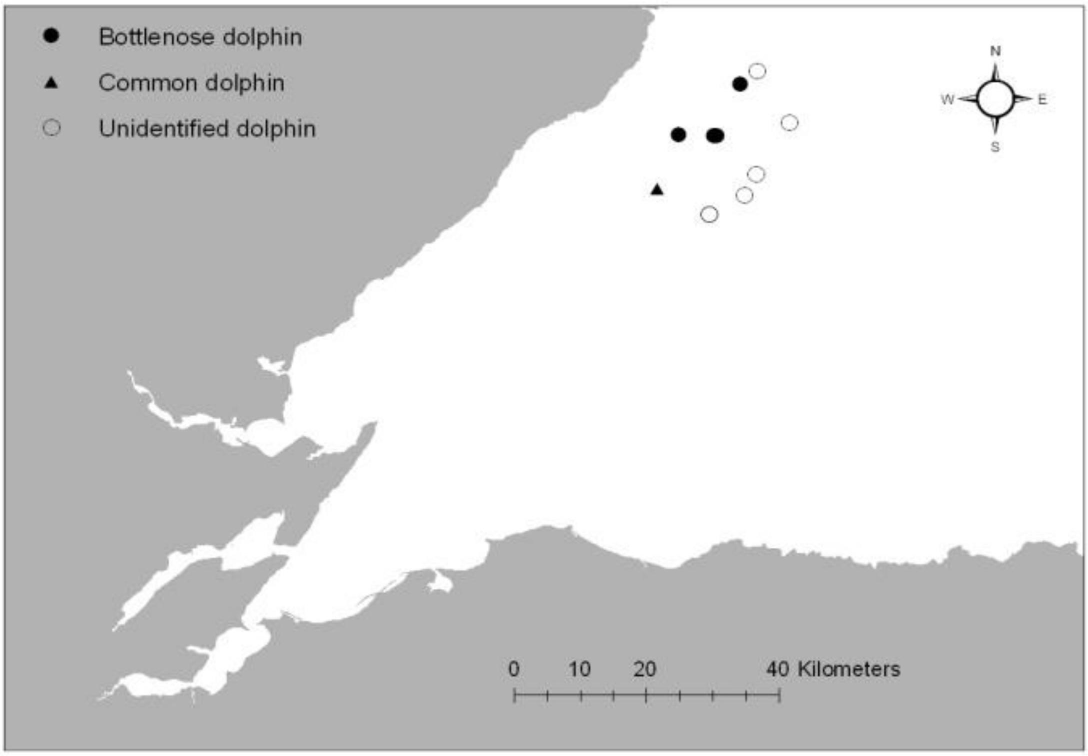

Figure 5.19a: Sightings of dolphins made during IECS boat surveys of the BOWL site between April and October 2010.

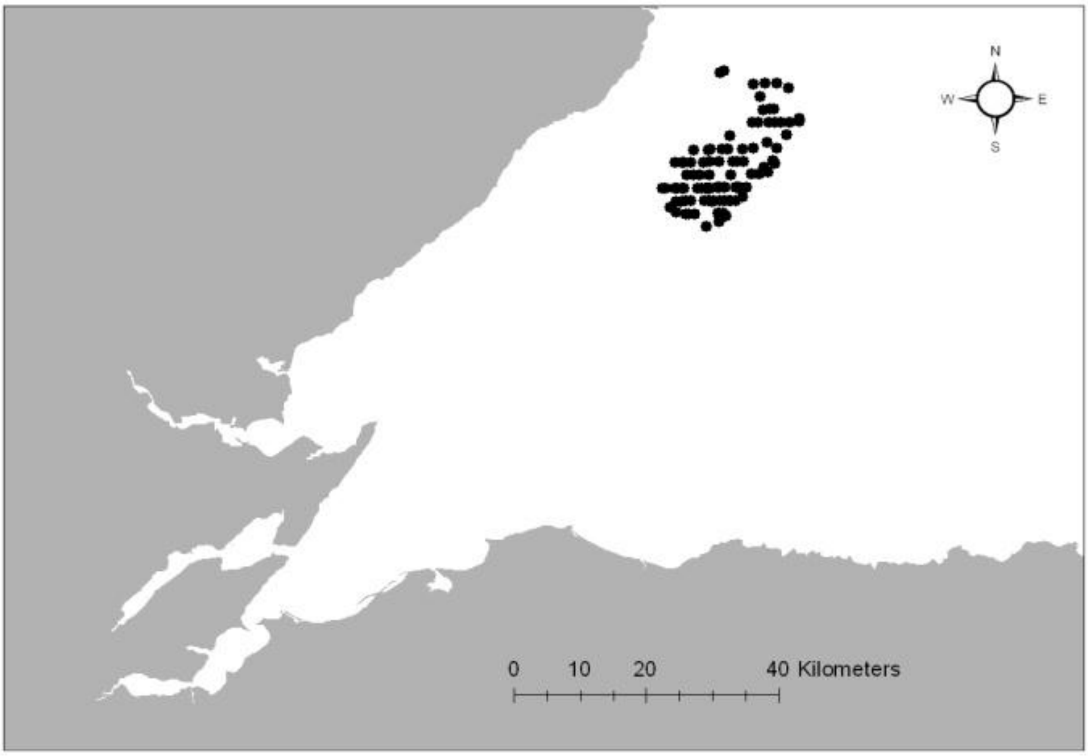

Figure 5.19b: Sightings of harbour porpoises made during IECS boat surveys of the BOWL site between April and October 2010.

5.4.2 Modelling harbour porpoise habitat association & distribution

Models were based on over 1000 sightings of porpoises from the five different surveys (Table5.7).

Table 5.7: Total effort and number of sightings of animals used from each dataset once datasets were adjusted to remove data from those cells where no habitat data were available.

Dataset	Total effort (km) used in models	Total porpoises used in models
UoA SAC	1298	62
UoA 2009 boat	1618	131
UoA 2010 aerial	4493	341
BOWL	1390	177
MORL	3015	362

The model with the lowest AIC (1739) excluded slope and then method, but a 2D smoother (the GAM equivalent of an interaction term) for depth and proportion of sand and gravelly sand was included. The final model therefore contained only this 2D smoother and effort as an offset in the fixed effects, and cell identity in the random effects. The r^2 of this model was 0.381.

The random effects of the model showed that there was a relatively strong correlation, of 0.69 between observations from the same cell. This was calculated as:

$$a^2/(a^2+b^2)$$

where ***a*** is variance of the random intercept and ***b*** is variance of the residual term (Zuur *et al*., 2009). In this case, a=0.710 and b=0.481.

The shape of the 2D smoother (Figure 5.20) produced by the final GAMM of porpoise numbers shows that few animals were sighted in shallow or deep waters, but more were found at intermediate depths of around 40 m to 50 m. At these depths, increases in the proportion of sand and gravelly sand lead to an increase in the probability of sightings. The peak in porpoise sightings in deep water with low proportions of sand and gravelly sand is a result of very few observations with these habitat characteristics, and any predictions for deeper water areas are therefore extremely uncertain.

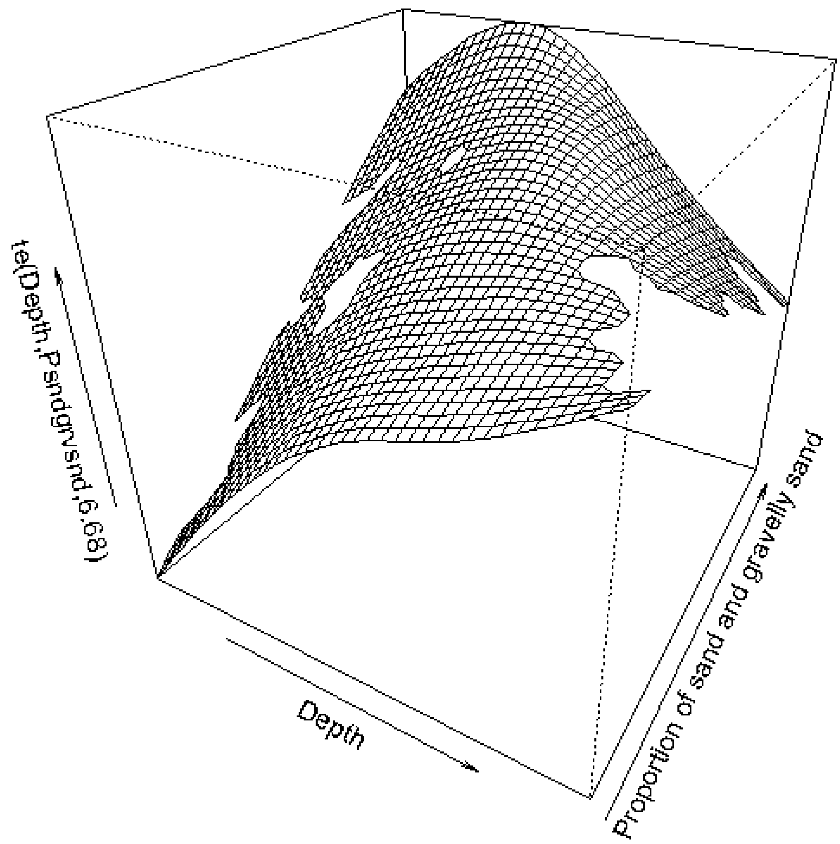

Figure 5.20: Two dimensional smoother used in the porpoise habitat association model to describe the relationship with both depth and the proportion of the sediment made up of sand and gravelly sand.

Table 5.8: Results of the GAMM of porpoise counts.

Parametric coefficients				
	Estimate	**Standard error**	**t-value**	**p-value**
Intercept	-3.010	0.084	-35.86	<0.001
Smooth terms				
	Estimated df	**Reference df**	**F**	**p-value**
te(Depth,Psndgrvsnd)	6.679	6.679	6.274	<0.001

The results of this model (Table 5.8) were then used to predict spatial variation in the relative abundance of porpoises across the Moray Firth. The predicted number of porpoises in each 4 x 4 km cell was based upon the depth and proportion of sand and gravelly sand within that cell, and standardised for a constant unit of effort. Figure 5.21a shows the predicted number of porpoises encountered in different parts of the Moray Firth for a standard 1 km of survey effort, and Figure 5.21b shows the standard error of this prediction for each cell.

Although cell identity was included as a random effect, model validation plots indicted there was still some spatial correlation in residuals. This means that predicted densities for cells outside the main survey area (see Figure 5.7) are the most uncertain (Figure 5.21b). This is particularly so for deep water areas due to the interaction with depth and sediment type (Figure 5.20), and the lack of survey effort in waters deeper than 80 m. Therefore, this report did not make predictions for any cells where water depth is greater than 120 m, and the higher uncertainty for the cells with depths in the range 75-120 m should be recognised when interpreting these data.

These values for the relative abundance of porpoises were subsequently scaled to absolute abundance using the density estimates obtained from the aerial line transect survey (see Section 5.7). This was based on the highest quality data from the 98 4 x 4 km cells that overlapped the two 25 x 25 km survey blocks (Figure 5.8). Using the estimated density value for each of these two blocks, we calculated the total number of porpoises that were predicted to be within these 98 cells. These animals were then re-distributed across the 98 cells according to each cells' predicted measure of relative abundance from the habitat association modelling (Figure 5.21a). The resulting values provide an indication of the number of porpoises likely to be present in each 4 x 4 km cell (Figure 5.22).

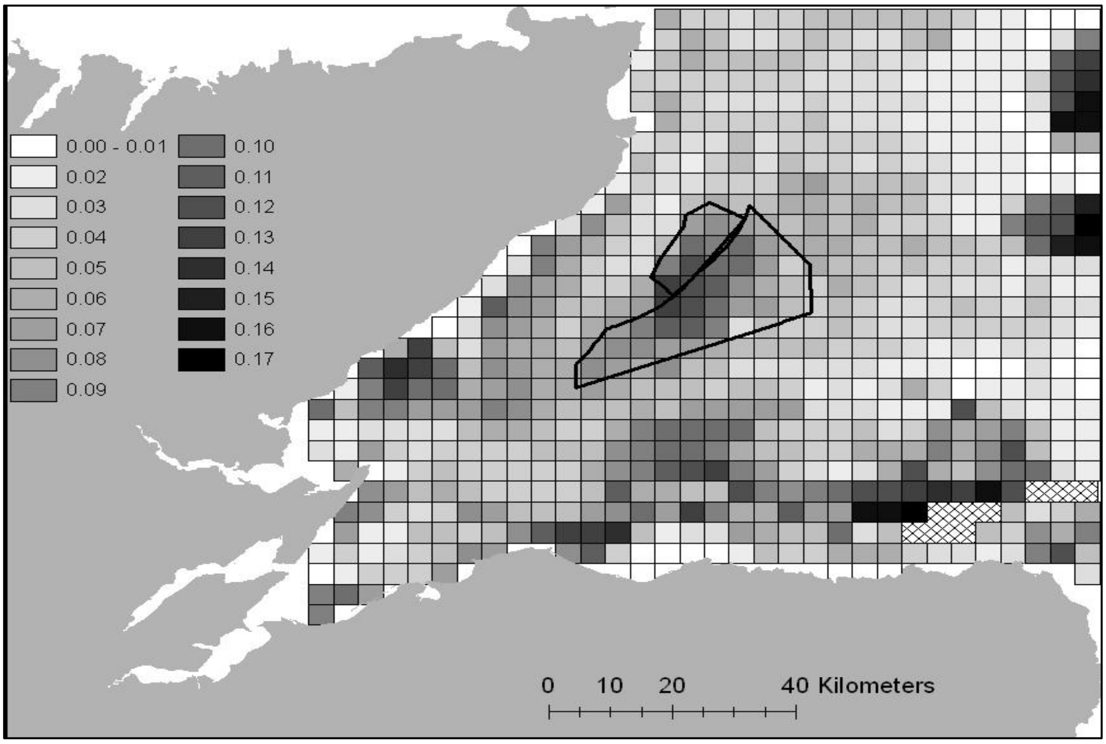

Figure 5.21a: Predictions of the number of harbour porpoise within each cell, given 1 km of effort.

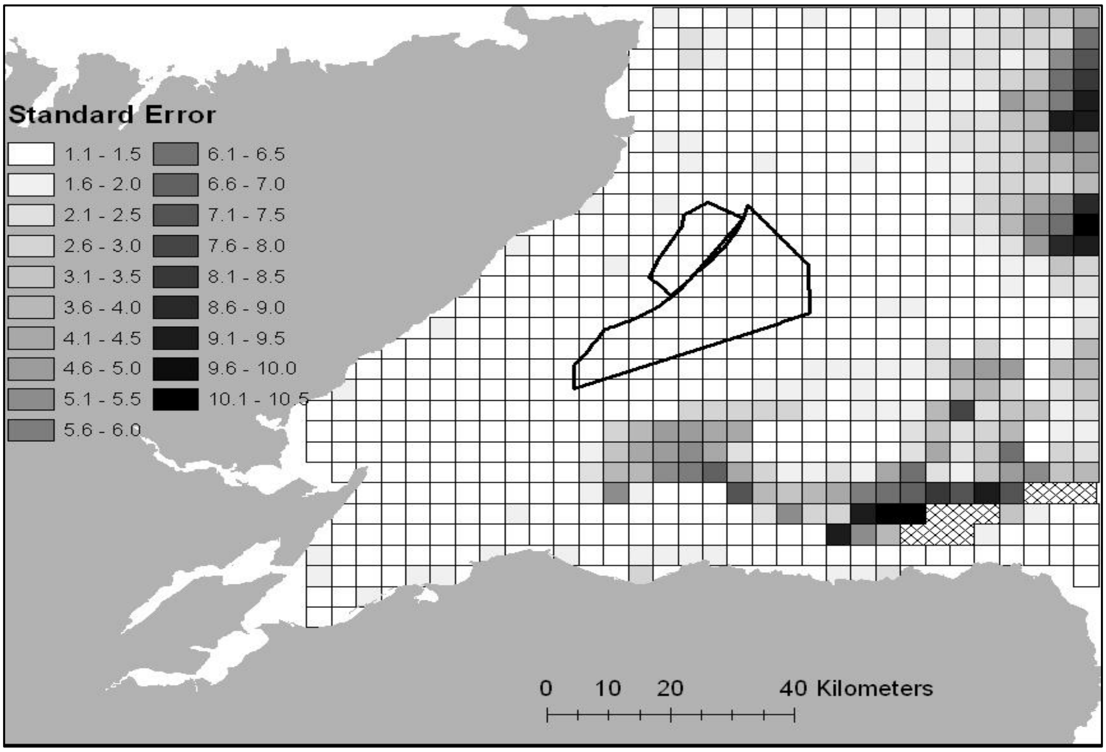

Figure 5.21b: Standard errors around predicted values in each cell.

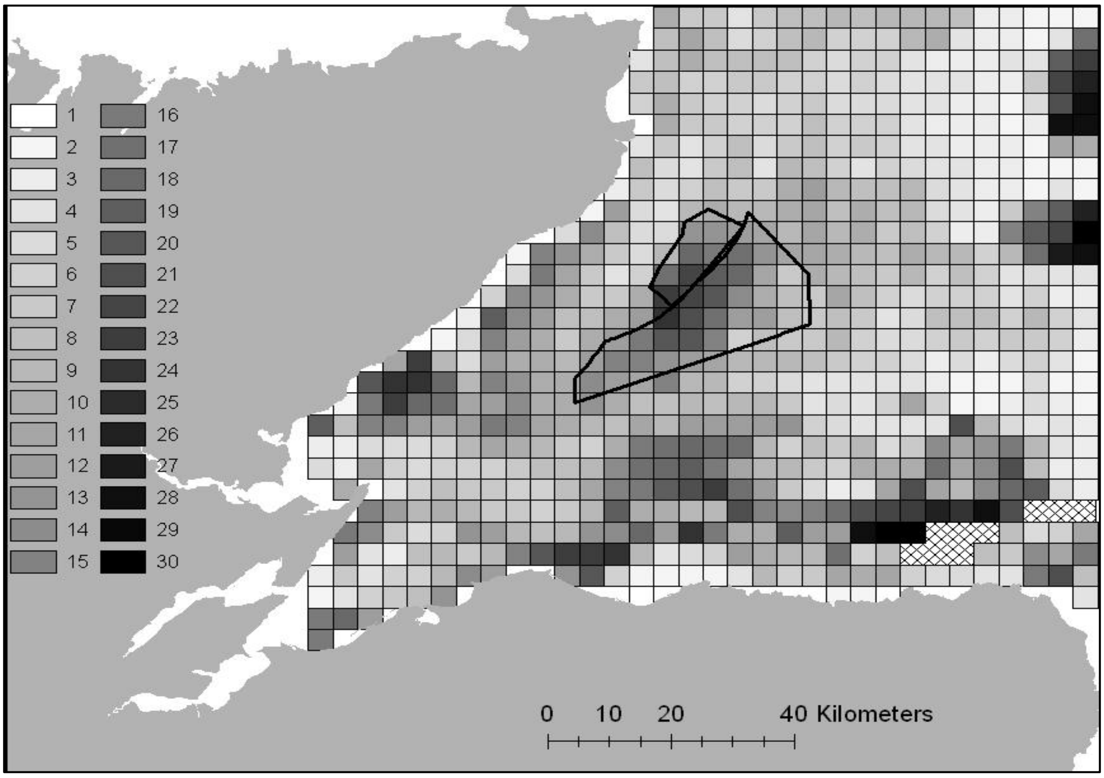

Figure 5.22: The predicted number of harbour porpoises in each cell. Values based upon measures of relative abundance derived from the habitat association modelling (Figure 5.21), scaled according to estimates of absolute abundance from aerial line transect surveys (Table 5.10), and extrapolated to other areas according to predicted relative abundance (Figure 5.21).

5.4.3 Assessment of spatial variation in cetacean occurrence using passive acoustic monitoring data.

This assessment of broad scale spatial variation in the occurrence of harbour porpoises and dolphins across the Moray Firth was based on data from the arrays of C-PODS deployed during the DECC funded study in 2009 and 2010 (Figure 5.12). The primary period of data collection in both years was between July and October, and data were recovered from 56 of 64 devices (88%) in 2009 and 60 of 68 devices (88%) in 2010. There were slight differences in both the spatial pattern and temporal coverage between years because of changes in the study design and patterns of equipment loss or failure (see Figure 5.12). Nevertheless, these passive acoustic monitoring data show a consistent pattern in both years.

Both dolphins and porpoises were detected on all PODS at least once during their deployments, but the number of days on which they were detected varied considerably. Currently, it is not possible to use these click characteristics to determine which species of dolphins have been detected on the PODs, and it is likely that detections in different areas represent different species.

Dolphins were detected regularly in the inner Moray Firth and along the southern Moray Firth coast, but detections were less frequent in the central part of the Moray Firth. However, dolphin detections increased again at more offshore locations, including those around the wind farm sites (Figure 5.23). In contrast, harbour porpoises were detected more commonly throughout the whole study area, with the lowest detection rates in those coastal areas where dolphins occurred more commonly (Figure 5.24).

A comparison of inter-annual consistency in spatial variation in occurrence was made using data from 33 sites that were used in both 2009 and 2010. Sampling periods differed slightly between years, but data from August and September were available from all sites. Figure 5.25 shows that there was a significant relationship between the percentage of days detected and the average number of hours that animals were detected on each of those days for both dolphins and porpoises. Given this finding, data were pooled from both 2009 and 2010 to provide an overall summary of spatial variation in the occurrence of porpoises and dolphins across the wider Moray Firth (Figure 5.26).

At offshore sites, porpoises were present on almost all sampling days (Figure 5.26). To provide finer scale information on variation in the occurrence of porpoises around the wind farm sites, the median number of hours per day that porpoises were detected at each of the offshore sites in and around the BOWL and MORL development areas was estimated (Figure 5.27).

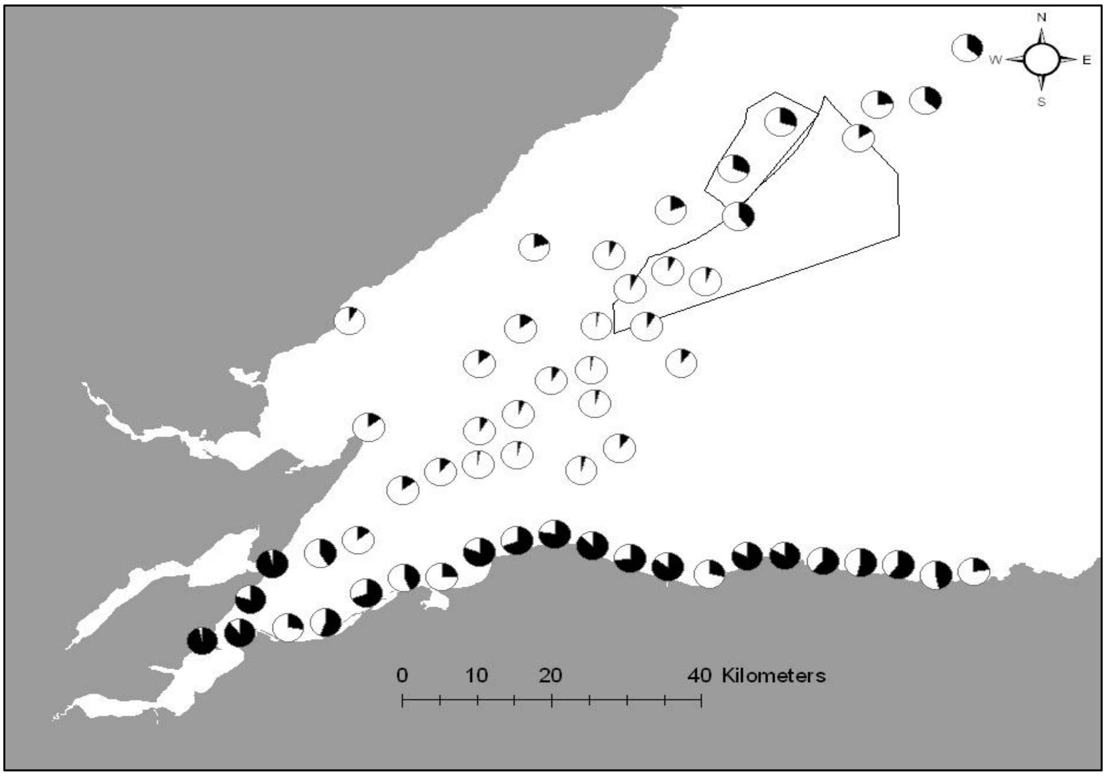

Figure 5.23a: Proportion of days that dolphins were detected in 2009 at each PAM site.

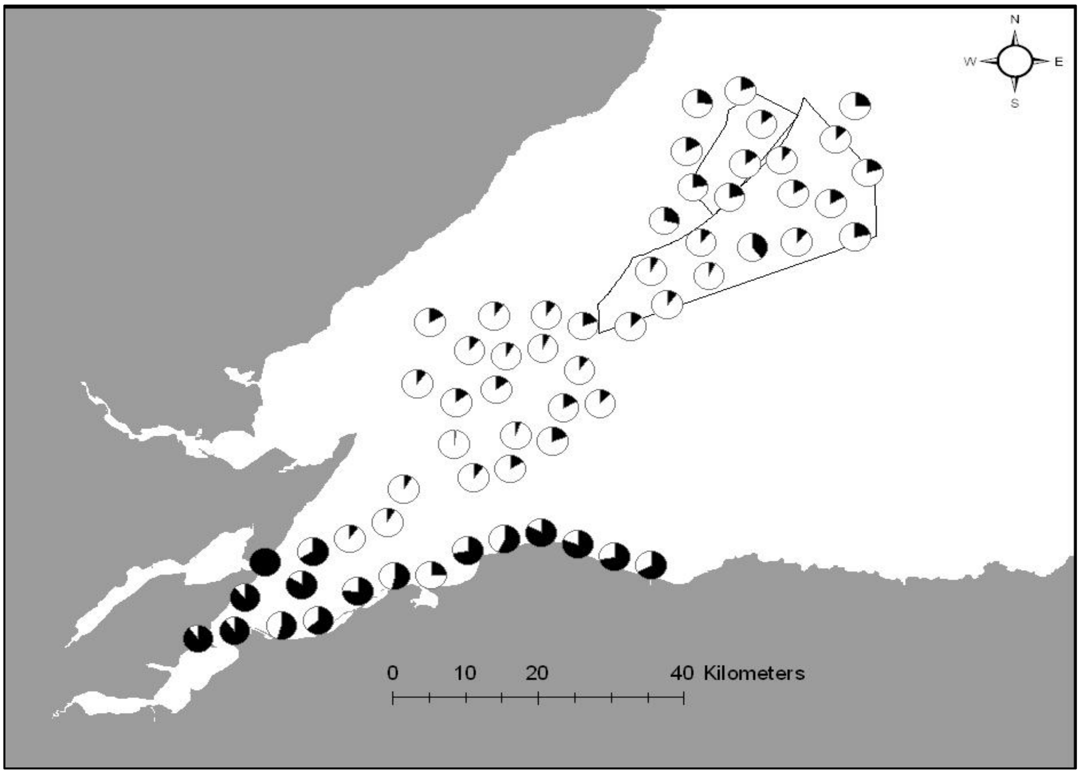

Figure 5.23b: Proportion of days that dolphins were detected in 2010 at each PAM site. Figures are updated versions of those presented in Thompson *et al*., 2010a and Thompson *et al*., 2011a.

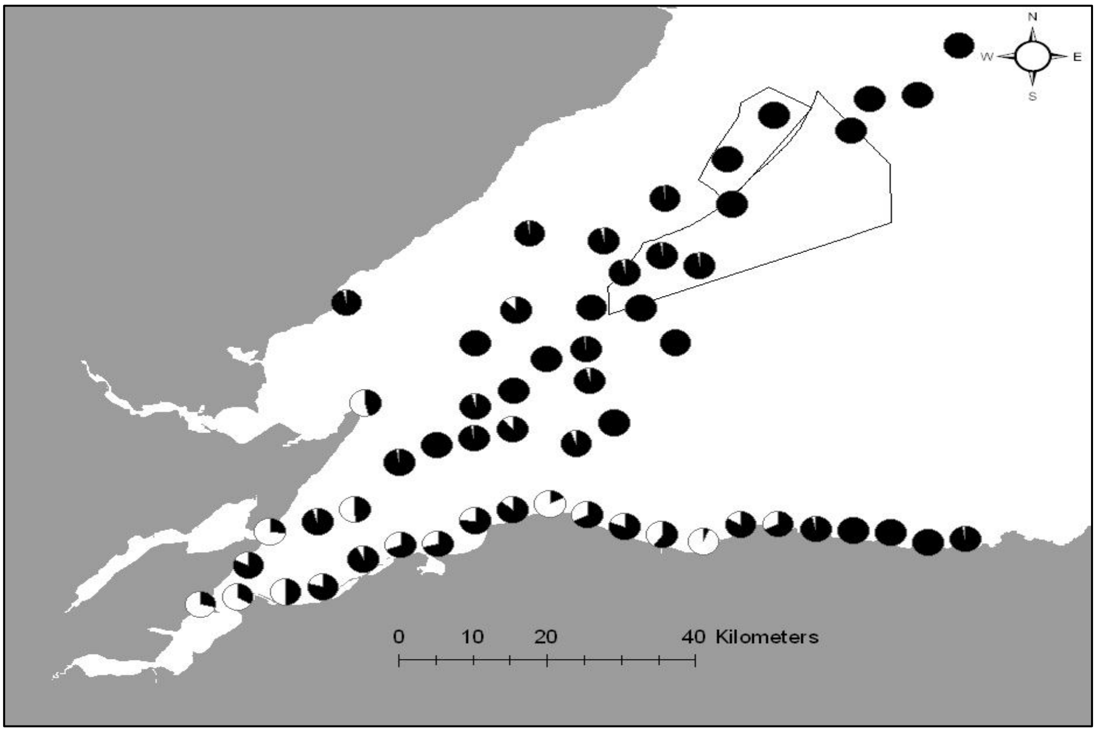

Figure 5.24a: Proportion of days that porpoises were detected in 2009 at each PAM site.

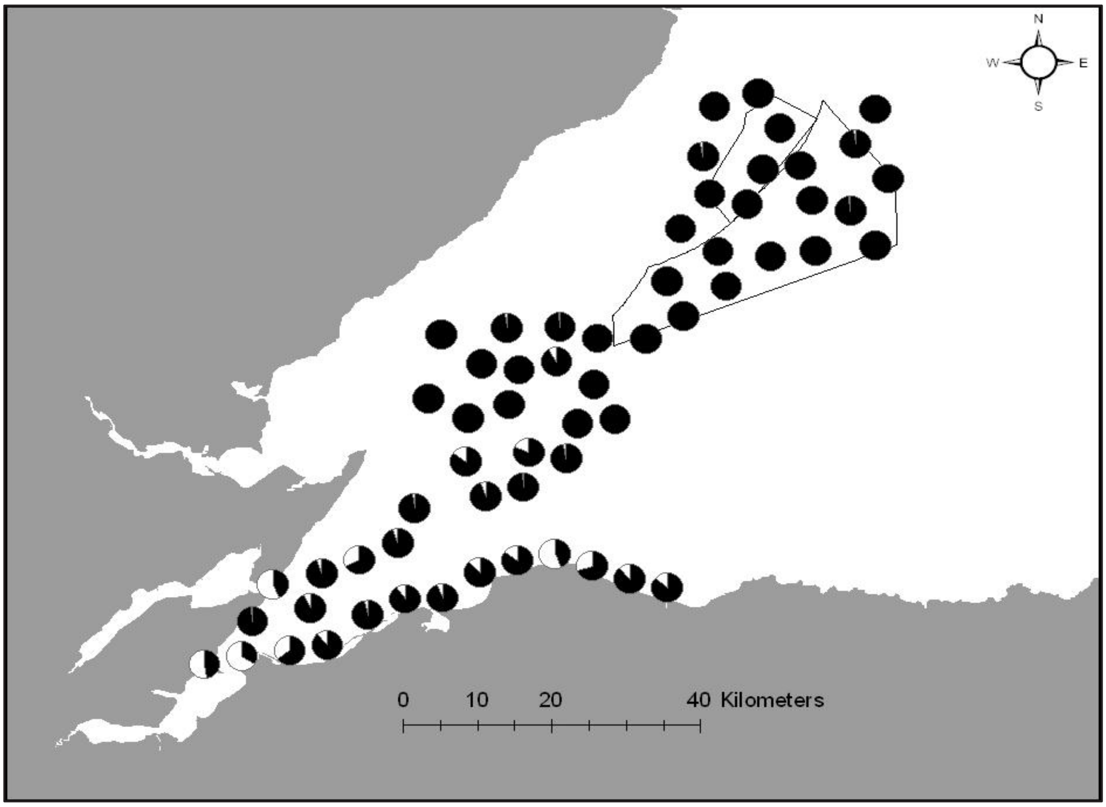

Figure 5.24b: Proportion of days that porpoises were detected in 2010 at each PAM site. Figures are updated versions of those presented in Thompson *et al.*, 2010a and Thompson *et al.*, 2011a.

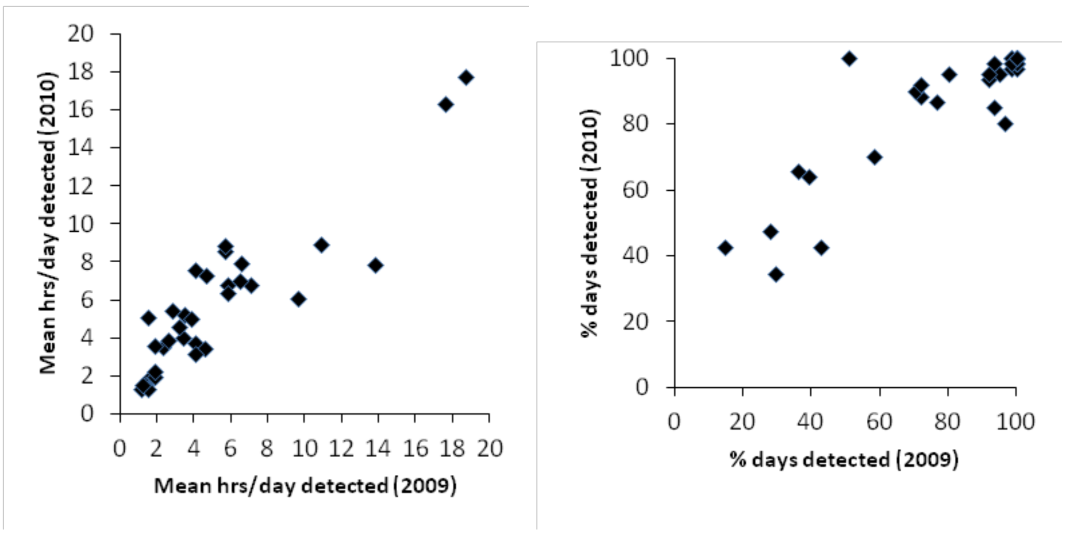

Figure 5.25a: Comparison of the percentage of days that porpoises were detected at 33 sites that were monitored in both 2009 and 2010.

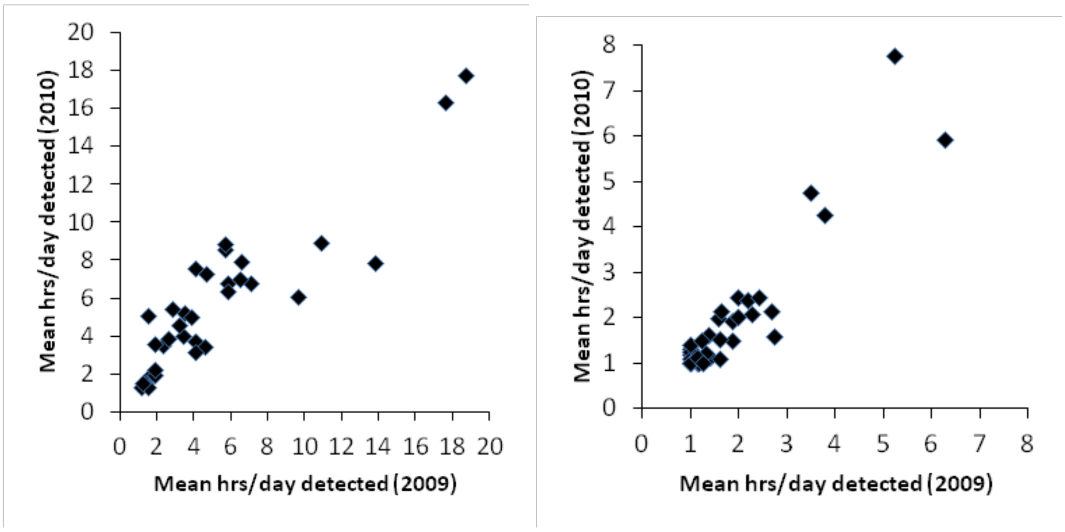

Figure 5.25b: Comparison of the percentage of days that dolphins were detected at 33 sites that were monitored in both 2009 and 2010. Also presented are the mean number of hours that animals were present on those days on which detections were made. Data are from August and September only. Figures are taken from Thompson *et al.*, 2011a.

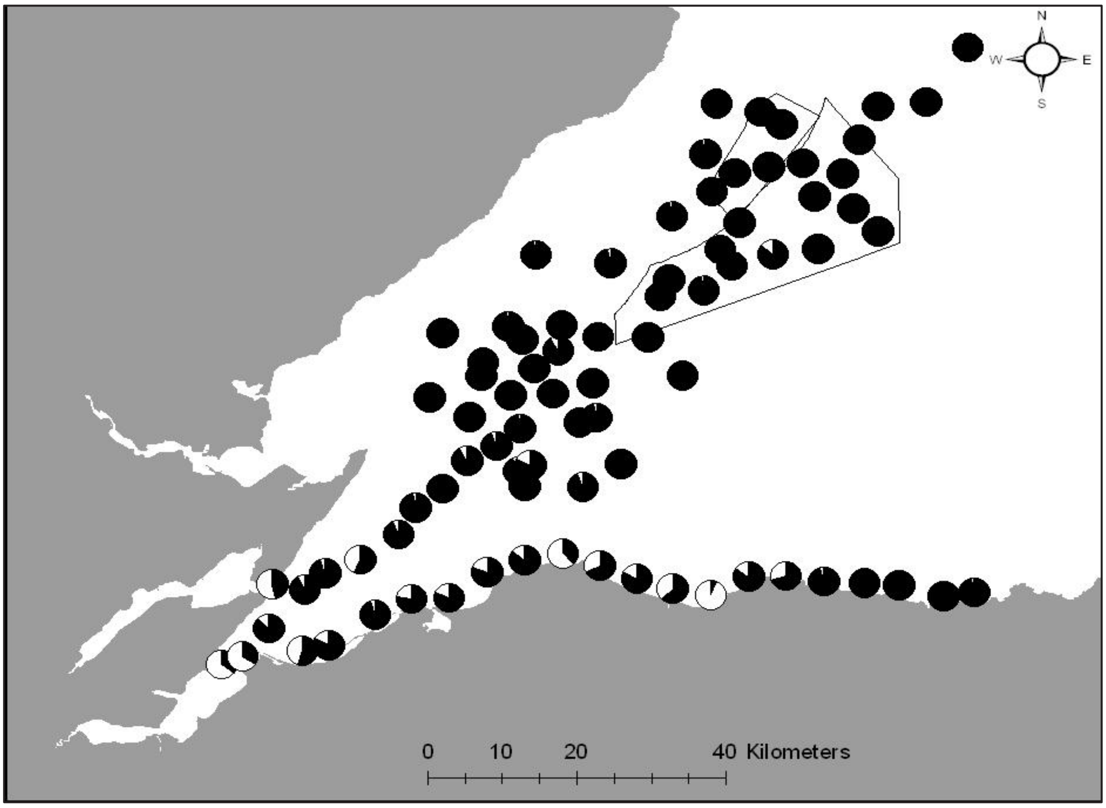

Figure 5.26a: Spatial variation in the occurrence of porpoise in the summers of 2009 and 2010.

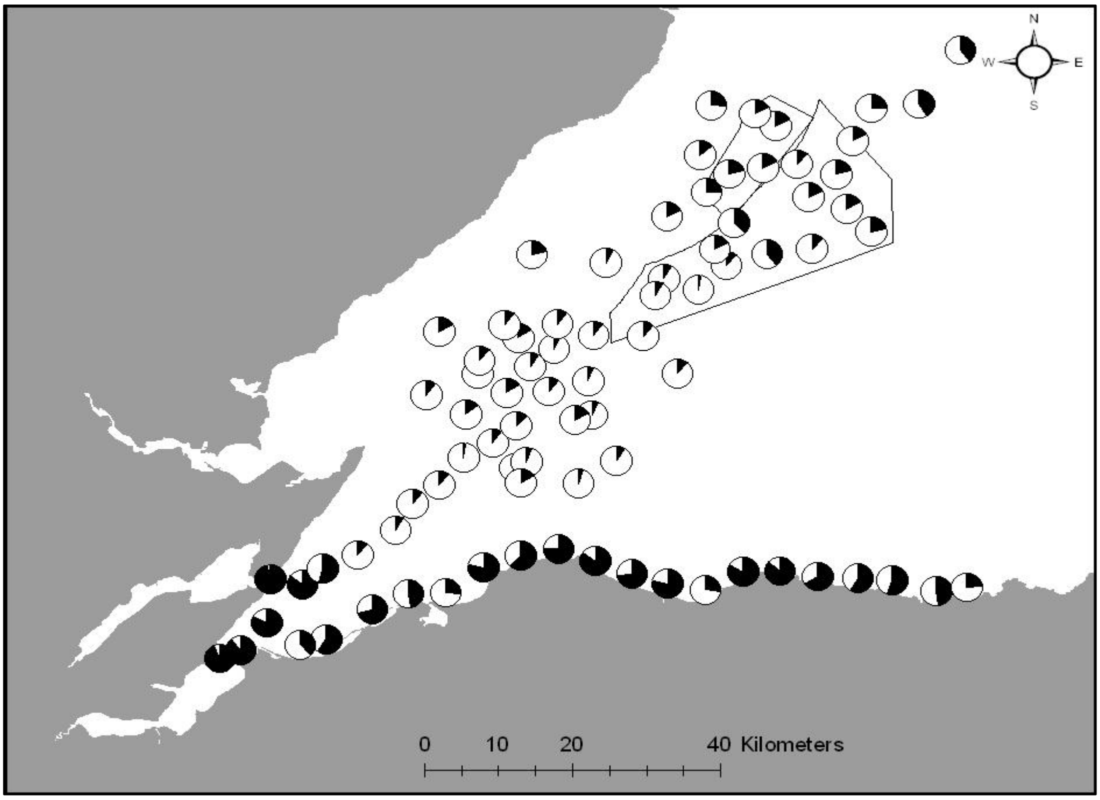

Figure 5.26b: Spatial variation in the occurrence of dolphins in the summers (April-Oct) of 2009 and 2010, using pooled data from Thompson *et al*., 2010a and 2011a.

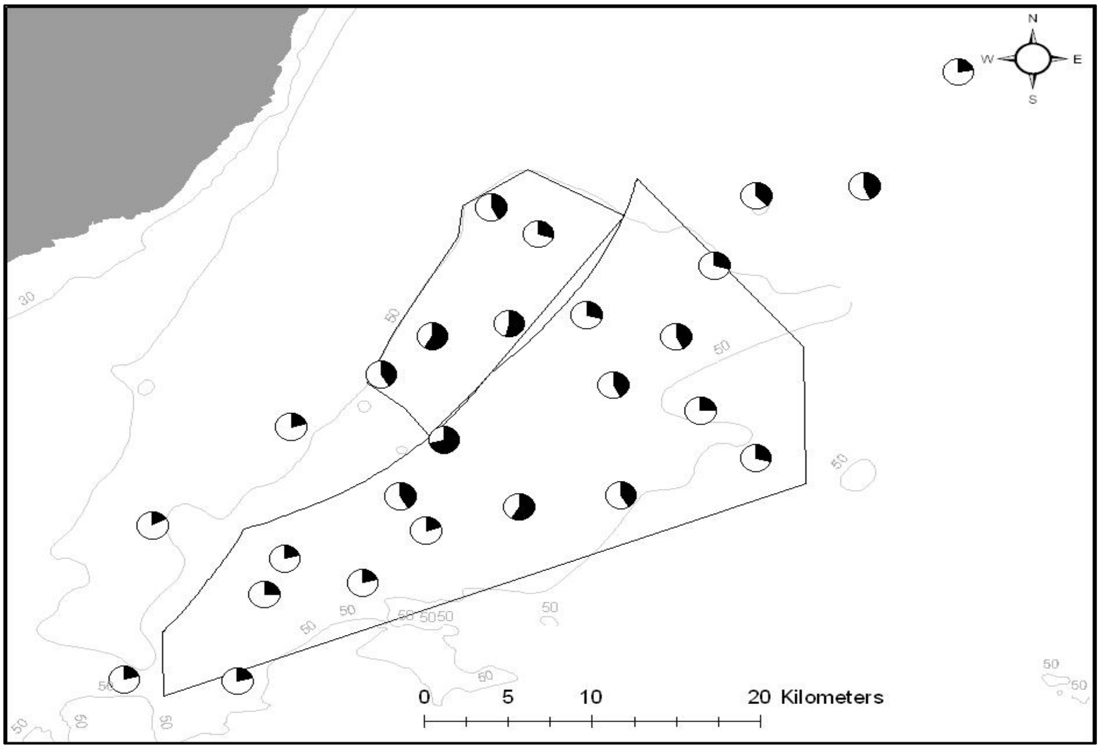

Figure 5.27: Pie-charts for each sampling site represent the median number of hours

that porpoises were detected each day during April –Oct of 2009 and 2010.

5.4.4 Classification tress to model spatial variation occurrence of different dolphin species

Over 1000 sightings dolphins were used in the analyses, although most of these were from surveys conducted in coastal areas (Table 5.9, Figure 5.28).

Table 5.9: The number of sightings and counts of animals of each of the four species of dolphin included in the analysis.

Species	Number of sightings	Number of animals
Bottlenose dolphin	919	7483
Common dolphin	15	241
Risso's dolphin	4	6
White beaked dolphin	50	168

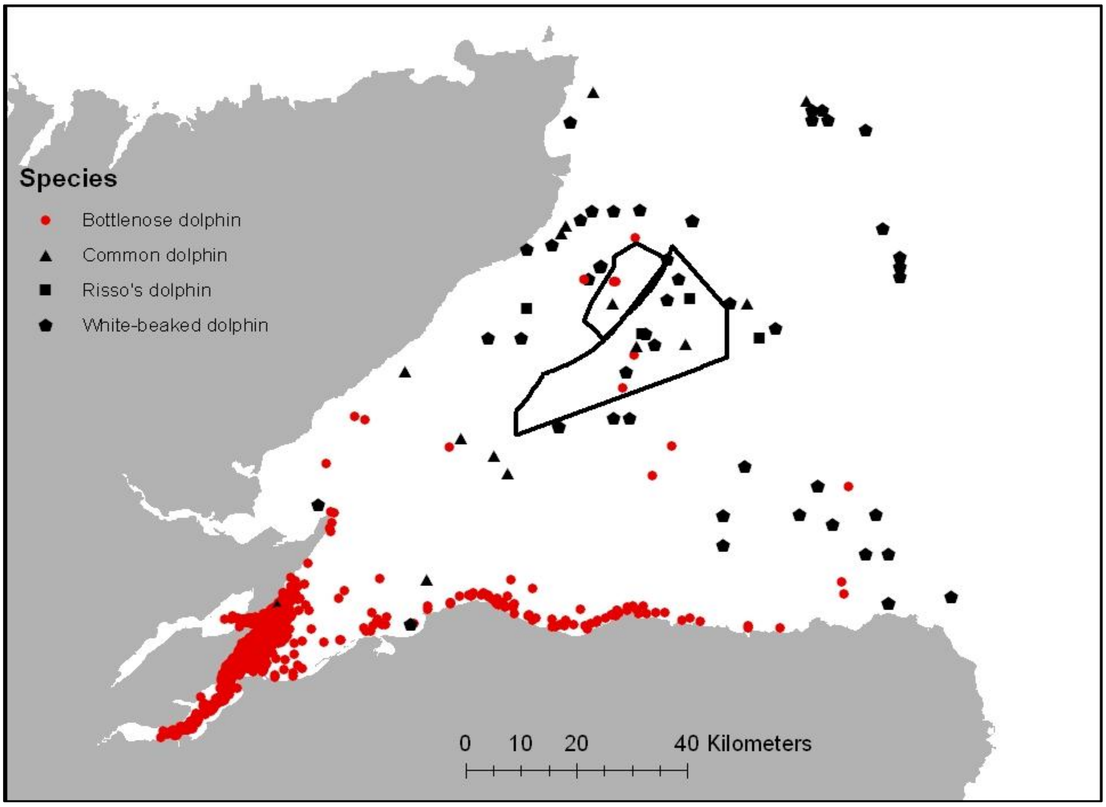

Figure 5.28: Sightings of dolphins from all data sources used in the classification tree.

The classification tree that included the full dataset used all six variables available to determine classes and had 23 terminal nodes. The results from this tree suggest that any dolphins encountered along the coastal strip are most likely to be bottlenose dolphins, but those encountered in offshore areas are, in general, more likely to be other species (Figure 5.29a). However, including the series of encounters recorded during the IECS/BOWL surveys meant that the model predicted a higher likelihood that dolphins encountered in this specific offshore area are likely to be bottlenose dolphins.

The tree which excluded the IECS/BOWL data had 21 terminal nodes and used depth, slope, distance to coast, sediment type and latitude. Given uncertainties over the reliability of species identification from the IECS surveys, and supporting evidence from the acoustic work, it is suggested that predictions from this model provide the more robust picture of likely species composition of groups of dolphins encountered in different parts of the Moray Firth (Figure 5.29b). Data on the likely presence of bottlenose dolphins are also presented separately in Figure 5.30.

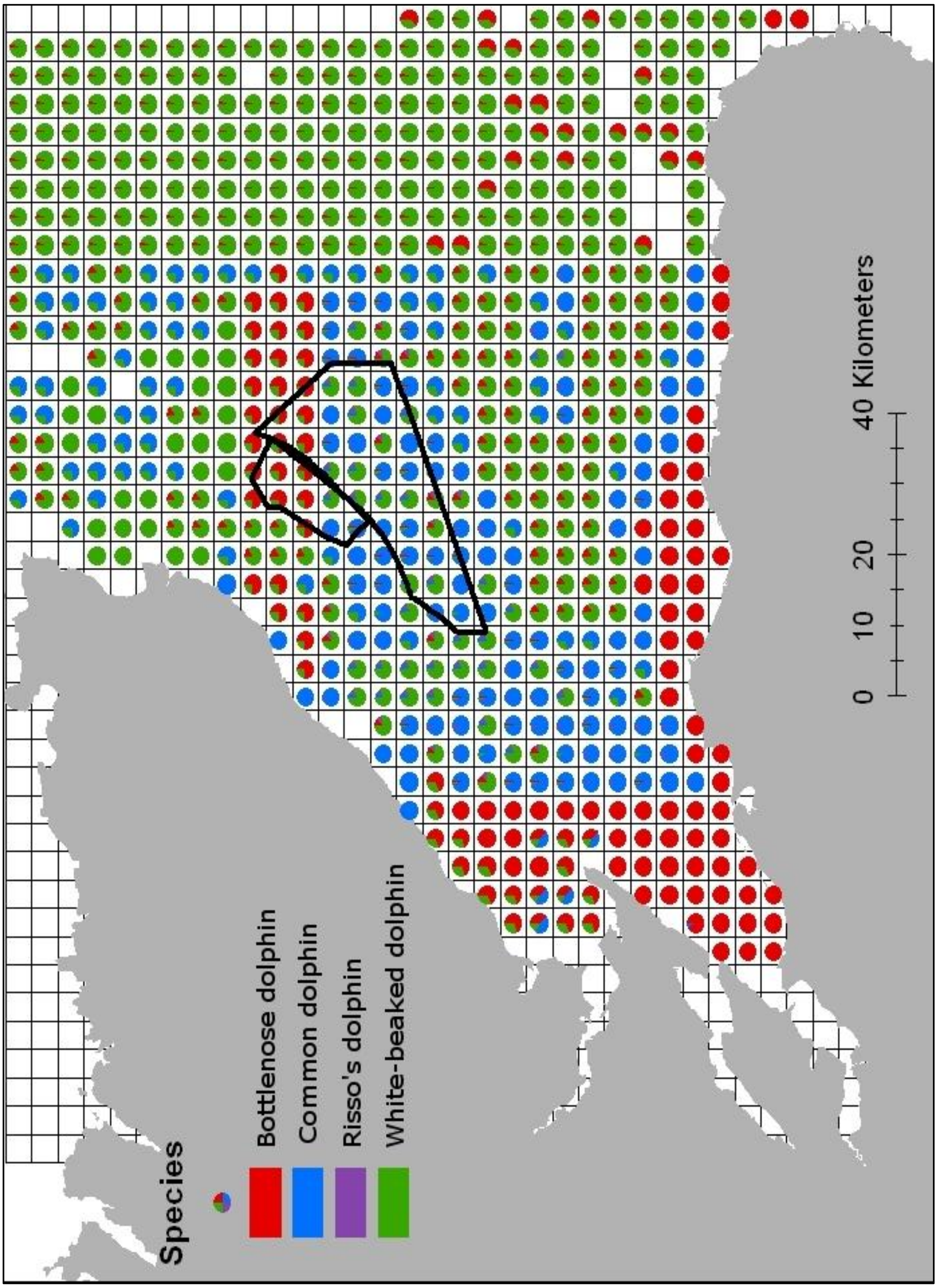

Figure 5.29a: Prediction of the dolphin species composition within each 4 x 4 km grid cell, using all data.

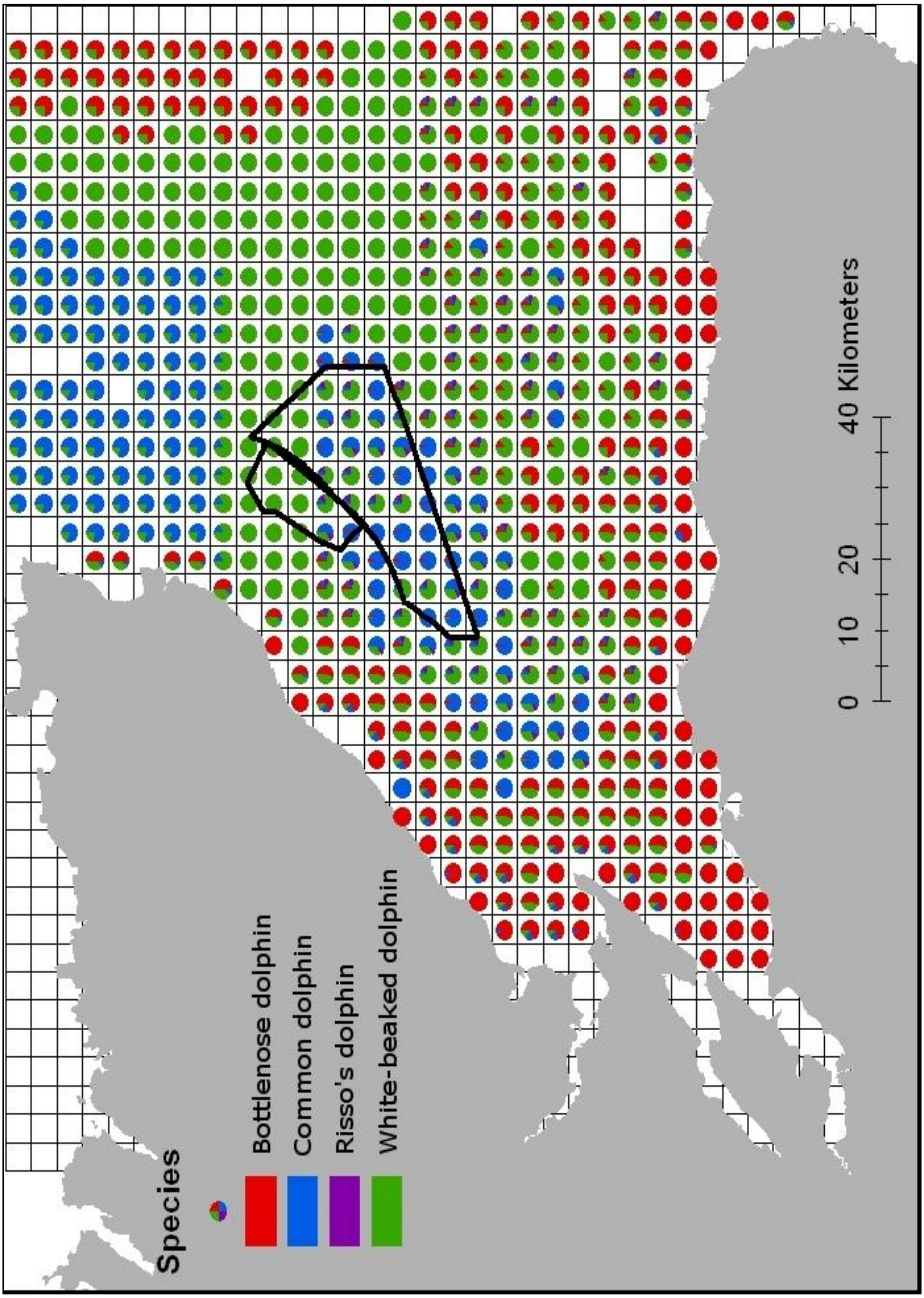

Figure 5.29b: Prediction of the dolphin species composition within each 4 x 4 km grid cell, using all data except for the IECS/BOWL dataset

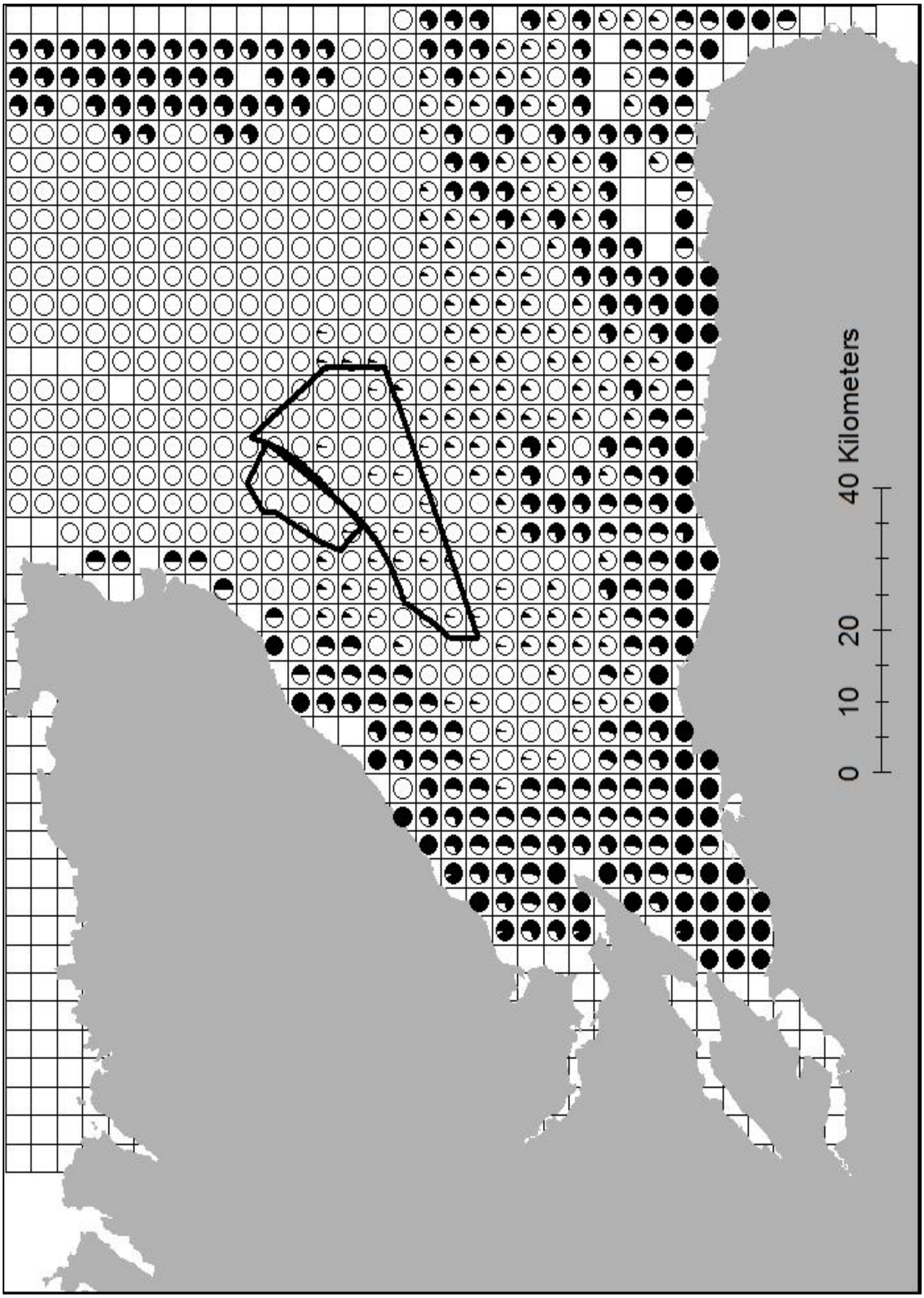

Figure 5.30: Prediction of the likelihood that dolphins encountered in each 4 x 4 km grid cell are bottlenose dolphins (black portion of pie chart).

5.4.5 Estimation of density

Harbour porpoise density

There were 230 sightings of harbour porpoises, representing 350 individuals, during the aerial line transect surveys shown in Figure 5.31. Density estimates were made both for the entire survey area, and for sub-areas (Table 5.10). Combining data from all areas, the density was estimated to be 0.64 porpoises per km^2. When analysed separately, these data indicated that densities were highest in the survey block that included the BOWL and MORL development sites, where densities were estimated to reach 0.81 porpoises per km^2. These estimates indicate that the BOWL and MORL development areas contained approximately 100 and 420 individual harbour porpoises respectively during this period (Table 5.11).

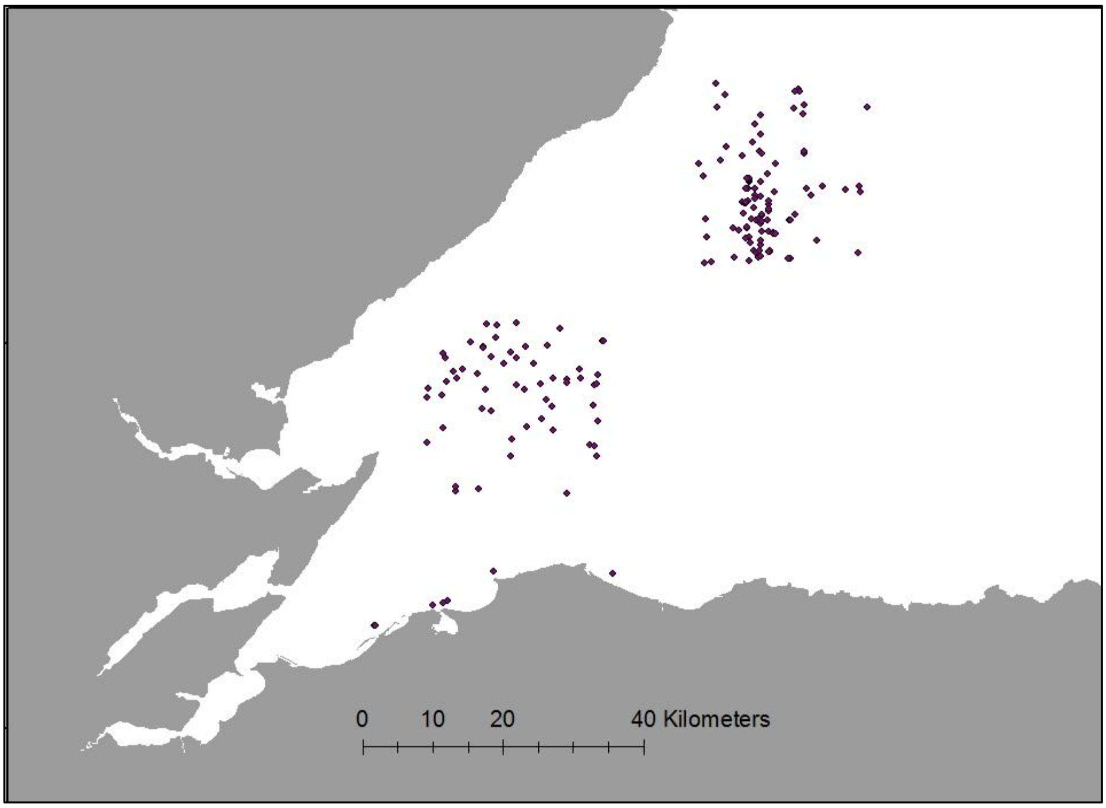

Figure 5.31: Locations of sightings of harbour porpoise made during the aerial line transect surveys in August and September 2010.

Table 5.10: Estimates of porpoise density (individuals per km²) in each of the survey areas.

Area	Porpoise density	Coefficient of variation	95% confidence range	Equivalent number of animals
All surveyed areas	0.637	0.18	0.45-0.90	863
Block A	0.535	0.18	0.38-0.76	334
Block B	0.812	0.30	0.45-1.47	508
Coast	0.265	0.24	0.16-0.44	66

Table5.11: Estimates of the number of individual porpoises present in the BOWL and MORL sites are based on data from Block B (see Table 5.10).

Site	Area (km²)	Number of porpoises	95% confidence range
BOWL Site	121	98	55-178
MORL R3 Zone	520	422	234-765

Dolphin density

Relatively few dolphins were recorded during the aerial surveys (30 sighting of 90 individuals). The resulting CV's of these estimates were relatively high compared with the porpoise estimate, but similar to those from for estimates density estimates for white-beaked dolphins (CV = 0.96) and bottlenose dolphins (CV = 0.87) in area J (Moray Firth, Orkney & Shetland) during SCANS II.

It was only possible to use these density estimates (Table 5.12) to estimate the combined abundance of all dolphin species (Table 5.13). Nevertheless, viewed in conjunction with results from the classification tree (Figure 5.29 and 5.30), these analyses highlight that the numbers of any species of dolphin, and particularly bottlenose dolphin, are likely to be low in the vicinity of the proposed wind farms. This is especially so given that estimates are likely to be positively biased given the use of a g(0) for harbour porpoises; a species that is more difficult to detect than dolphins. Furthermore, estimates of the total numbers of animals within the coastal strip are also likely to be high because the surveys were conducted over parts of the Moray Firth that are known to be used regularly by bottlenose dolphins.

SCANS II was unable to estimate abundance of common dolphin and Risso's dolphin in this area, but the density estimates for white-beaked dolphin (0.0182 individuals per km²) and bottlenose dolphins (0.011 individuals per km²) for area J are similar to estimates obtained in this study.

Table 5.12: Estimates of dolphin density (individuals per km²) in each of the survey areas.

Area	Dolphin density	Coefficient of variation	95% confidence range	Equivalent number of animals
All surveyed areas	0.066	0.46	0.0285-0.158	100
Block A	0.012	0.75	0.003-0.044	7
Block B	0.018	0.63	0.006-0.055	11
Coast	0.259	0.49	0.096-0.693	64

Table 5.13: Estimates of the number of individuals present in different regions within the Moray Firth based on the estimated density in the sample blocks within each of those regions (see Table 5.12).

Site	Area (km²)	Number of Dolphins	95% confidence range
BOWL Site	121	2	1-7
MORL R3 Zone	520	9	3-28
Coastal Strip	1955	506	188-1355
Central Moray Firth	2070	25	25-91
Outer Moray Firth	8146	146	49-448

5.4.6 Temporal patterns of acoustic detections within the MORL and BOWL development sites.

Comparability of data from T-PODs and C-PODs

Data were recovered from nine of the Outer Moray Firth sites at which a both a C-POD and T-POD had been deployed during 2010. Data were available from both devices for between 20 and 101 days depending upon the site. Porpoises were detected regularly at all nine sites. Comparison of the number of detection positive hours each day indicated that there was a significant relationship between the detection rates on C-PODs and T-PODs both for all sites combined (Figure 5.32a) and specifically for the Beatrice Demonstrator site where there had been a time series of data using both types of device (Figure 5.32b).

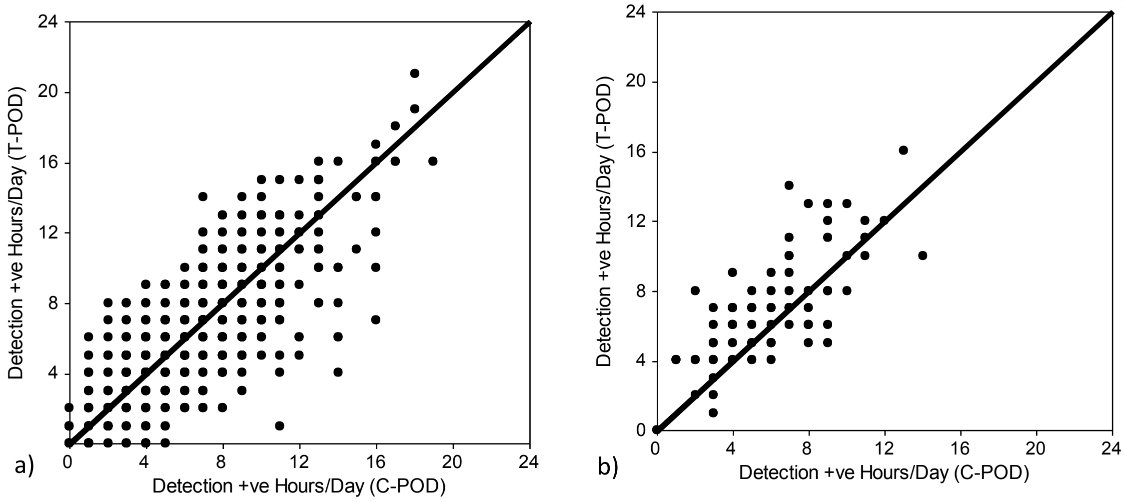

Figure 5.32: Comparison of the number of hours per day that porpoises were detected on paired T-PODs and C-PODs in 2010; a) for all nine paired devices (see Table 5.12) and b) data for the Beatrice Demonstrator site. The line shown on each figure represents a 1:1 relationship.

Overall, the average difference in the number of hours each day that porpoises were detected was close to zero (x = - 0.34, SD = 2.33), suggesting that there was no consistent bias when using one or other device (Figure 5.33a). Detection rates for dolphins were much lower, preventing a more detailed comparison of the number of hours that dolphins were detected on each device in each day. However, the average difference in the number of hours each day that dolphins were detected was also close to zero (x = - 0.04, SD = 0.63; Figure 5.33b).

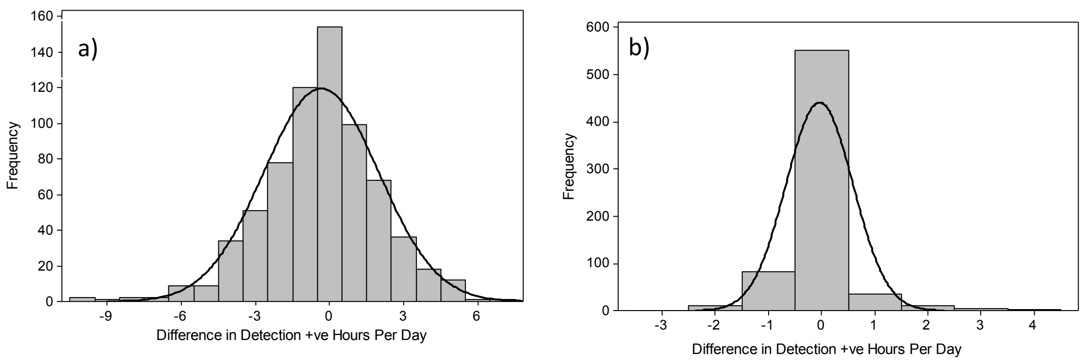

Figure 5.33: Differences in the number of hours that a) porpoises and b) dolphins were detected on the nine matched pairs of T-PODs and C-PODs (see Table 5.12 for sample sizes).

Table 5.14: Comparison of the mean numbers of hours per day that dolphins and porpoises were detected on the T-PODs and C-PODs that were deployed together at each of nine sites in the summer of 2010.

Site	Dolphins		Harbour Porpoise				N (days)
	X Hrs/day detected (SE)		X Hrs/day detected (SE)		Median Hrs/day (IQ)		
	T-POD	C-POD	T-POD	C-POD	T-POD	C-POD	
E02	0.09 (0.04)	0.11 (0.04)	7.60 (0.40)	7.80 (0.36)	7 (5-10)	8 (5-10)	81
E07	0.44 (0.09)	0.10 (0.03)	6.13 (0.35)	5.47 (0.27)	6 (4-8)	5 (4-7)	100
A14	0.01 (0.01)	0.15 (0.04)	5.97 (0.25)	6.33 (0.28)	6 (4-8)	6 (4-8)	101
D04	0.08 (0.05)	0.10 (0.03)	6.99 (0.33)	6.05 (0.32)	7 (5-8)	6 (4-8)	83
E16	0.25 (0.14)	0.25 (0.10)	5.50 (1.69)	5.10 (1.66)	1.5 (0-14)	1 (0-13)	20
E26	0.10 (0.04)	0.34 (0.09)	7.27 (0.47)	7.15 (0.49)	6 (5-10)	7 (4-10)	67
A21	0.02 (0.02)	0.13 (0.05)	4.85 (0.47)	8.69 (0.58)	5 (2-7)	8.5 (5 -11)	48
A23	0.29 (0.07)	0.34 (0.06)	6.66 (0.35)	6.86 (0.33)	6 (4-9)	7 (5-9)	100
E22	0.09 (0.03)	0.29 (0.05)	3.43 (0.24)	4.87 (0.28)	3 (2-5)	5 (3-7)	97

Temporal variability in T-POD and C-POD detections at the Beatrice Demonstrator site.

The longest time-series of passive acoustic monitoring data was available from the Beatrice Demonstrator site, where devices were deployed between August 2005 and December 2007. After a break in studies during 2008, devices were again deployed at this site in May 2009 and data collection is anticipated to continue until at least autumn 2011. There have been some gaps in the time-series due either to equipment loss or failure (Table 5.15), but these data provide a unique opportunity to explore longer-term temporal change in the occurrence of dolphins and porpoises at an offshore site.

Overall, porpoises were detected on most days (> 93%) that T-PODs or C-PODs were deployed at this site, whereas dolphins were detected only rarely

(< 6% of deployment days). This pattern was consistent across all five years in which data were collected (Figure 5.34).

On those days that porpoises were detected, they were recorded for a median of 4 hours (IQ range = 2-7), whereas on those days that dolphins were detected, they were recorded for a median of one hour (IQ range = 1-1) (Figure 5.35). The median number of hours that porpoises were detected on each day was also consistent across years (Figure 5.36).

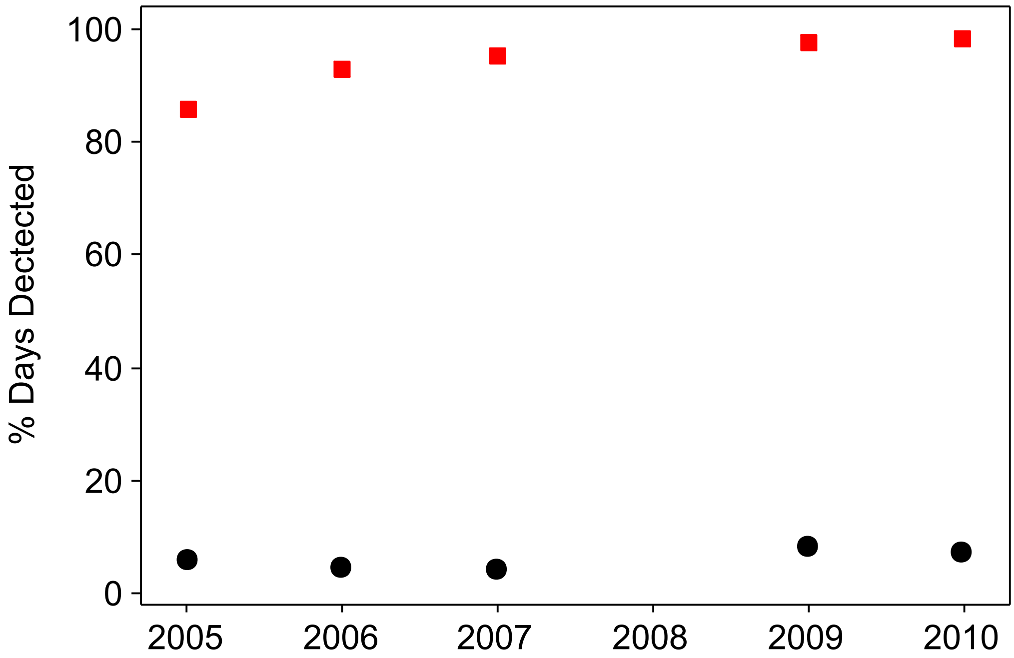

Figure 5.34. Annual values for the % of days that porpoises (squares) and dolphins (circles) were detected at the PAM site near the Beatrice Demonstrator. See Figure 5.10 for the site location and Table 5.13 for sample sizes.

Table 5.15: The number of T-PODs (T) and C-PODS (C) deployed and successfully recovered at the Beatrice Demonstrator site in each month of 2005-2011, Months blocked in black are those where a single device has been deployed but not yet recovered.

	2005		2006		2007		2008		2009		2010		2011	
	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Jan			2		1									
Feb			2		1									
Mar			2		1							1		
Apr			1		1							1		
May			2									1		
Jun			2		2					1	1	1		
Jul			2		2					1	1	1		
Aug			2		2					1	1	1		
Sep	2		2		2					1	1	1		
Oct	2		2		2					1	1	1		
Nov	2		2		2					1				
Dec	2		2		1									

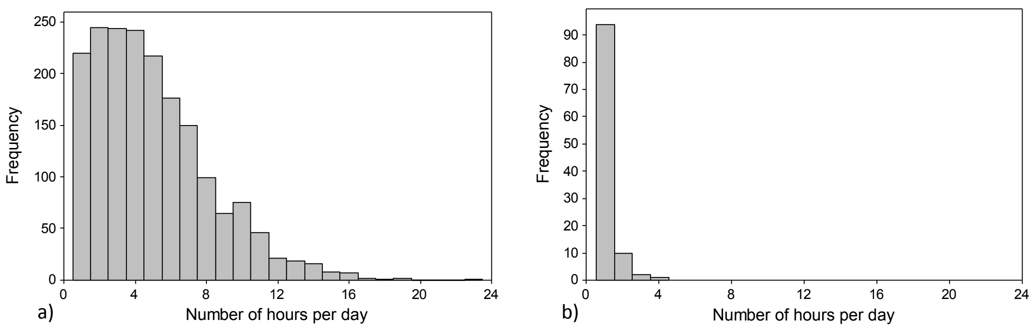

Figure 5.35: Frequency histograms for the number of hours that a) porpoises and b) dolphins were detected on those days in which there was at least one detection (data are from the entire period 2005-2010).

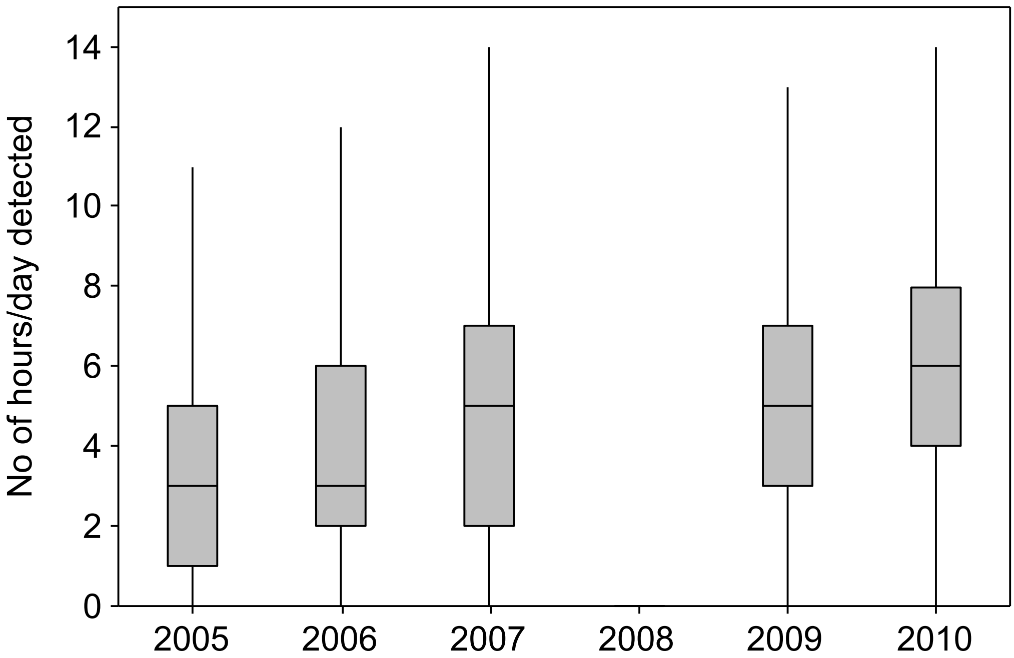

Figure 5.36: Annual estimates in the median number of hours per day (with IQ ranges) that porpoises were detected at the PAM site near the Beatrice Demonstrator.

Seasonal variability in C-POD detections within the BOWL site.

Passive acoustic monitoring data are available from two sites within the BOWL development area for a period of almost two years, and from three additional sites for the final nine months of the study (Table 5.16). Inspection of these data indicates that porpoises were present in the area on an almost daily basis, whereas dolphin detections remained much lower throughout the year (Figure 5.37). However, the median number of hours that porpoises are detected does appear to vary seasonally, with peaks in the winter and late summer (Figure 5.37). Not only were porpoises detected almost daily, but they were typically present for many hours each day. In contrast, dolphins were generally detected for only one or two hours a day, even on those few days that they were detected (Figure 5.39).

Table 5.16: The number of sites within the BOWL and MORL development areas at which C-POD data were collected in each month of 2009, 2010 and 2011. Numbers in brackets represent devices deployed for DECC study but not yet recovered.

	BOWL			MORL		
	2009	**2010**	**2011**	**2009**	**2010**	**2011**
Jan		2	5		2	11
Feb		2	5		2	11
Mar		2	5		1	11
Apr		2			1	11
May		2		1	1	11
Jun		2		6	1	10
Jul	2	5	(5)	6	8	1 (14)
Aug	2	5	(5)	6	9	(14)
Sep	2	5	(5)	6	9	(14)
Oct	2	5	(5)	6	9	(14)
Nov	2	5		6	9	
Dec	2	5		3	9	

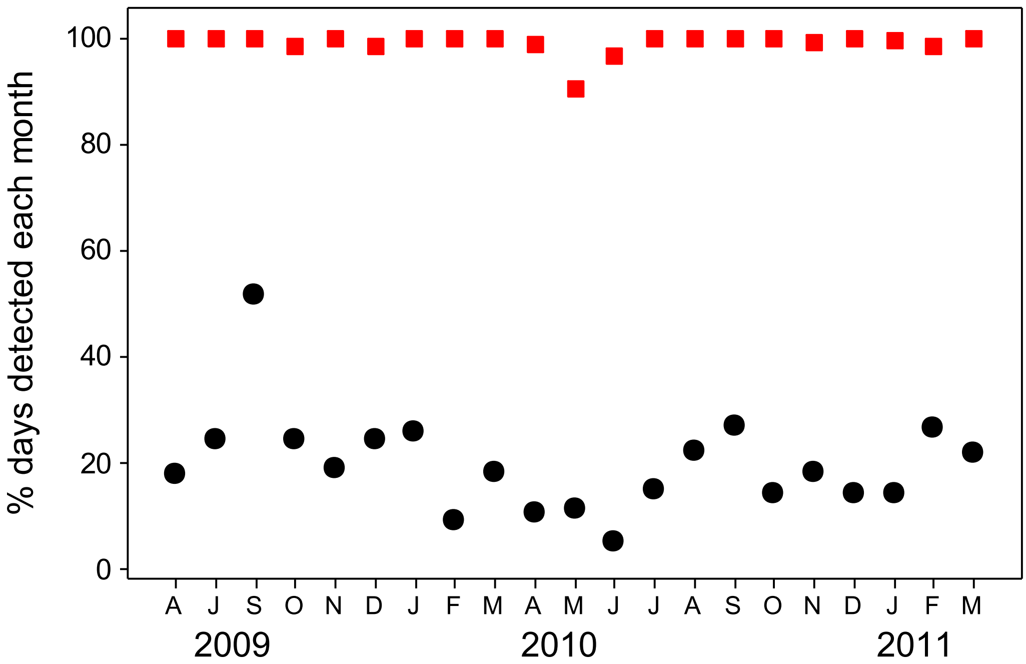

Figure 5.37: Monthly values for the % of days that porpoises (squares) and dolphins (circles) were detected at site within the BOWL development area. See Table 5.13 for sample sizes.

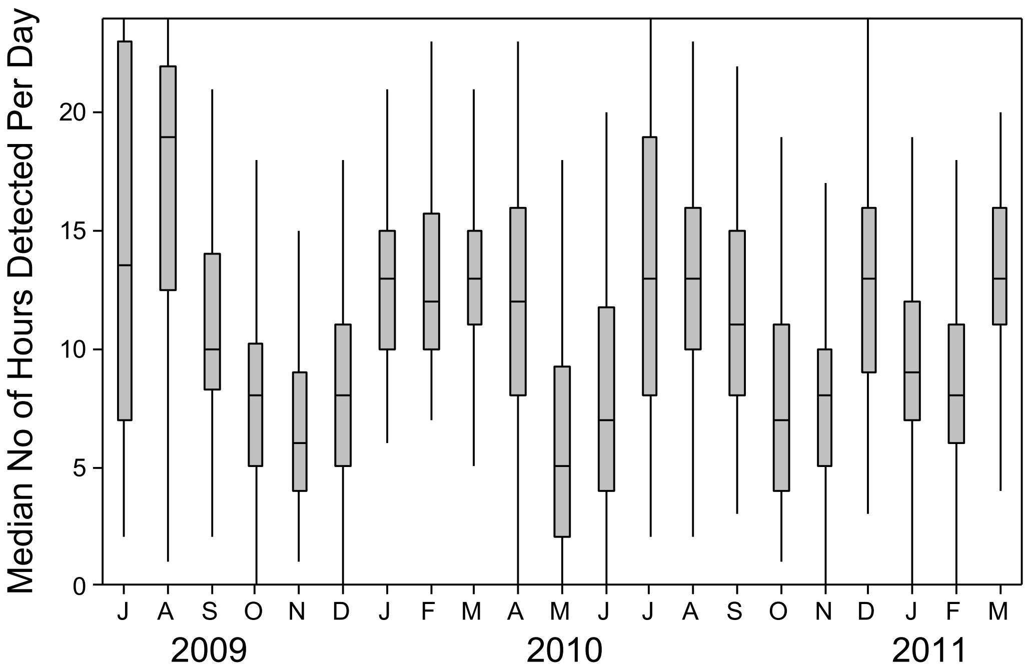

Figure 5.38: Monthly variation in the median number of hours per day that porpoises were detected on C-PODs within the BOWL development area. Sample sizes are provided in Table 5.13.

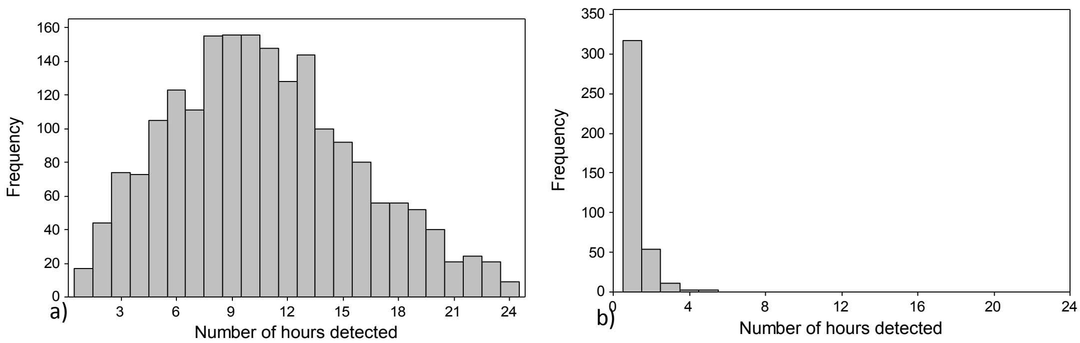

Figure 5.39: Frequency histograms showing the number of hours that a) porpoises and b) dolphins were detected on C-PODs from the BOWL site. Data are from 2009-2011, and only include those days on which any animals were detected.

Seasonal variability in C-POD detections within the MORL R3 zone.

Due to equipment loss, there were no complete records from any single site within the MORL development area, although data were collected from at least one site in each month of the study (Table 5.16). However, extensive additional data will be available from the current deployments and further DECC-funded work planned for the latter half of 2011.

Porpoises again appear to be present in the area on an almost daily basis, whereas dolphin detections remain low throughout the year (Figure 5.40). Seasonal patterns in the median number of hours that porpoises are detected remain less clear at this stage, and further evaluation will be undertaken once additional data are recovered. Nevertheless, it is clear that porpoises are typically present in the area throughout the year, for several hours a day (Figures 5.41 and 5.42). In contrast dolphins were typically only detected for one or two hours on those days that they were recorded on the site (Figure 5.42).

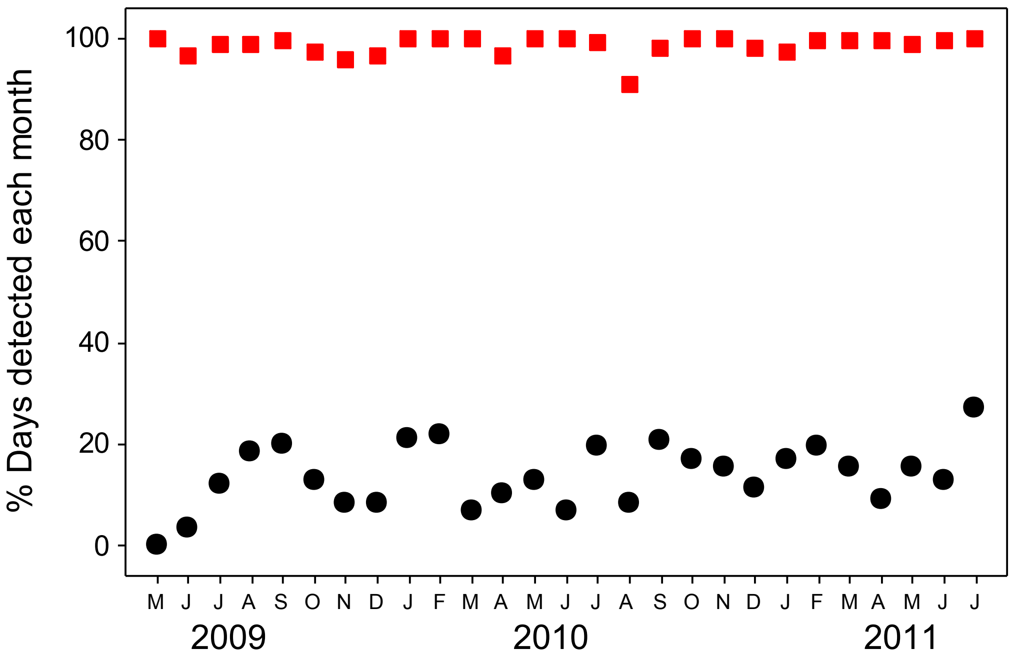

Figure 5.40: Monthly values for the % of days that porpoises (squares) and dolphins (circles) were detected at site within the MORL development area. See Table 5.14 for sample size.

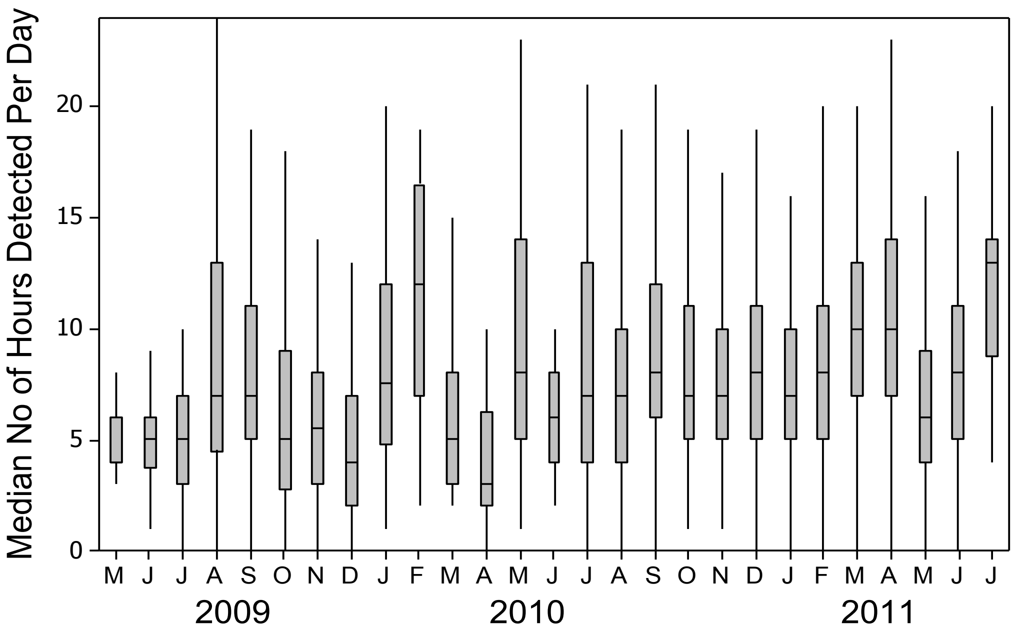

Figure 5.41: Monthly variation in the median number of hours per day that porpoises were detected on C-PODs within the MORL development area. Sample sizes are provided in Table 5.13.

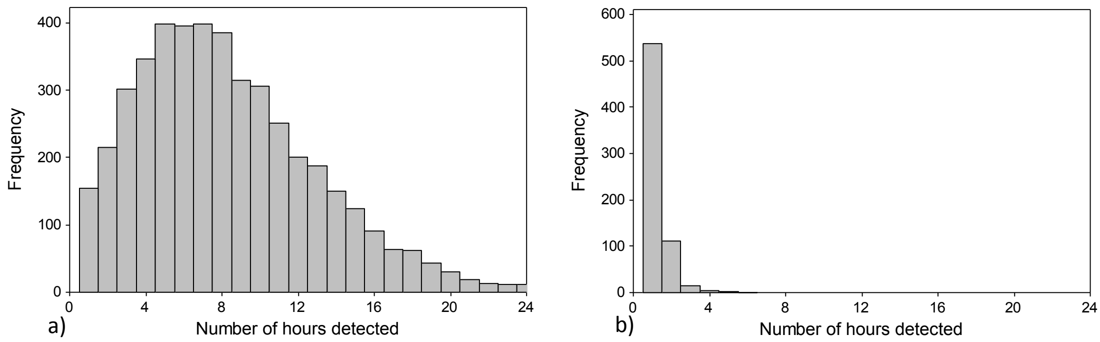

Figure 5.42: Frequency histograms showing the number of hours that a) porpoises and b) dolphins were detected on C-PODs from the MORL R3 zone. Data are from 2009-2011, and only include those days on which any animals were detected.

5.5 Acknowledgements

Much of this work builds upon data collected through recent studies conducted for DECC, COWRIE, Oil & Gas UK and Marine Scotland. We would like to thank them and all the funding bodies that have supported the collection of other external data used in this report. Thanks also to the other organisations that provided data for the integrated analyses of historical sightings and to the many individuals who have collected survey data at sea over the years. Particular thanks go to Tim Barton, Barbara Cheney, Nick Richardson, Helen Bates and Bill Ruck for all their work on recent PAM studies, and to Rasmus Nielson, Gareth Bradbury and other staff at WWT Consulting Ltd for their skilled work during the 2010 aerial survey programme.

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6. Spatial variation of bottlenose dolphins

In preparation for the MORL and BOWL consenting applications, various technical documents have presented bottlenose dolphin survey data and discussed how these data can best be used in environmental impact assessments (EIAs). No agreed guidance for assessments of this kind exists, and the process has been further complicated withthis being an area of active research; some of it funded by regulators in response to the need to develop more robust assessment procedures. Consequently, new data and analysis results have been emerging through the period over which EIAs have been prepared, and this will continue over the period in which EIAs are being considered by regulators.

This chapter aims to provide an overview of the best available data and analysis frameworks at the current time. Recent work carried out both for the developers and for regulators has meant that current understanding is significantly greater than that existing a year or two ago. However, this work has identified a number of further avenues which are being actively pursued by various parties. This document also highlights where ongoing work may lead to new outputs over the course of the next year.

6.1 Abundance and ranging patterns of the bottlenose dolphin population that uses the Moray Firth.

The most recent estimate of the abundance of bottlenose dolphins along the whole of the east coast of Scotland is based on co-ordinated photo-identification studies in 2006 and 2007, which produced an estimate of 195 (95% highest posterior density intervals (HPDI): 162-253) (Cheney *et al*., In Press a).

More detailed annual surveys within the Moray Firth SAC between 2002 and 2010, indicate that around 50% of these animals use the SAC in each year, with estimates ranging from 68 to 114 individuals; (mean = 93.3) but with overlapping confidence limits (Cheney *et al*., In Press b). Overall, the number of dolphins using the SAC between 1990 and 2010 appears to be stable (Cheney *et al.,* In Press b).

Annual estimates of the east coast bottlenose dolphin population were also made for the period 1990-2010 by updating the Bayesian capture-recapture model developed in Corkrey *et al*., (2008). A Bayesian linear regression suggested that there is a >80% probability that the bottlenose dolphin population on the east coast of Scotland is either stable or increasing (Cheney *et al*., In Press b).

Repeat observations of these individually recognisable dolphins have demonstrated that dolphins off the east coast of Scotland are highly mobile, with individuals ranging from the inner Moray Firth to Fife. Some individuals that have been regular sighted within the Moray Firth have occasionally ranged further south with one confirmed sighting in 2007 of a group near Whitley Bay and the Tyne river mouth (Thompson *et al*., 2011).

Longer range movements have also been recorded (between the Moray Firth and both the West coast of Scotland and SW Ireland), but these have involved individuals that have only ever been observed within the Moray Firth for a very short period (Robinson *et al*., In Press).

Consequently, whilst the Moray Firth is clearly an important area for this population, they are not restricted to the either the Moray Firth SAC or its immediate surrounding waters. Instead, these animals are highly mobile, and appear to have a broad potential range around the UK coast and possibly beyond.

6.2 Distribution and density bottlenose dolphins within the Moray Firth.

This is one of the most intensively studied cetacean populations in the world. However, until recently, almost all research has been focussed on near-shore waters, particularly in the inner Moray Firth (eg. Wilson *et al*., 1997; Hastie *et al*., 2004; Cheney *et al*., In Press b) and along the southern Moray Firth coast work (Culloch & Robinson, 2008). Although almost all sightings of dolphins in the Moray Firth have been made relatively close to the shore, uncertainty over potential use of offshore areas has constrained previous assessments for developments in the outer Moray Firth.

In recent years, effort has therefore been put into collecting data and developing new approaches for providing a robust description of broad-scale distribution across the Moray Firth. Ongoing work for DECC, with additional support from MORL and BOWL, is now using a combination of broad-scale passive acoustic monitoring and classification analysis of visual sighting data to predict bottlenose dolphin distribution across the Moray Firth.

A robust estimation of the spatial variation of bottlenose dolphins within the Moray Firth was calculated and used in combination with independent estimates of population size to provide average densities of bottlenose dolphins across the area. Classification trees were used to determine the probability that a "dolphin" detection was a bottlenose dolphin (Figure 6.1). Population estimates were then used to provide an estimate of the total number of bottlenose dolphins present within the Moray Firth and how they are dispersed across 4 x 4 km grid squares (Figure 6.2).

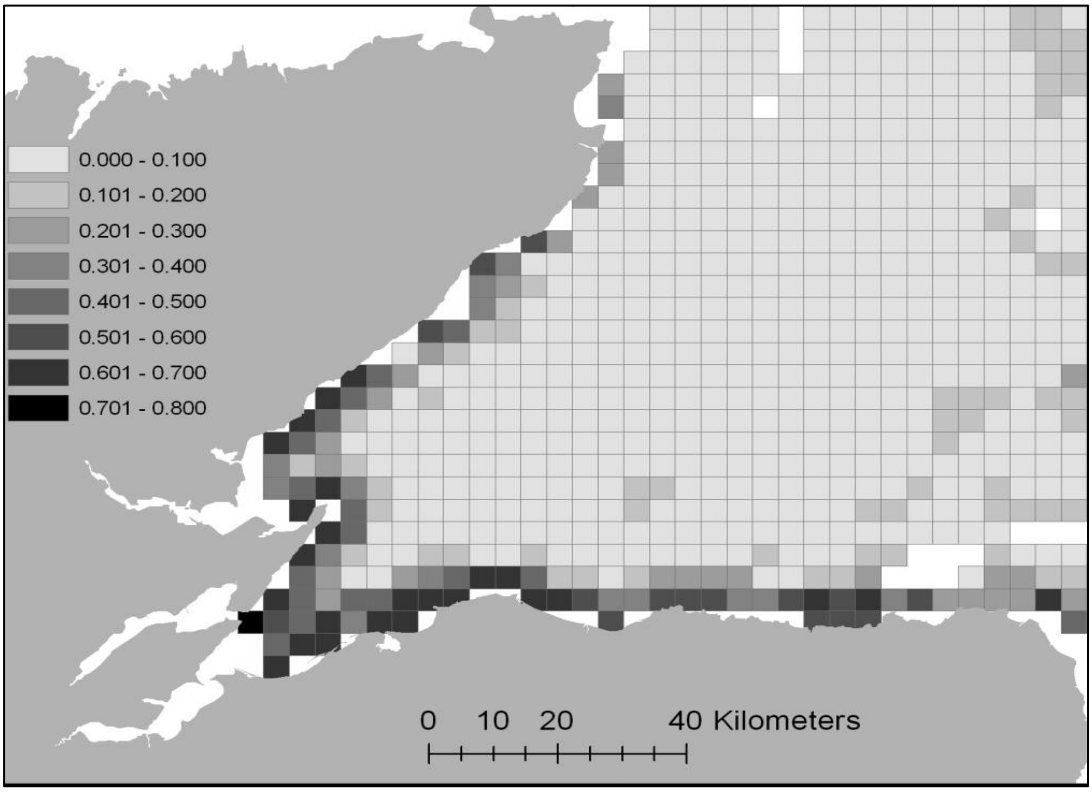


Figure 6.1: Predicted probability of encountering bottlenose dolphins within each 4 x 4 km cell.

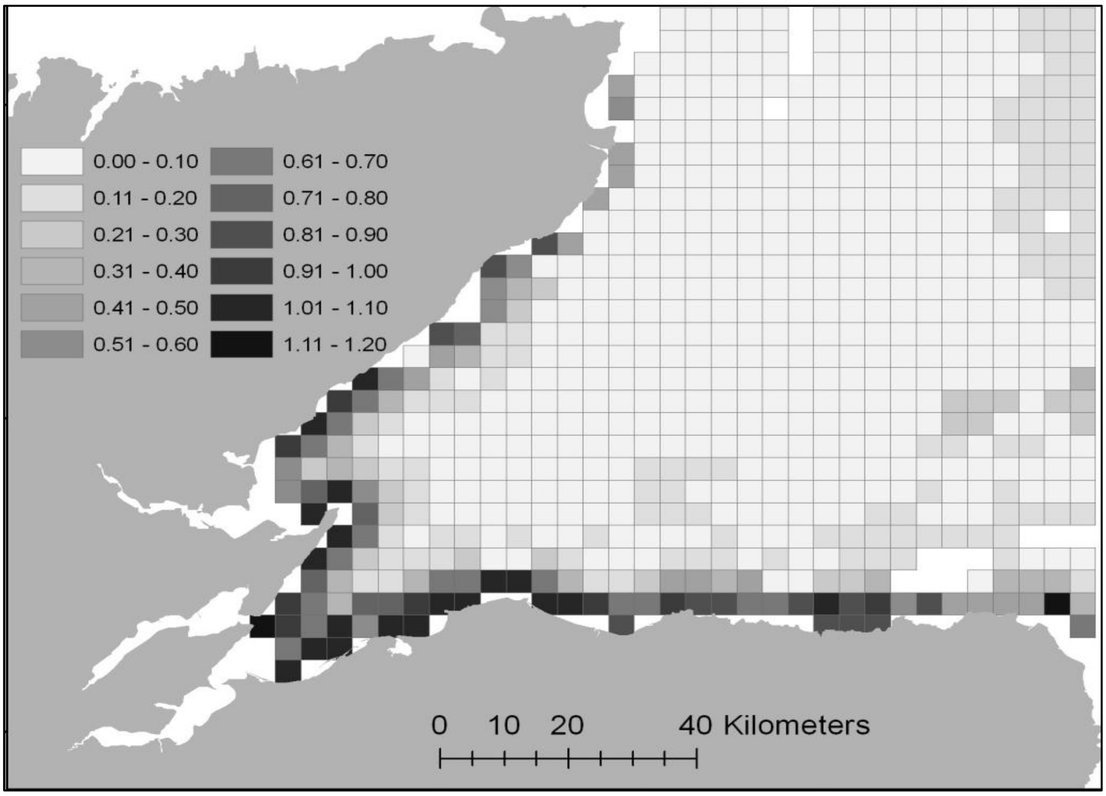


Figure 6.2: Predicted number of bottlenose dolphins in each 4 x 4 km cell.

In theory, one could then use this density surface to "distribute" the known population of dolphins across the area to estimate how many dolphins occur in different grid squares. However, comparison of these predictions with existing data from finer-scale studies within inshore waters has highlighted that this would not be appropriate. For example, bottlenose dolphins are normally encountered in groups rather than individually as would be suggested by such an approach when using the lower figures of the density surface predictions.

When deciding which of these predicted distributions should be used to underpin different assessments, it's importnant to remember that these are modelled averages across the period for which data are available. This is particularly important for bottlenose dolphins given they form social groups, and their distribution at any one moment in time will always be more clumped than presented here. Based upon other data sets, it is suspected that this approach tends to underestimate the use of the inner firth and south coast of the Moray Firth, and over estimate their use of the north coast. However, at present this is the only dataset that provides an overview of distribution across the whole area of interest.

In particular, it appears that the C-POD data should be modelled at finer-temporal scale (than the daily data used here) to capture known variability in the probability of encountering dolphins in different inshore areas. For example, inspection of Figure 6.3, shows that the model clearly highlights the importance of areas within ~5 km of the coast, but predicts limited variation within that coastal zone. In contrast, a series of studies have highlighted the importance of foraging hotspots such as the tidal narrows at Chanonry point and the mouth of the Cromarty Firth (Wilson *et al*., 1997; Hastie *et al*., 2004; Bailey & Thompson, 2006). Furthermore, this pattern was evident in broader scale survey data used to model distribution across at the whole SAC (see Figure 6.3).

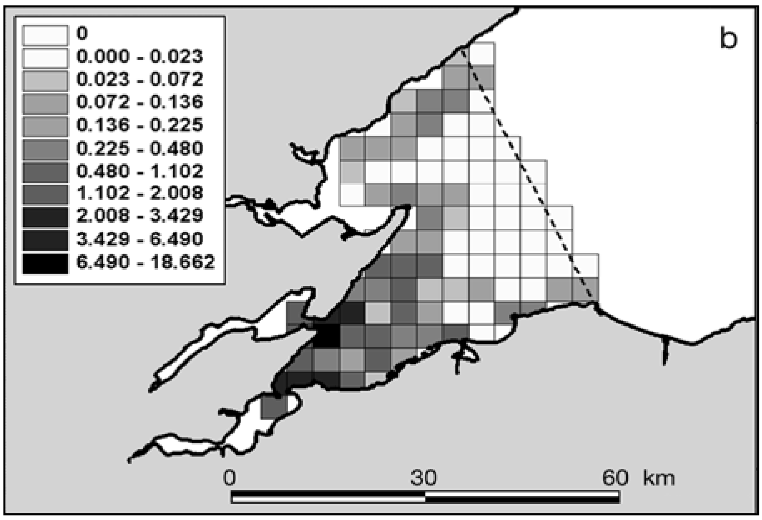


Figure 6.3. Predicted distribution of bottlenose dolphins within the Moray Firth SAC (taken from Bailey & Thompson, 2008) showing more clumped inshore distribution than that predicted in Figure 5.23.

This discrepency appears to result partly from additional variability in the amount of time that dolphins spend in each of these different areas on those days on which they are encountered. This can be illustrated through analysis of a sub-set of data from year-round coastal T-POD deployments made during a recent study for SNH and Scottish Government (Thompson *et al*., 2011). Figure 6.4 highlights that there is variation in the proportion of days that dolphins were detected at different sites around the coast, with higher detection rates in the inner Moray Firth and Spey Bay. Furthermore, there were significant differences in the number of hours that dolphins were detected on those days that they did occur at each site; with much higher levels of use at site 3 (Sutors), site 4 (Chanonry) and site 7 (Spey Bay) as shown in Figure 6.5.

These findings suggest that the C-POD data used to produce Figure 5.23 shoud be re-analysed at the hourly scale. However, this is complicated because high levels of temporal auto-correllation mean that hourly samples are not independant. Ongoing work is now using Generalised Estimating Equations to account for this autocorrellation (as suggested by Bailey *et al*., In Press) for land-based visual data with similar characteristics.

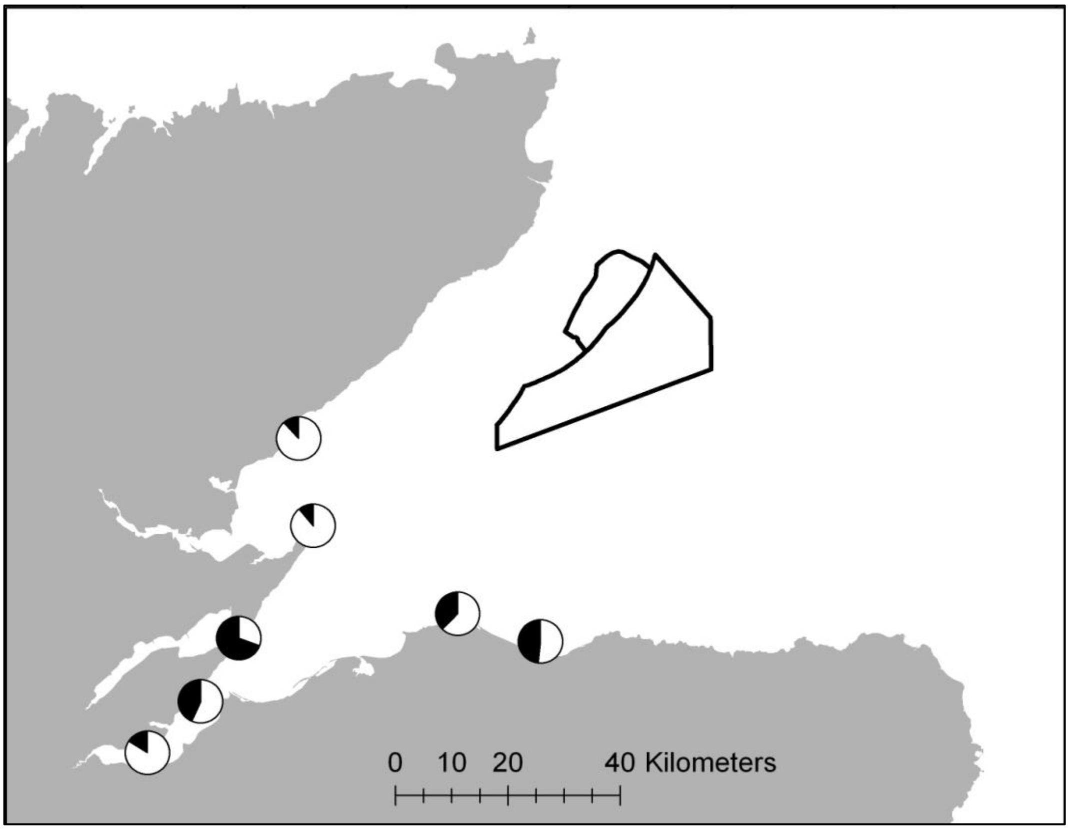
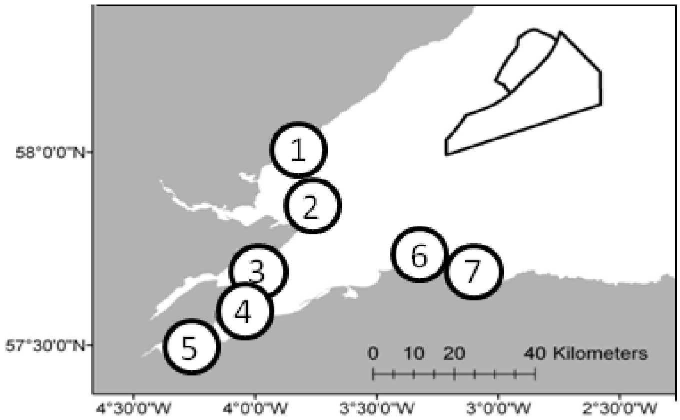


Figure 6.4. Variation in the probabaility of detecting dolphins on T-PODs at different coastal sites around the Moray Firth SAC. Data are for Jan-Dec 2008. The black section of each pie chart represents the proportion of days in the year that dolphins were detected at each site.



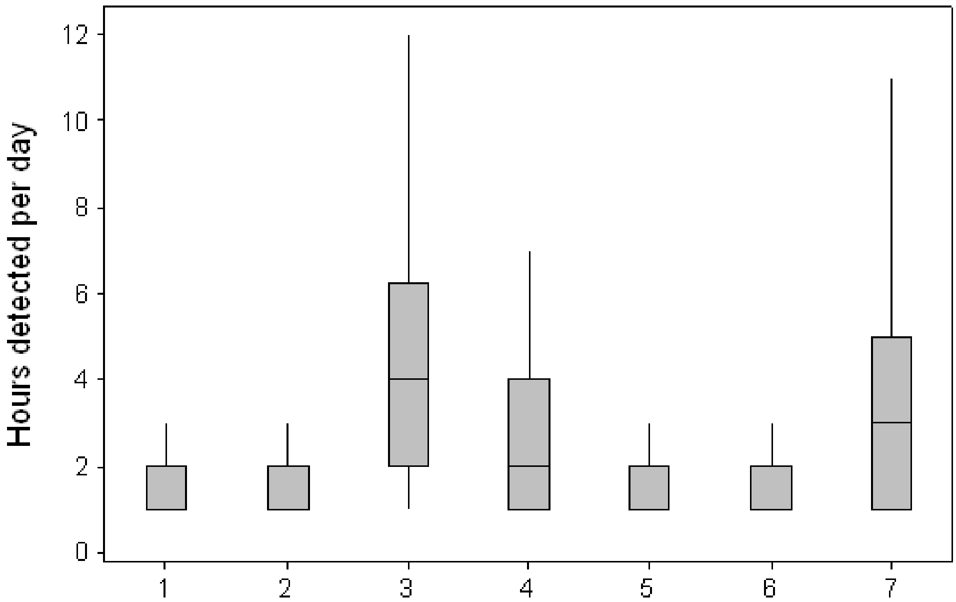


Figure 5.36. Variation in the median number of hours (+/- Inter-quartile rnages) that dolphins were present on those days that they were detected on T-PODs at different coastal sites around the Moray Firth SAC. Data are as for Figure 5.35.

6.3 Conclusions

Recent work has provided robust data that confirm that bottlenose dolphins rarely occur in offshore parts of the Moray Firth. Work is underway to model available data so that they better represent variations in the occurrence at both broad scale (inshore-offshore) and finer scale (within the coastal zone). Outputs from this work are anticipated during 2012. In the meantime, the exisiting data sources referred to here provide good information on finer-scale variability in the occurrence of bottlenose dolphins within coastal waters of the Moray Firth.

As discussed within the MORL/BOWL Seal Assessment Framework Document, there are no exisiting examples, or either regulator or scientific guidance, on how these data may best be used to quantify exposure to underwater noise or other potential impacts. In particular, the high level of mobility and schooling nature of bottlenose dolphins means that the average measures of density that are traditionally produced from survey data are difficult to interpret. This is an important area for discussion and research agenda development in the regulator-led workshops proposed for 2012.

6.4 References

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7. Acoustic method for determining bottlenose dolphin presence

7.1 Background

The aim of this study was to identify which dolphin species are found on the MORL and BOWL sites using acoustic methods. A new whistle classifier was constructed to identify bottlenose dolphins from other dolphin species that might be encountered at the wind farm sites using their whistles.

Previous studies by the University of Aberdeen using C-PODs have shown relatively high levels of dolphin activity around both BOWL and MORL sites (Figure 7.1) (Thompson *et al*., 2010). While the C-POD software can distinguish clicks made by dolphins from those made by porpoises, C-PODs cannot discriminate between dolphin species.

Knowing the identity of the dolphin species using the proposed wind farm sites is important because of their proximity to the Inner Moray Firth Special Area of Conservation (SAC) for bottlenose dolphins (*Tursiops truncatus*). Although previous data suggest that use of the outer Moray Firth by bottlenose dolphins is limited (Hastie *et al*., 2003; Bailey *et al*., 2010), the C-POD results lead to the possibility that bottlenose dolphins use this area more than previously thought. This has clear implications for any Appropriate Assessments being carried out for this species. However, historic sightings indicate that several other dolphin species are likely to occur at the wind farm sites, including common, white-beaked and Risso's dolphin (data summarised in Thompson *et al*., 2010).

In this study a novel approach was developed which used dolphin whistle contours extracted from broadband sound recordings made at the wind farm sites to discriminate between the different dolphin species occurring in the area.

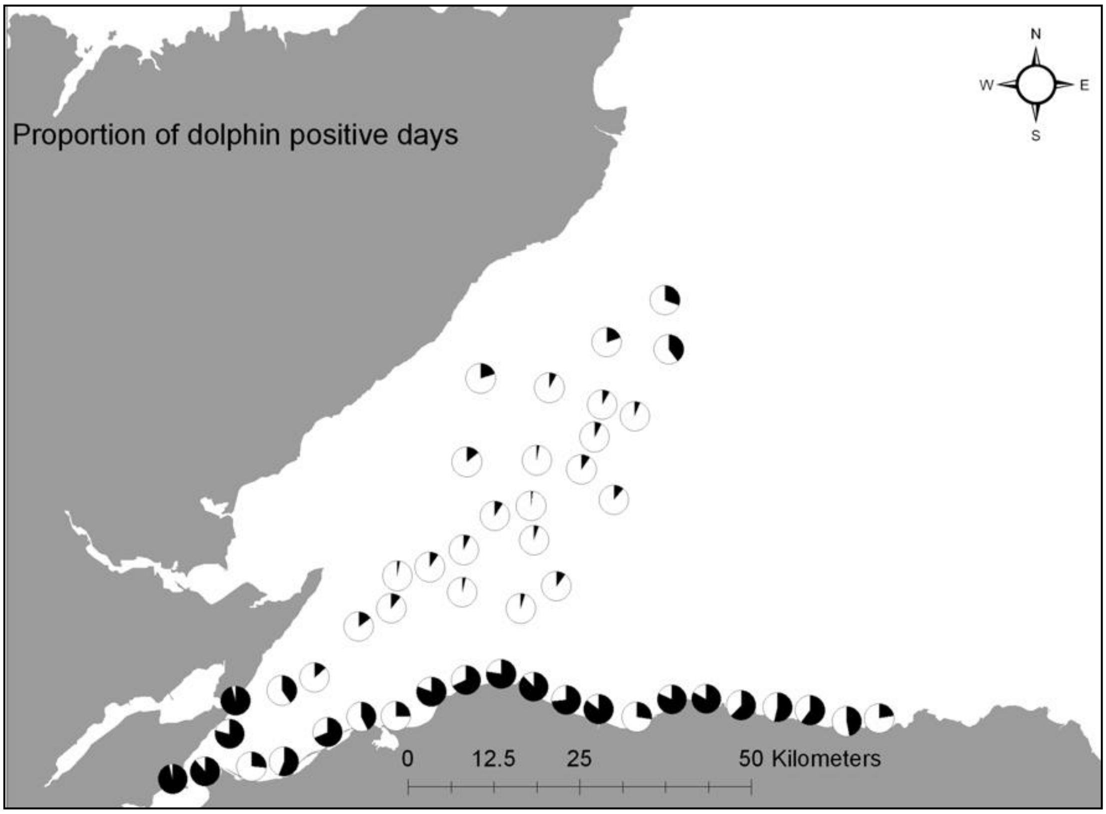

Figure 7.1: Proportion of days that dolphins were detected at each of the C-POD sample sites (taken from Thompson *et al.*, 2010).

To determine which species are using the MORL and BOWL sites, it was necessary to collect recordings of known delphinid species to 'train' whistle classifier software. This classifier software was then used to identify species present from whistles recorded at the MORL and BOWL sites and a comparative site within the Moray Firth SAC.

7.2 Data collection

7.2.1 Training Data

Existing data

Whistle classifier training was carried out using recordings of known species from existing datasets; recordings of common dolphin, white-beaked dolphin, white-sided dolphin and Risso's dolphin were obtained from the Hebridean Whale and Dolphin Trust[5] (HWDT) and further recordings of bottlenose and Risso's dolphins were sourced from the University of St Andrews. These existing recordings were collected at different locations around Scotland (see Figure 7.2; Table 7.1).

[5] http://www.whaledolphintrust.co.uk/

Table 7.1: Data collated and used to train the whistle classifier and the general location in which it was collected

Species	Species Class	Location	Number of whistle contours extracted
Bottlenose dolphin	BND	Moray Firth, St Andrews Bay, Shetland	71,013
Common dolphin	Other	West Coast	69,761
White-beaked dolphin	Other	West Coast	2,554
White-sided dolphin	Other	West Coast	5,505
Risso's dolphin	Other	West Coast, Shetland	6,358

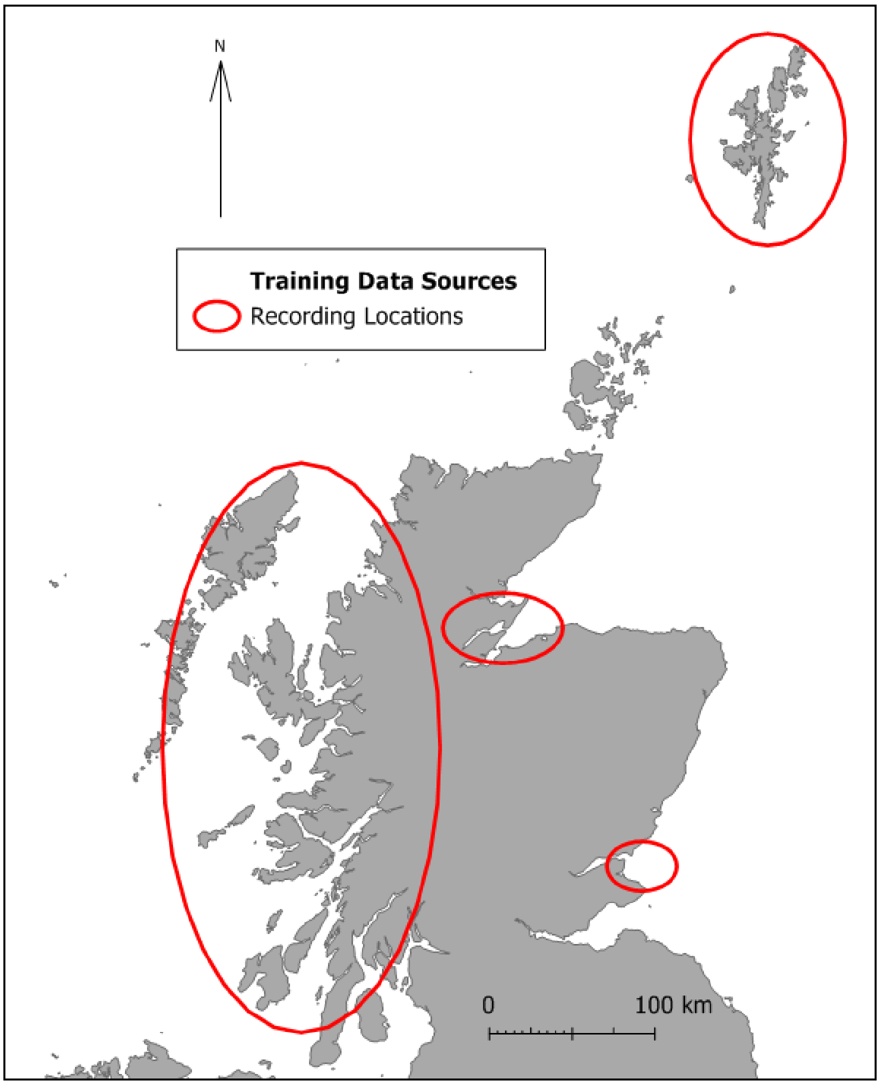

Figure 7.2: Map showing where training data were collected.

Data from field recording kits

Field recording kits were also given to organisations which are regularly out on the water in the Moray Firth (e.g. benthic surveyors, key eco-tourist operators and other local research groups) with the aim of collecting new recordings of the different dolphin species. However, at the time of publication, this data has not received been received.

7.2.2 Test Data

Ecological Acoustic Recorders[6] (EARs) were used to collect broadband sound recordings (sampling at 64 kHz; providing an effective bandwidth of 0-32 kHz) at six sites throughout the Moray Firth. These data were collected to determine what species use the BOWL and MORL sites.

[6] http://oceanwidescience.org/docs/EAR.htm

Five deployments were made within the BOWL and MORL sites in 2010 (Table 7.2; Figure 7.3), although one device failed after just one day's recording. For comparison, a further deployment was made inshore in a core area within the Moray Firth SAC (see Hastie *et al.*, 2003) that is regularly used by bottlenose dolphins (D01; Table 7.2; Figure 7.3).

EARs were deployed on existing moorings used for the concurrent Aberdeen University studies using C-PODS, and were set to record on a schedule of 30 minutes on, 30 minutes off for periods of approximately 20-30 days (limited by battery life). The data were recovered from the EARs and the .bin files generated as a standard were converted to .wav files using Matlab in preparation for further analysis.

Table 7.2: Details of EAR deployments. Depths are shown in metres.

Site No.	Site	Latitude	Longitude	Depth	Deployment Date	Recovery Date	No. Days
E16	MORL	58.12095	-2.8588	41	22/09/2010	16/10/2010	24
A20	MORL	58.19663	-2.7634	44	25/07/2010	15/08/2010	21
A22	MORL	58.27113	-2.6635	50	22/09/2010	23/09/2010	1
E17	BOWL	58.22713	-2.9354	41	24/07/2010	11/08/2010	18
E21	BOWL	58.30542	-2.8862	56	16/08/2010	09/09/2010	24
D01	Sutors	57.69025	-3.9831	11	07/10/2010	01/11/2010	25

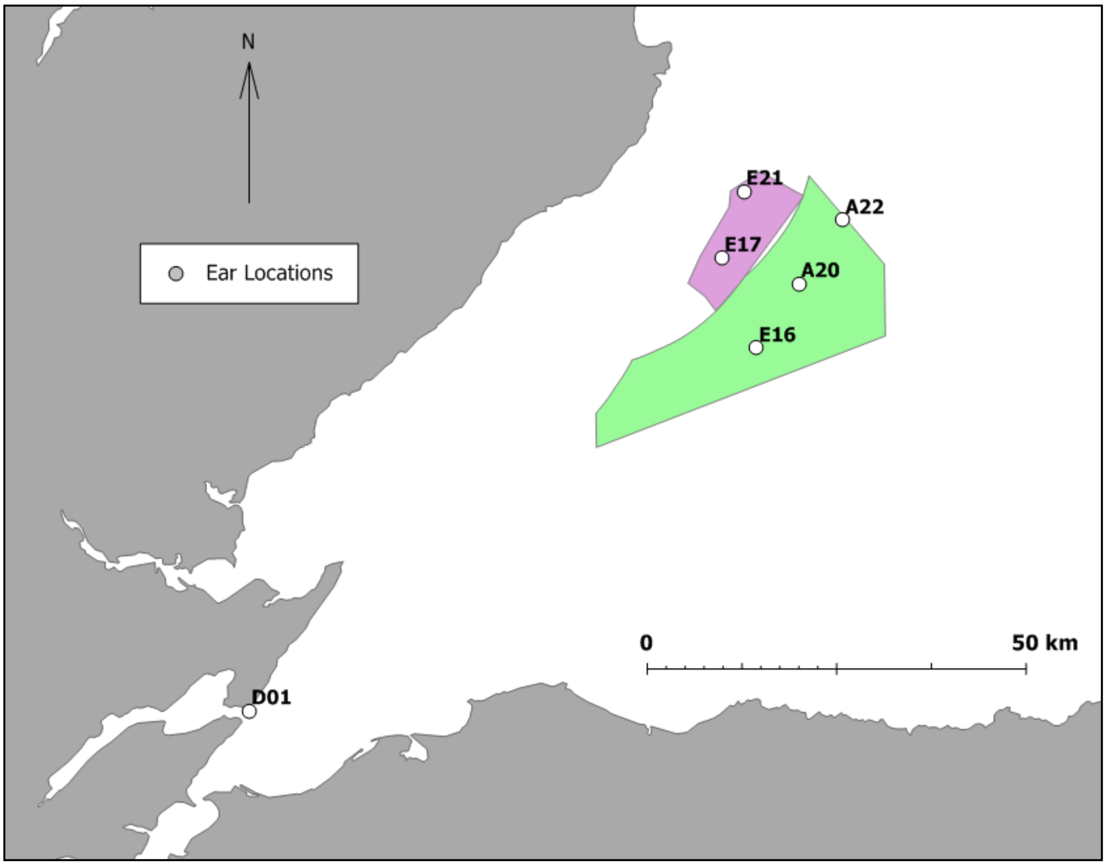

Figure 7.3: Map showing location of EAR deployments. The BOWL site is shown in purple, the MORL R3 zone is shown in green.

7.3 Data Processing

7.3.1 Whistle detection

Whistles were automatically detected using the 'Whistle and Moan' detection module (WMD) in the PAMGUARD software (Gillespie *et al.*, 2008; SMRU Ltd, 2011). The PAMGUARD WMD works by performing a series of four noise suppression calculations on a spectrogram of sound data. These are designed to remove both impulsive noises such as echolocation clicks and constant pure noise tones such as electrical interference. The output of the detector is the time-frequency contour of each whistle, i.e. the instantaneous frequency at a series of points in time. An example of WMD output is shown in Figure 7.4. Outputs from the detector were permanently stored in binary data files in preparation for classification.

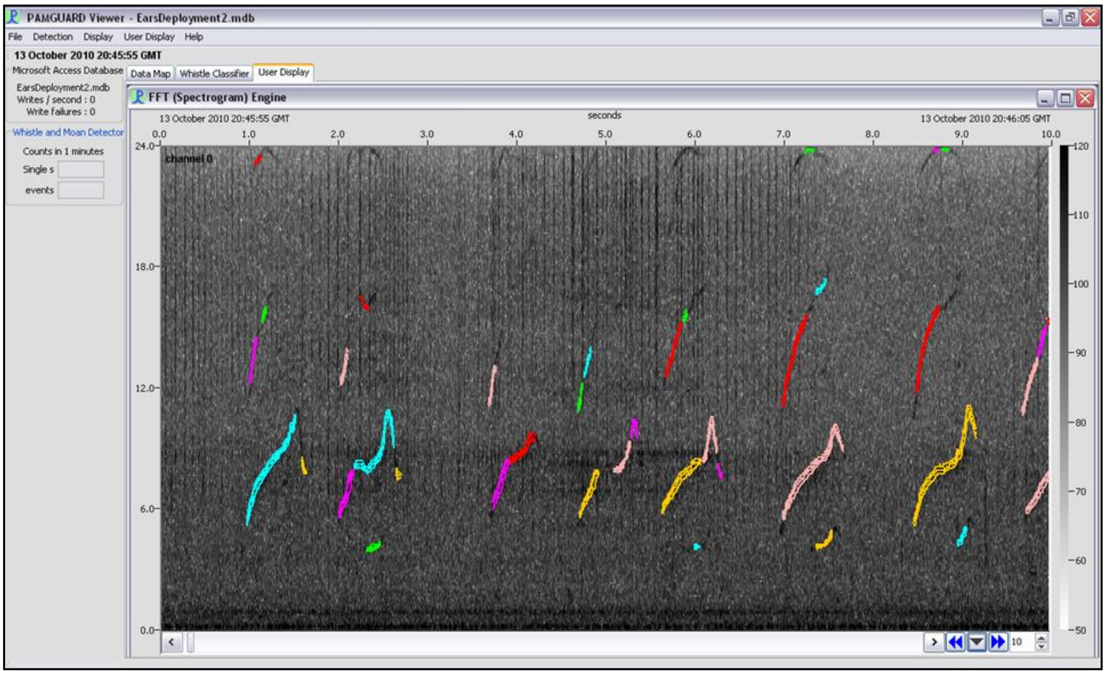

Figure 7.4: Example screen grab showing whistle contours extracted from recordings of bottlenose dolphins using PAMGUARD. Frequency (kHz) is on the y-axis and time (10 seconds) is on the x-axis). The different colours show the contours identified by the WMD (clicks are also visible above 6 kHz).

7.3.2 Whistle classification

The PAMGUARD Whistle Classifier is an automated classifier which works with output from the PAMGUARD WMD and was used in this study. Previously, other studies have attempted to develop automated whistle classification systems; a feature of those classifiers has often been that they require whistles which have been selected by hand (i.e. by a human operator) as their input (e.g. Oswald *et al*., 2007).

Fully automatic detectors, such as the PAMGUARD WMD, tend to detect only parts of each whistle, or will break up whistles into multiple segments. This is commonly caused by transient noise sources (such as dolphin echolocation clicks) intersecting whistles and causing breaks in the contour extraction process. The segmentation is also caused by amplitude modulation over the course of a whistle which causes some parts of the whistle to be above a detection threshold and other parts to fall below it.

The PAMGUARD classification system is designed to work with such fragmented or partially detected whistles. It does this by accumulating a statistical description of the detected whistle segments over a period of time and then makes a classification decision based on the statistics of those multiple segments. In fact, the first stage of the whistle classification process was to further fragment all detected whistle segments into fragments of equal length before the fragment accumulation process starts.

Parameterisation

For each whistle fragment, three parameters were measured. These were the mean frequency of the fragment, the slope (frequency against time) and the curvature (rate of change of frequency against time) of each fragment. Once the preset number of fragments had been accumulated, then for each of the three sets of parameters (mean, slope and curvature) three further parameters were extracted from those initial parameter sets. These were the mean value of each parameter distribution, its standard deviation (i.e. the width of each distribution) and the skewness (asymmetric nature) of each distribution. These nine parameters used for classification do not describe individual whistle detections, but the properties of a group of whistles.

Classifier Training and Testing

Nine parameters from a group of whistles (see above) were used in a discriminant analysis function to assign a species not to individual whistle contours, but to the group of contours as a whole. The discriminant analysis function must be trained with a sample of each species (or species group) of interest.

Here, the training data of known dolphin species collected from around Scotland was used. Since bottlenose dolphins were the focal species of this study, the classifier was trained to discriminate bottlenose dolphins against a general class containing all other species (recordings of common dolphins, Risso's dolphins, white-sided dolphins and white-beaked dolphins were used here). As there is potential that the vocalisations of a particular species vary regionally, data used to train the PAMGUARD classifier should ideally be taken from the region in which the classifier is to be used.

To train the classifier, the recordings of known species were first processed with PAMGUARD to extract their contours. Extracted contours were stored in binary files so that they could be reused multiple times as different classifier configurations were trained and tested.

Training data used in this study were collected at a variety of sample rates, ranging from 48 kHz to 500 kHz. While sampling at higher frequencies may yield additional information to the classifier, limiting ourselves to higher frequency data would have severely limited the amount of training data available. Therefore all training data were decimated to a standard sampling rate of 48 kHz prior to contour extraction.

During the training of the whistle classifier, the data were split with two thirds being used to train the classifier and one third being used to test the efficiency of its predictions. Training data were then selected sequentially from within the data set, starting at a random point. This training / testing process was repeated a large number of times using different randomly selected training and test samples (a process known as bootstrapping). This enabled the estimation of the efficiency and false alarm rate for each species and the estimation of their likely variance.

As part of the classifier training process, a 'Confusion Matrix' was produced which describes how data which are of a known species are likely to be classified. Each row represents the true species, while each column shows how those whistle contours have been classified. Since all contour events must be classified as a species, the sum of each row must always be 100%.

The two key parameters which are important when training the classifier are the fragment length (i.e. the size of the parts detected contours are broken up into prior to being input to the classifier) and the section length (i.e. the number of fragments to accumulate prior to parameterisation of the parameter distributions and classification).

It was expected that longer fragment lengths and longer section lengths would yield a more stable classifier. However, long fragment and section lengths require large numbers of whistles and thereby make classifying brief encounters with lone or small numbers of animals impossible. To select appropriate fragment and section lengths, the training bootstrap process was repeated for varying fragment and section lengths. Classification success increased gradually with increasing fragment length and section length.

In particular, there was a decline in efficiency for short fragment lengths of < about 20 FFT bins or section lengths of < 40 fragments. The optimal fragment and section lengths were set at 25 and 50 respectively. In the event that sections did not contain a sufficient number of whistle contours (preset by the user in PAMGUARD) to generate a classification, the counter was reset to avoid a large number of false detections being generated.

During classifier training it was possible to specify a minimum probability threshold which must be exceeded for a 'classification event' to occur. The whistle classifier was developed using the default probability of 0.5 (in which whistles have to be classified as bottlenose dolphins or 'other species').

Processing of EAR Data

Following training of the whistle classifier software using recordings from known species, data collected using the EARs in and around the MORL and BOWL sites were used to assess which species (bottlenose dolphins or 'other' candidate species) were present. For compatibility with the training dataset, all EAR data (which were collected at a sample rate of 64 kHz) were decimated to 48 kHz in PAMGUARD.

Whistle contour extraction was performed in the same way as for the training data, and detected contours were processed with the whistle classifiers described above. Once the EAR data had been classified, the number of dolphin encounters in each EAR deployment was determined (Figure 7.5; Figure 7.6). An encounter was defined as any classification events occurring within one hour of one another. A manual operator checked each classification event to determine whether dolphin whistles were present in the data or whether there were false detections (e.g. from other ambient noise sources) that could have impacted the classification.

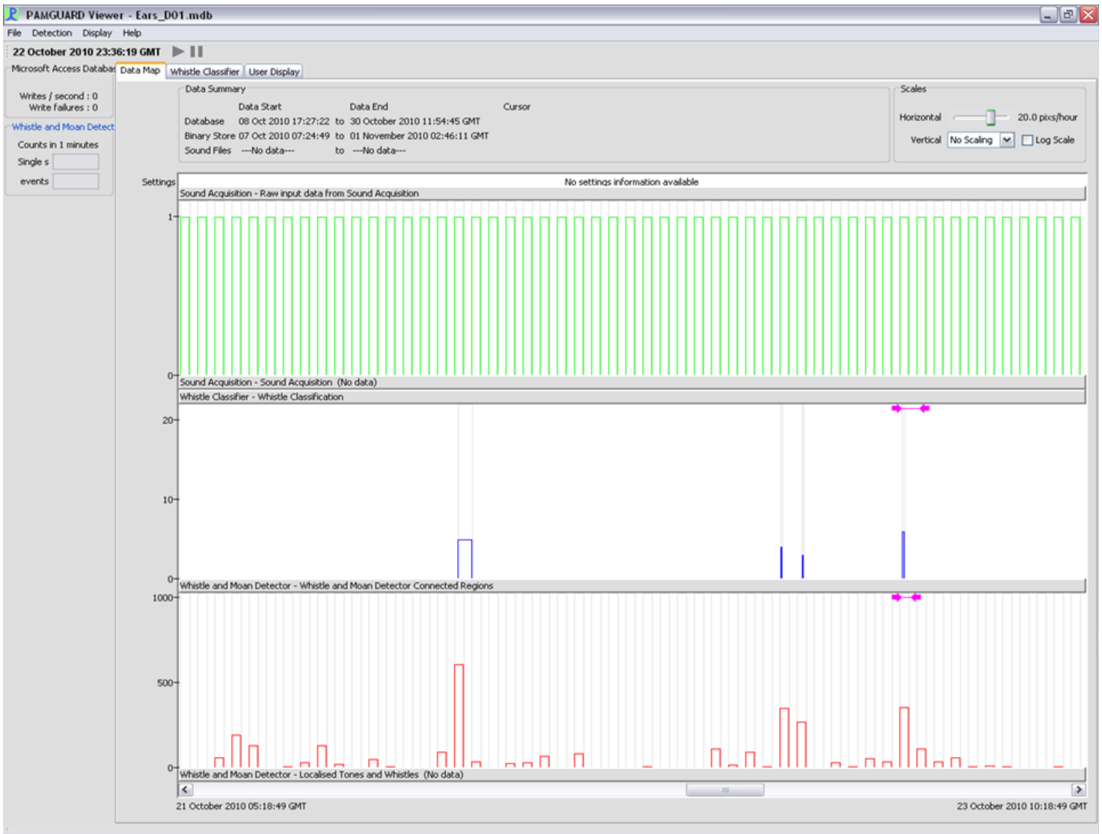

Figure 7.5: Screengrab from PAMGUARD showing the data map generated by the whistle classifier module for approximately 53 hours of EAR data. The sequential 30 minute EAR recordings (green bars - top panel), whistle classification events (blue bars - middle panel) and the number of whistle contours that were detected in each 30 min recording (red bars) are shown.

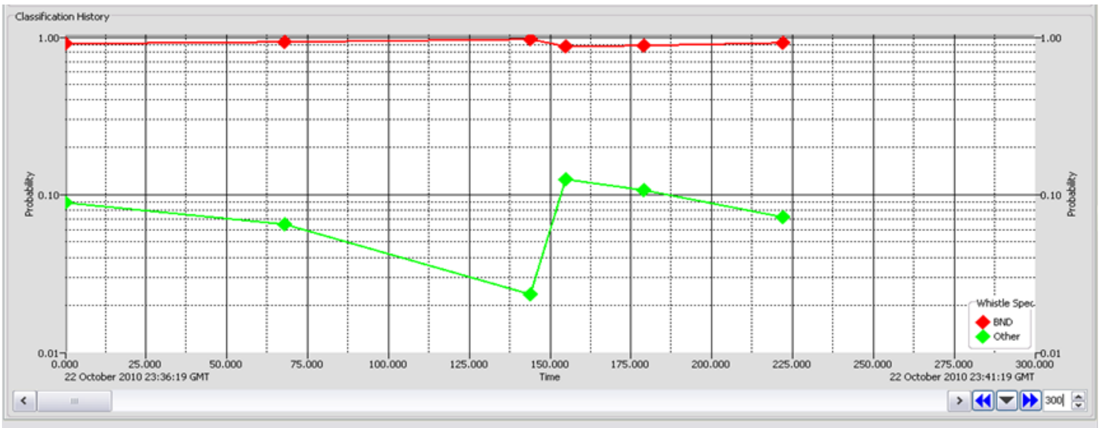

Figure 7.6: Screengrab from PAMGUARD showing each classification section (each diamond) and the probability (on y axis - log scale) associated with different whistles being attributed to species (BND in red, OTHER in green). N.B. In each classification section, the probability of BND and Other add up to 1.

7.4 Results

7.4.1 Classifier Training

Confusion Matrices

The confusion matrix resulting from the whistle classifier trained with all data in Table 7.3. The results show a mean successful classification rate for bottlenose dolphin of 87% and the misclassification rate of other species is only 6% (i.e. 6% of all classifications will be incorrectly classified as bottlenose dolphins).

Table 7.3: Training confusion matrix for the whistle classifier showing the mean classification rate *(standard deviation) [95% Confidence Interval]*.

		Classified Species	
		BND	**Other**
True Species	**BND**	0.87 (0.10) [0.70-0.98]	0.13 (0.10) [0.01-0.29]
	Other	0.06 (0.02) [0.01-0.10]	0.94 (0.02) [0.89-0.98]

7.4.2 Analysis of EAR data

The EAR data were processed using the whistle classifier (Table 7.4; Figure 7.7) to determine the species of dolphins detected at each of the study sites (see Section 7.7 for full details of classifications).

A total of 50 classification events were generated using the classifier (Table 7.4). Of these, 22 were of bottlenose dolphins, 21 were classified as 'others' and seven were determined by a manual operator to be false detections. It is noteworthy that all of the false detections had been classified by the detector as bottlenose dolphins rather than 'other' dolphins. This issue is further discussed in Section 7.6.3.

Table 7.4: Summary of the classification of the EAR data using the whistle classifier. BND = bottlenose dolphin.

Site No.	Location	Number of classification	Number of BND	Number of "Other"	Number of False
E16	MORL	3	0	0	3
A20	MORL	7	0	4	3
A22	MORL	0	0	0	0
E17	BOWL	4	0	4	0
E21	BOWL	8	0	1	7
D01	Sutors	28	22	6	0
TOTAL	ALL	50	22	15	13

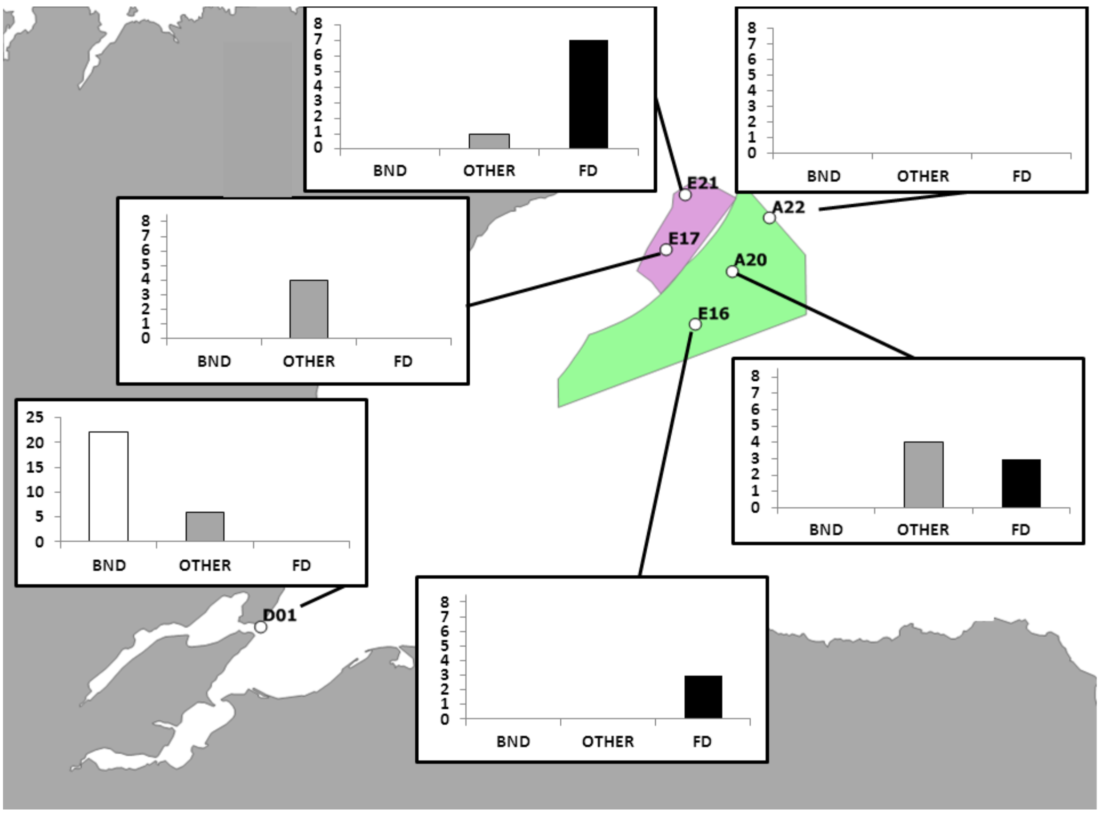

Figure 7.7: The results of the classification of whistle events in the EAR data using the whistle classifier. BND = events classified as bottlenose dolphins (white), OTHER = events classified as 'other species' (grey) and FD = events classified as dolphins, but identified as false detections by the manual operator (black). N.B. The scale of the y-axis for the 'D01' EAR is different to the EARs deployed on the BOWL site and MORL R3 zone.

Of the EARs deployed, two were within the proposed BOWL site (E17 and E21). There were 12 classification events at these sites, and no bottlenose dolphins were detected. Five of the classification events contained whistles and were classified as 'other species'. There were seven other classification events classified as bottlenose dolphins, although these were determined to contain no dolphin whistles and thus to be false detections by the manual operator.

The EARs deployed on the MORL R3 zone (A20, A22 and E16) were determined to contain a total of 10 classification events. At the A20 site there were a total of seven events that were detected by the classifier. Of these, four were determined to be 'other species' and three were identified as false detections by the manual operator. The EAR at the A22 site was only active for one day and did not detect any classification events during this time. At the E16 site, all of the classification events were determined to be false detections (classified as bottlenose dolphins) i.e. no dolphins of any species were detected at this site.

The EAR deployed at the D01 'Sutors' site recorded the most dolphin activity. At that site there were 28 classification events, of which 22 (79%) were determined to be bottlenose dolphins. The remainder (21%) were classified as 'other species'. There were no false detections impacting the classification events at this site.

False detections

A manual operator investigated each classification event produced by the classifier to determine whether there had been any false detection (i.e. classification events indicated to be dolphins by the classifier, but instead being artificial detections). Thirteen classification events that were initially classed as dolphin events were determined to be false detections by the manual operator. This occurred at three of the EAR sites (E21, A20 and E16).

All of the false detections were classified as bottlenose dolphins by the classifier. Some classification events determined to be dolphins contained a small number of false detections along with dolphin whistles. In these cases, it is considered unlikely that these false detections significantly impacted the proper classification of dolphin species.

The most common sound causing the false detections was a 'rubbing' sound, likely associated with a swivel on the mooring of some of the EARs. This 'rubbing' sound generated an upsweeping tonal sound with several harmonics between 1.5 – 24 kHz (the maximum recorded by the sampling rate after decimation) (Figure 7.8).

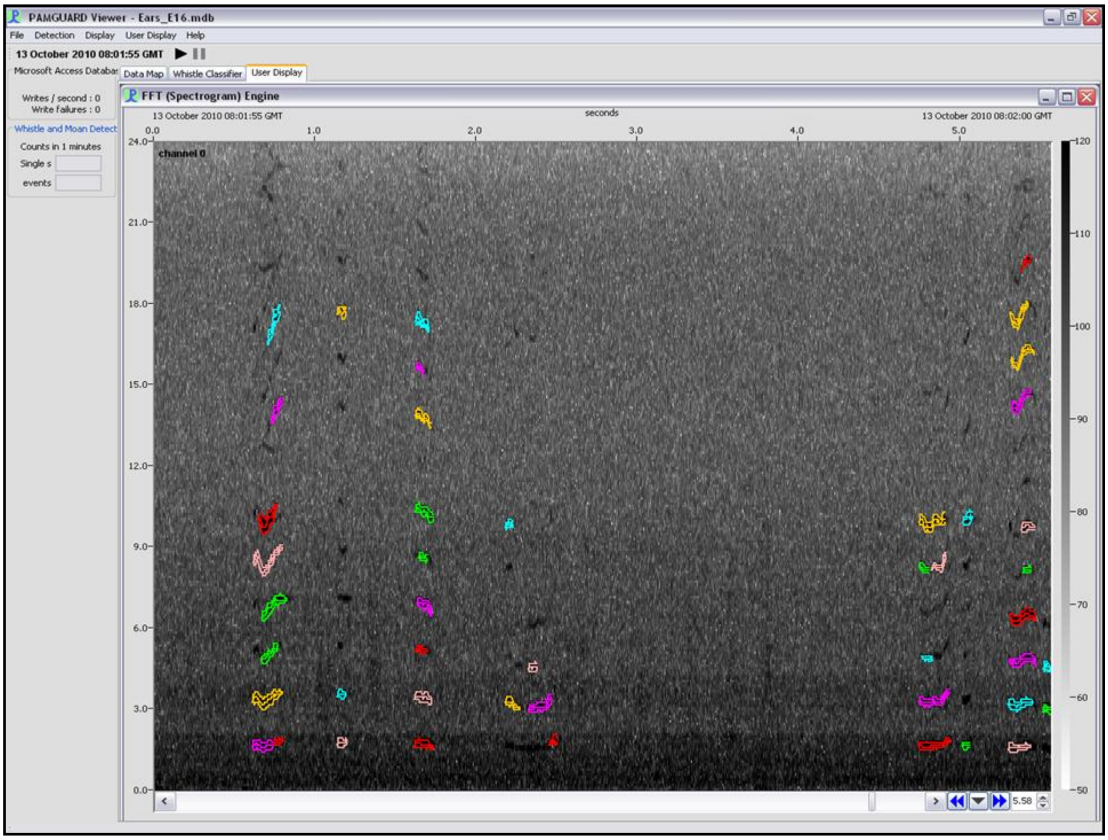

Figure 7.8: Screengrab from PAMGUARD whistle classifier of a 'rubbing' false detection. Frequency is on the y-axis and time (5.58 seconds) is on the x-axis. The different colours show the contours generated by the WMD.

7.5 Discussion

The aim of this study was to identify which dolphin species are found on the MORL and/or BOWL sites using acoustic data collection methods. In order to achieve this, a new classifier was constructed to identify bottlenose dolphins from other dolphin species that might be encountered at these sites.

7.5.1 Dolphin species in the MORL/BOWL sites

The results of this study support previous evidence that bottlenose dolphins are generally not present at either the MORL or BOWL sites, at least during the summer (July-October) sampling period used in this study. The recordings made by five EARs deployed on these sites did not record any whistle events that could be attributed to bottlenose dolphins.

A number of marine mammal surveys have previously been conducted on, or in the proximity of, the MORL and BOWL sites. Whilst some dolphins were not identified to species, almost all positive dolphin identifications in these areas were of common dolphins, white-beaked dolphins and Risso's dolphins.

7.5.2 Dolphin species in the Moray Firth SAC site (D01)

Bottlenose dolphins were identified by the classifier to be present at the D01 site. A number of surveys have identified that bottlenose dolphins are common in this region (e.g. Thompson *et al*., 2006). In this study, 79% of all classification events were identified by the classifier as bottlenose dolphins.

The classifier predicts that 13% of events where the true species is bottlenose dolphins would be incorrectly classified as 'other species'. With this in mind it was noteworthy that the data from the D01 site indicated 21% of all whistle events were classified as 'other species'. There are a number of possible explanations for this result.

Firstly, it must be considered that these whistle events are genuine detections of 'other species' and that such species are present in proximity to the D01 site. Estimates of dolphin whistle detection ranges vary (depending on the species and the environment in which the sounds are produced), but they are generally considered to propagate between 1.5 - 4 km (Gordon *et al*., 2000; Janik, 2000; Quintana-Rizzo *et al*., 2006). It is possible that 'other species' could be present near these sites (i.e. within 4 km). Both common dolphins and pilot whales have occasionally been detected in this area in the last 10 years, but sightings of these species are rare compared to very regular encounters with bottlenose dolphins (University of Aberdeen, unpublished data).

Given this, the most likely explanation for the classification of other species is that the classifier constructed in this study did not capture the full vocal repertoire of the dolphin species of interest. In addition, there may be overlap between the whistle repertoires of bottlenose dolphins and the other species of interest.

Where significant overlap exists, it is unlikely that the classifier will be able to distinguish between species groups. This is particularly so when only a small number numbers of whistles are recorded. Inspection of the summarized data presented in Section 7.7 (Appendix) shows that classification events of 'other' species at the D01 site typically involved a small number of sections and low levels of probability compared to those at offshore sites. This lends further weight to the conclusion that these are miss-identifications. In future the collection of more whistle datasets of known dolphin species of interest will allow the classifier to be re-trained and refined in order to improve classification of dolphin species whistles.

7.5.3 Impacts on detection of dolphin whistles

It is important to consider that in order for dolphins to be detected by EARs (and consequently the species identified) they must be vocalizing. Dolphin whistles are considered to be social or communicative signals and whistle rates are likely to vary depending on context (Quick & Janik, 2008) which may impact detection by the classifier. However, given the potential range of the EARs, it seems unlikely that dolphins could be present at sites without being detected acoustically, however low whistle rates may lead to no classification occurring.

Despite this, the sampling regime of the EARs is not continuous (30 minutes recording, followed by 30 minutes off) and it is possible that some dolphin events are missed by the EARs during periods when they are not recording.

Ambient noise levels may also potentially impact the detection and classification of dolphin whistles. The classifier functions by analyzing the output of the PAMGUARD whistle and moan detector. If in training and/or test (EAR) recordings, there is an elevated noise floor (i.e. high ambient noise), it may be harder to detect whistle contours resulting in certain frequency portions of whistles being masked and thus not be detected by the WMD. This could lead to only the higher frequency segments of whistles being detected and the classification of species to be skewed to higher frequency whistles (which may be species specific).

7.5.4 False detections

False detections were identified at many of the EAR sites and in recordings from three sites (E21, A20 and E16) these resulted in incorrect classification events. In all these cases the false detection sounds were classified as bottlenose dolphins.

Assessment by a manual operator identified that these noises were consistent in their intensity and frequency characteristics and were likely generated by the EAR devices themselves or parts of the mooring structures (e.g. swivels, loose chains etc.). Identifying the source(s) generating these false detections and removing it is essential in the use of EARs in future monitoring. Where real-time whistle classification is required for mitigation purposes, and manual supervision is not feasible, it will not be possible to identify these common false detections of bottlenose dolphins.

7.5.5 Future work

This study represents the first application of fragmented (or incomplete) whistles in the development of a dolphin species acoustic classifier. The results of this ‘proof of concept’ classifier indicate that this is a valid method for detecting and identifying dolphin species groups using only their whistles. Future work could build upon the classifier developed here and such work could include:

Further data collection

The collection of further species whistle data would refine future generations of the whistle classifier and improve acoustic species identification.

Development of a statistical framework

A further step in the development of suitable whistle classifiers is the use of a statistical framework to better define differences in species whistle repertoire.

Assessment of background noise

It is important to consider the ambient noise during recordings of dolphin whistle events. This may provide insight into whether whistle contours detected by the WMD are being impacted by the ambient noise floor.

In addition, further field data collection could be carried out to increase sample sizes and consolidate the conclusions of this study. Year-round data would be particularly valuable in this respect, and longer term data collection may be possible through the deployment of PAMBOUY[7] hardware at the site.

7.6 References

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[7] http://pambuoy.com/

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7.7 Appendix

Details of the whistle classification events from each of the EARs:

EAR name is shown above each table (no whistle classification events occurred at A22); *Event time* = the start time for each whistle classification event, *n* = the number of sections in each classification event; *nBND* = the number of classification sections in each event attributed to bottlenose dolphins; *pBND* = the likelihood that the whistles in the event were generated by bottlenose dolphins; *nOther* = the number of classification sections in each event attributed to 'other species' of dolphin; *pOther* = the likelihood that the whistles in the event were generated by 'other species' of dolphin; *Dolphins* = whether or not genuine dolphin whistles were recorded during the classification event (determined by a manual operator); *False Detections* = whether or not false detections occurred during the classification event (determined by a manual operator) (N.B. – the presence of false detections during a whistle classification event, does not invalidate the classification; in most cases only a small number of FD occurred during a classification event), *Classified As* = the final result of the classification.

EAR: A20								
Event Time	**n**	**n**	**p**	**n**	**p**	**Dolphin**	**False**	**Classified**
22/07/2010 17:15:43	1	1	1	0	0	N	Y	FD
26/07/2010 09:27:43	88	8	0.2	80	0.8	Y	N	Other
29/07/2010 10:06:04	93	5	0.1	88	0.9	Y	N	Other
29/07/2010 13:02:22	119	5	0.1	114	0.9	Y	N	Other
01/08/2010 23:01:27	42	0	0	42	1	Y	N	Other
03/08/2010 09:02:24	10	10	1	0	0	N	Y	FD
04/08/2010 18:26:48	4	3	0.9	1	0.1	N	Y	FD

EAR: E17								
Event Time	**n**	**n**	**p**	**n**	**p**	**Dolphin**	**False**	**Classified**
29/07/2010 09:22:19	14	1	0.1	13	0.9	Y	Y	Other
29/07/2010 13:22:47	40	4	0.2	36	0.8	Y	Y	Other
01/08/2010 23:39:40	53	0	0.1	53	0.9	Y	N	Other
04/08/2010 21:50:36	4	0	0.1	4	0.9	Y	N	Other
EAR: E16								
Event Time	**n**	**n**	**p**	**n**	**p**	**Dolphin**	**False**	**Classified**
07/10/2010 12:17:07	1	1	1	0	0	N	Y	FD
08/10/2010 13:04:43	1	1	1	0	0	N	Y	FD
13/10/2010 06:20:58	83	83	1	0	0	N	Y	FD
EAR: D01								
Event Time	**n**	**n**	**p**	**n**	**p**	**Dolphin**	**False**	**Classified**
08/10/2010 17:27:22	3	2	0.7	1	0.3	Y	N	BND
09/10/2010 07:47:14	5	3	0.5	2	0.5	Y	Y	BND
10/10/2010 03:47:00	2	1	0.6	1	0.4	Y	N	BND
10/10/2010 23:38:13	1	1	0.8	0	0.2	Y	N	BND
11/10/2010 20:26:07	3	3	0.8	0	0.2	Y	N	BND
11/10/2010 22:34:51	1	1	0.6	0	0.4	Y	N	BND
12/10/2010 06:49:28	1	1	0.8	0	0.2	Y	N	BND
12/10/2010 15:35:51	1	1	0.9	0	0.1	Y	N	BND
13/10/2010 20:45:44	20	20	0.9	0	0.1	Y	N	BND
14/10/2010 12:25:38	1	0	0.4	1	0.6	Y	N	Other
14/10/2010 17:52:23	1	1	1	0	0	Y	Y	BND
15/10/2010 13:42:35	2	0	0.1	2	0.9	Y	N	Other
15/10/2010 16:53:27	1	1	1	0	0	Y	N	BND

16/10/2010 09:27:20	1	1	1	0	0	Y	N	BND
16/10/2010 19:49:43	1	1	0.7	0	0.3	Y	N	BND
18/10/2010 01:40:11	3	2	0.6	1	0.4	Y	N	BND
20/10/2010 22:28:17	3	0	0.2	3	0.8	Y	N	Other
21/10/2010 21:37:40	5	5	0.9	0	0.1	Y	N	BND
22/10/2010 16:29:24	4	2	0.5	2	0.5	Y	N	BND
22/10/2010 17:45:04	3	2	0.5	1	0.5	Y	N	Other
22/10/2010 23:36:19	6	6	0.9	0	0.1	Y	N	BND
23/10/2010 22:47:10	1	1	0.9	0	0.1	Y	N	BND
24/10/2010 18:27:55	4	3	0.6	1	0.4	Y	N	BND
25/10/2010 01:35:30	3	2	0.7	1	0.3	Y	Y	BND
25/10/2010 20:42:36	1	0	0.4	1	0.6	Y	Y	Other
27/10/2010 15:33:22	2	1	0.5	1	0.5	Y	Y	Other
28/10/2010 12:30:46	9	5	0.7	4	0.3	Y	N	BND
30/10/2010 11:54:22	3	3	1	0	0	Y	N	BND
EAR: E21								
Event Time	**n**	**n**	**p**	**n**	**p**	**Dolphin**	**False**	**Classified**
18/08/2010 02:21:24	3	3	1	0	0	N	Y	FD
18/08/2010 12:08:15	13	13	1	0	0	N	Y	FD
20/08/2010 15:30:41	2	2	1	0	0	N	Y	FD
22/08/2010 03:26:08	4	1	0.3	3	0.7	Y	N	Other
24/08/2010 00:23:50	1	1	1	0	0	N	Y	FD
24/08/2010 06:36:36	1	1	1	0	0	N	Y	FD
29/08/2010 15:20:59	1	1	1	0	0	N	Y	FD
29/08/2010 20:15:05	4	4	1	0	0	N	Y	FD

8. NPC boat-based surveys

8.1 Background

Natural Power Consultants (NPC) was commissioned to undertake boat-based marine mammal baseline surveys for the proposed development sites (Telford, Stevenson and MacColl) within the Moray Firth R3Z1 Offshore Wind Farm from April 2010 to March 2012 inclusive. The purpose of these surveys was to provide up-to-date, fine scale, site specific information on marine mammal distribution and abundance within the proposed development sites.

8.2 Baseline Methodology

8.2.1 Boat-based surveys, 2010-2012

NPC has undertaken boat-based marine mammal and bird surveys since April 2010. 28 surveys have been carried out with the final survey taking place in March 2012.

The survey methodology utilised followed the technique for ship-based surveys outlined by Camphuysen *et al*., (2004) and the recommendations to improve this methodology outlined by Maclean *et al*., (2009). The characteristic of this approach was the use of a line-transect survey method within a survey area that incorporated the proposed development areas plus a buffer of approximately 4 km (Figure 8.1). East-west transects routes were selected as this placed them generally perpendicular to the Caithness coast.

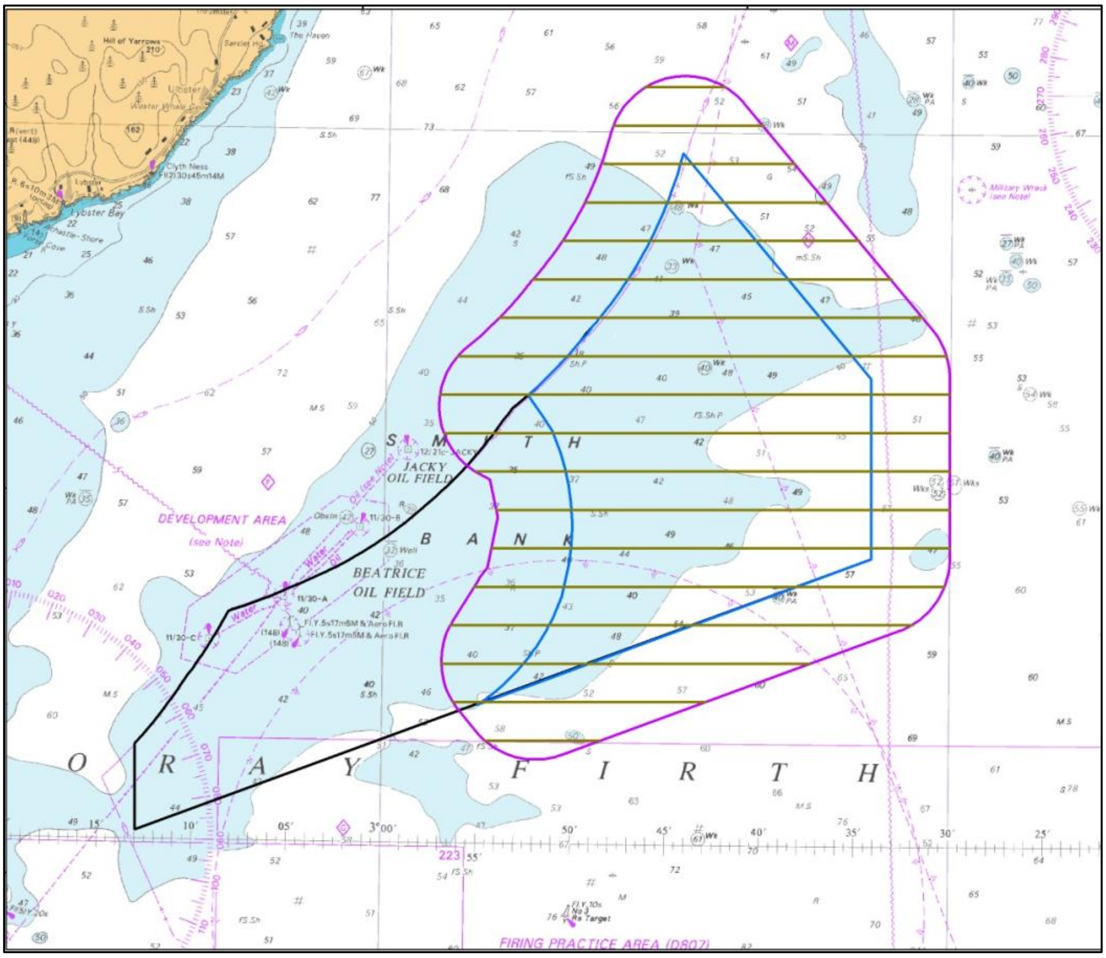

Figure 8.1: Illustration of transect lines followed during the boat-based surveys of the proposed sites (Telford, Stevenson and MacColl) combined plus a 4 km buffer zone. Pink line represents the survey area including buffer; Blue line the three proposed sites combined; Black line the R3Z1.

- **Vessels**

Four vessels have been used to date, depending on their availability, for the boat-based surveys (Images 8.1-8.3; Table 8.1). Each of these vessels complies with COWRIE guidance (Camphuysen *et al*., 2004; Maclean *et al*., 2009) of having:

- A length of 20-100 m;
- A forward viewing platform of at least 5 m above sea level; and
- The capability of travelling in the range of 5-15 knots (generally approximately 10 knots) whilst surveying.

Table 8.1: Specifications of the vessels used for the bird and marine mammal surveys of the proposed sites (Telford, Stevenson and MacColl).

Vessel	Length	Observer eye height	Survey speed	Image
Kintore	32.50 m	6.0 m	10 knots	7.1
Keverne	32.50 m	6.0 m	10 knots	7.1
Gemini Explorer	22.00 m	6.0 m	8.5 knots	7.2
Smit Yare	28.95 m	5.8 m	11 knots	7.3

Image 8.1: Kintore and Keverne vessels.

Image 8.2: Gemini Explorer vessel.

Image 8.3: Smit Yare vessel.

- **Data collection**

Twenty-eight boat-based bird and marine mammal surveys were carried out between April 2010 and March 2012 (Table 8.2). These surveys were undertaken monthly with additional surveys carried out in August 2010, April 2011, June 2011 and August 2011.

The boat-based survey followed a line-transect method, designed to enable distance sampling of biological data and calculation of densities. Marine mammal surveys were conducted alongside the ornithology surveys. Marine mammals and other mega fauna sightings (e.g. basking shark) were recorded by a dedicated observer. The information recorded included:

- Species;
- Date and time;
- Group size, recording the minimum, maximum and best estimate, plus the number of calves where appropriate;
- Distance and bearing from vessel using reticule binoculars; and
- Additional information regarding age and behaviour (i.e. normal swim, breaching, feeding) and cue for sighting, (i.e. breach, splash, blow).

All those undertaking observations were trained to JNCC standards. The surveyors were highly experienced with the survey and recording methods and marine mammal identification, including familiarity with all relevant scarce and common marine species.

Table 8.2: Dates of bird and marine mammal surveys undertaken for the proposed sites (Telford, Stevenson and MacColl).

Survey	Dates	Survey vessels
1	27th, 28th, 29th April 2010	Keverne/Kintore
2	24th, 25th, 26th May 2010	Kintore
3	15th, 16th, 17th June 2010	Keverne
4	26th, 27th, 28th July 2010	Gemini Explorer
5	7th, 8th, 9th August 2010	Keverne
6	18th, 19th, 31st August 2010	Keverne / Gemini Explorer
7	22nd, 30th September and 13th October 2010	Keverne/Kintore
8	13th, 16th, 31st October 2010	Keverne/Kintore / Smit Yare

9	15th, 22nd November and 4th December 2010	Keverne
10	14th, 21st, 22nd December 2010	Keverne
11	13th, 19th, 22nd January 2011	Keverne / Smit Yare
12	10th February and 3rd, 4th March 2011	Kintore / Gemini Explorer
13	5th, 22nd, 25th March 2011	Kintore / Gemini Explorer
14	14th, 15th, 16th April 2011	Kintore
15	24th, 25th, 26th April 2011	Keverne
16	3rd, 4th, 12th May 2011	Gemini Explorer
17	4th, 5th, 6th June 2011	Keverne
18	19th, 20th, 21st June 2011	Keverne
19	9th, 10th, 11th July 2011	Gemini Explorer
20	6th, 14th August 2012	Gemini Explorer / Smit Yare
21	18th, 19th, 26th August 2011	Gemini Explorer
22	15th September and 1st, 2nd October 2011	Gemini Explorer
23	12th October and 5th, 6th November 2011	Gemini Explorer
24	6th, 7th, 20th November 2011 and 14th January 2012	Gemini Explorer
25	14th, 15th, 16th January 2012	Gemini Explorer / Smit Yare
26	16th, 28th January and 2nd February 2012	Gemini Explorer
27	9th, 11th, 12th February 2012	Gemini Explorer
28	13th, 14th, 15th March 2012	Gemini Explorer

- **Data analysis**

Data exploration

Marine mammal sightings recorded by all personal onboard the survey vessel, included the ESAS bird surveyors. As a result, sightings were coded according to whether they were first observed by the MMO, ESAS observer or other personal (i.e. scribe or resting birder). Sightings recorded between survey lines were excluded from the analysis. All data were visualised using ArcGis.

For each species observed, sightings were grouped according to calendar month (appose to individual surveys). The level of effort conducted in each month was also calculated allowing sightings to be expressed per unit effort.

For those species with sufficient data, density plots and abundance estimates were calculated (see below). The location of the remaining species were visualised on simple sightings maps.

Density plots

In order to show the distribution of individuals across the site and buffer areas, density plots were constructed for harbour porpoise, minke whale, grey seal, and all seals combined.

The survey area was divided into 2 x 2 km grid squares, ensuring that a survey transect passed through the centre of each grid square. The mean number of observations within each grid square were calculated by dividing the total number of animals observed within each square by the number of surveys (n = 28) to give the number of observations per survey for each 2 x 2 km grid square. All sightings were used in this analysis.

Abundance estimates

Distance software Version 6.1 was used to calculate apparent density and population size within the site and the buffer areas for all seals combined, grey seals, harbour porpoise and minke whale. Since numbers of observations of other species were low, this analysis was not considered to be appropriate for all species. The analysis provides an estimate of the density (individuals per km^2) and the population size (overall numbers) of each species within each area.

Distance sampling operates on the principle that randomly distributed targets become more difficult to detect with increasing distance from the observer (Buckland *et al*., 2001). As a result, an increasing proportion of targets that are present will go undetected with increasing distance from the observation platform. In order to account for this decline in detectability, a detection function is included within the analysis. This function allows the estimation of the number of undetected individuals present within the area surveyed, which is then incorporated into the calculations of overall density and population for each species.

Transects were divided into segments in such a way to allow the proposed sites combined and buffer zone to be separated. If transects passed through the site, they were divided into three separate transect segments, a site transect and two segments representing the length of the transect passing through the buffer either side of the site area. The result was 48 replicate transect segments (15 falling within the site and 33 falling within the buffer area). The shape of the curve used to model the change in detectability with distance was selected based on AIC[8] and goodness of fit, using all observations combined across surveys and regions.

[8] Akaike Information Criteria: measure of goodness of fit and model complexity. The lower the value, the better the model.

Estimates of density and population size were then calculated for each region (proposed sites combined and buffer zone), using the global detection function to allow estimation of undetected individuals and incorporating a multiplier of 28 in order to account for repeated visits.

Only sightings recorded by the MMO and ESAS observer were used in this analysis. Distance analysis is usually only possible with more than 60-80 observations, which was the case for all seals, grey seals and harbour porpoise. The number of minke whale observations did not quite meet this criteria but it was decided to run the analysis with the caveat that the small sample size be taken into account when interpreting the results.

The data for each species was examined independently prior to analysis and the data truncated accordingly. As a result, the minke whale data was truncated at 800 m (n = 39), harbour porpoise data at 600 m (n = 448) and the grey seal (n = 160) and all seals combined (n = 266) data at 400 m.

Sample size prevents this analysis being conducted on each of the three proposed sites independently. In order to achieve an estimate of abundance within the three individual sites, the proportion of sightings within each site was calculated and the combined site estimates divided accordingly to give an level of abundance within each site.

A key assumption of distance analysis (and the production of a detection function) is that all animals are detected on the survey track line (expressed as g(0) = 1). It is important to note that for marine mammal species, their diving behaviour (often in direct response to the boat presence) results in low numbers being available at the surface for detection during boat-based surveys. As a result, not all animals "on the line" are detected therefore population estimates based on this collection method are likely to underestimate total population size. These estimates can, however, provide a proxy for true population size and can be useful for comparisons between sites.

It can be possible to estimate the proportion of animals missed however in practice this is difficult to achieve. If the detection rate on the track line is known (i.e. how many are missed), it is possible to incorporate this into the density estimate calculation. It was not possible to calculate such a value for the surveys under discussion here, but detection rates are available for the SCANS II boat surveys (SCANS II). While not directly comparable, it is possible to use the detection rates calculated for SCANS II to illustrate the potential level of under-estimation in the density calculations presented here.

As a result, the density estimates and populations sizes were re-calculated for harbour porpoise and minke whales, using the detection rates calculated in the SCANS II boat surveys. No such proxy's were available for the seal data, as the normal practice it to calculate seal densities based on hauled-out numbers appose to those in the water.

8.3 Boat-based Baseline Results

8.3.1 General overview

Ten species of marine mammal were identified during the boat-based surveys (Table 8.3 below): grey seal, harbour seal, minke whale, killer whale, sperm whale, common dolphin, bottlenose dolphin, Risso's dolphin, white-beaked dolphin, and harbour porpoise.

Table 8.3: Total number of marine mammal recorded during boat-based surveys conducted between April 2010 and March 2012 inclusive within the Telford, Stevenson and MacColl sites and 4 km buffer zone combined. Number of surveys = 28.

Species	Total
Grey seal	178
Harbour seal	6
Unidentified seal species	121
Harbour porpoise	835
Common dolphin	64
Bottlenose dolphin	1
Risso's dolphin	1
White-beaked dolphin	18
***Lagenorhynchus* species**	6
Sperm whale	1
Killer whale	9
Minke whale	49
Small cetacean species	2
Unidentified dolphin species	60
Unidentified whale species	7

8.3.2 Seals

In total, 298 sightings of seals (305 individuals) were recorded between April 2010 and March 2012 (Table 8.3 above). Of these 176 (178 individuals) were positively identified as grey seal, and six animals as harbour seal.

Seal sightings occurred throughout the year with a peak in sightings in the spring (April) and late summer (August and September; Figure 8.2a). The distribution of grey seal sightings followed a similar pattern (Figure 8.2b).

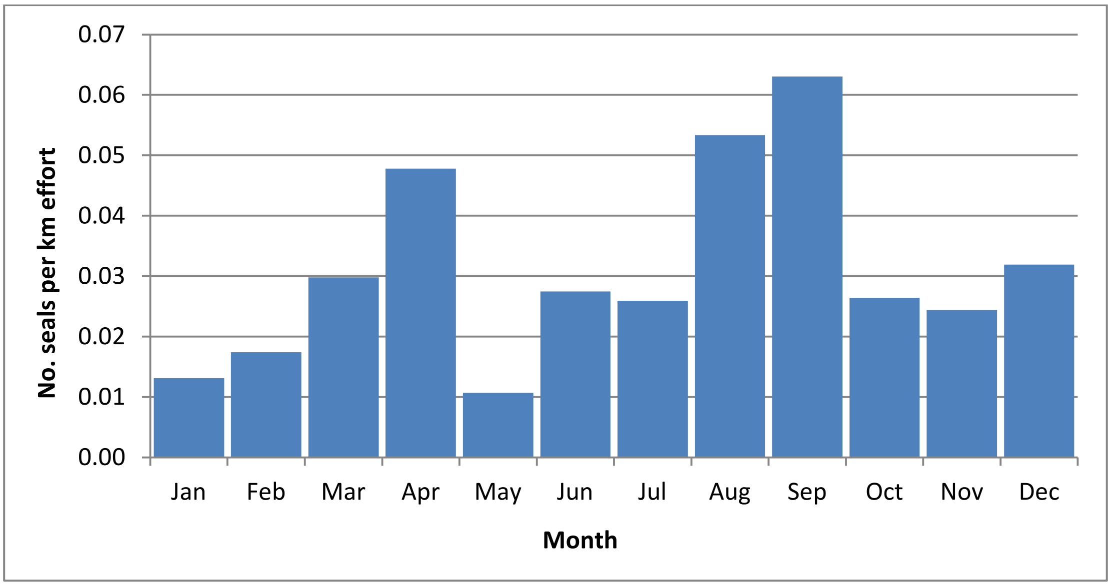

Figure 8.2a: Mean number of seal observations (any species) recorded per calendar month between April 2010 and March 2012 (n = 28).

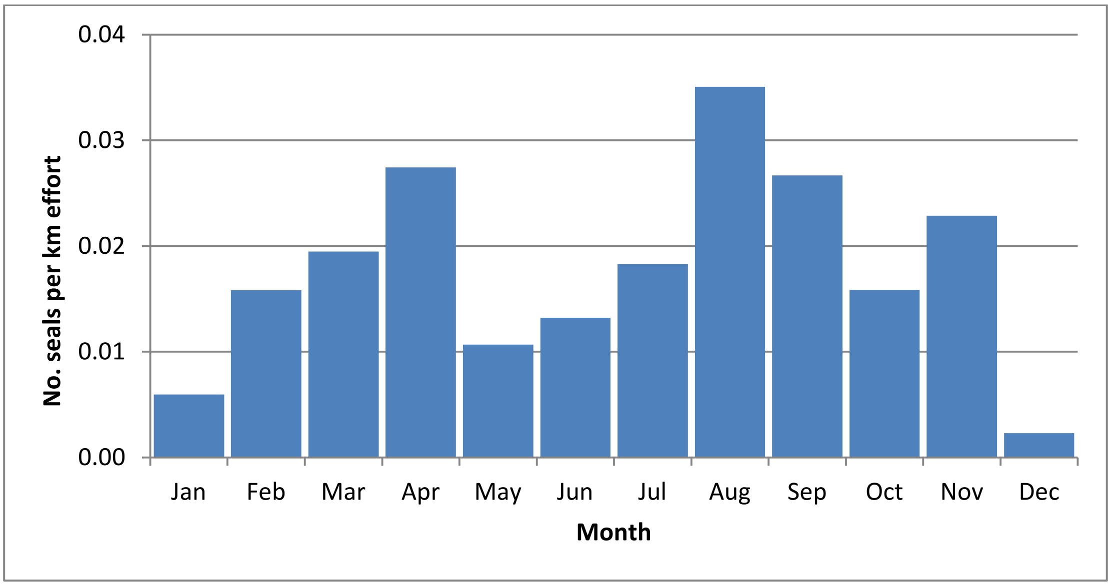

Figure 8.2b: Mean number of grey seal observations recorded per calendar month between April 2010 and March 2012 (n = 28).

While seals were generally distributed throughout the survey area, the highest densities appear to be in the south-west, in the slightly shallower areas of the Smith Bank (Figure 8.3 below). The distribution of those identified as grey seals follows a similar pattern (Figure 8.4), and this trend is consistent with the predicted at sea grey seal distribution described in Chapter 5 and predicted at sea harbour seal distributions described in Chapter 3 of this technical appendix.

Grey seal diet in the UK is primarily small fish such as sandeel, cod, and whiting along with flatfish such as place and flounder (SCOS 2010). The area with the highest density of seal sightings is also the same area that minke whales have been recorded (see below), suggesting an abundance of prey species in the area. Results from sandeel trawls conducted for this ES (Chapter 4.2: Fish and Shellfish Ecology) suggests that seal distribution observed during the boat surveys may, in part, be related to sandeel distribution.

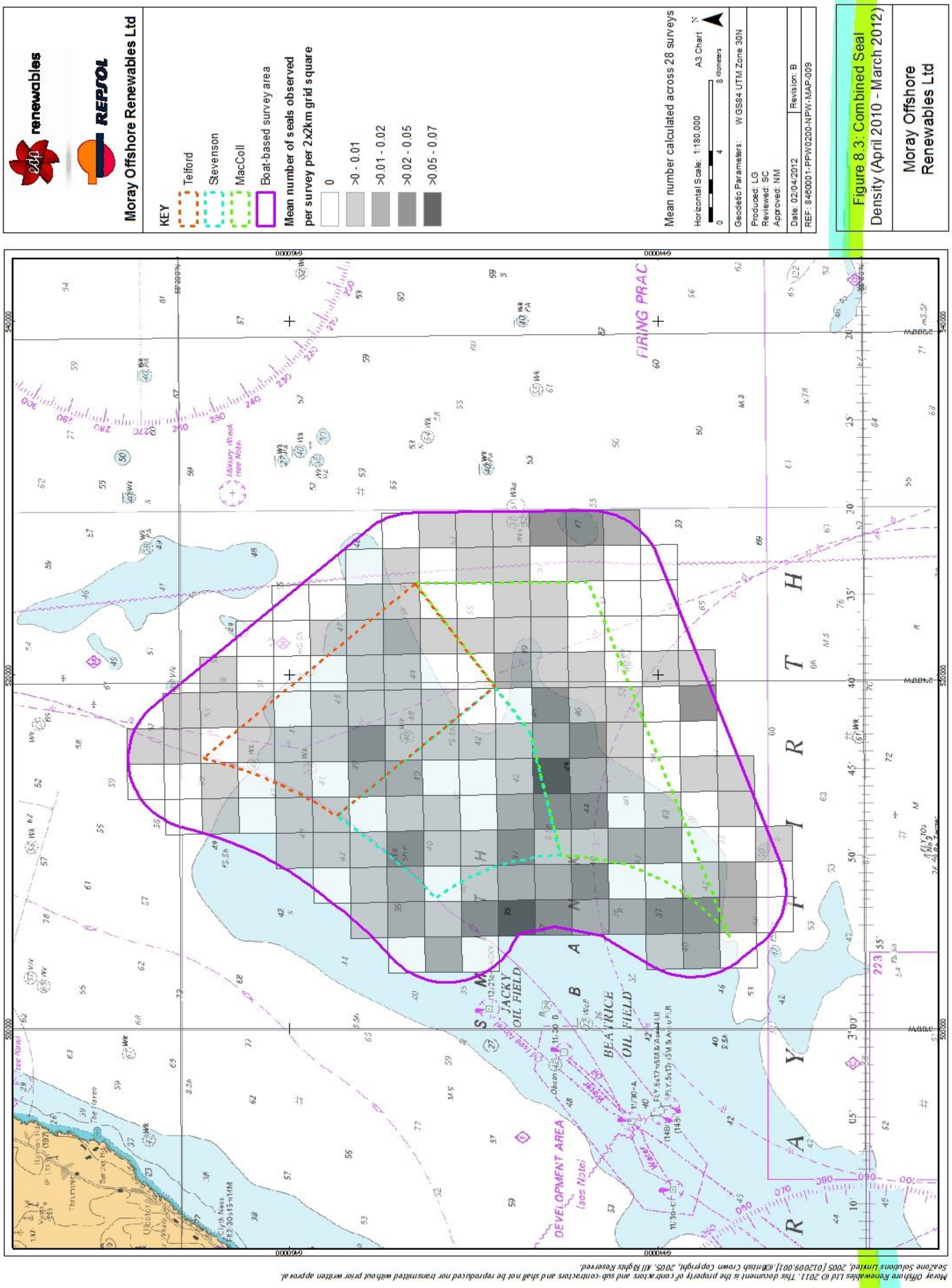

Figure 8.3: Density plots of all seals observed during the boat-based surveys. Grey scale (light to dark) = 0; >0-0.01; 0.01-0.02; 0.02-0.05 and 0.05-0.07. Dotted orange line = Telford; dotted blue line = Stevenson and dotted green line = MacColl. Solid pink line = survey area.

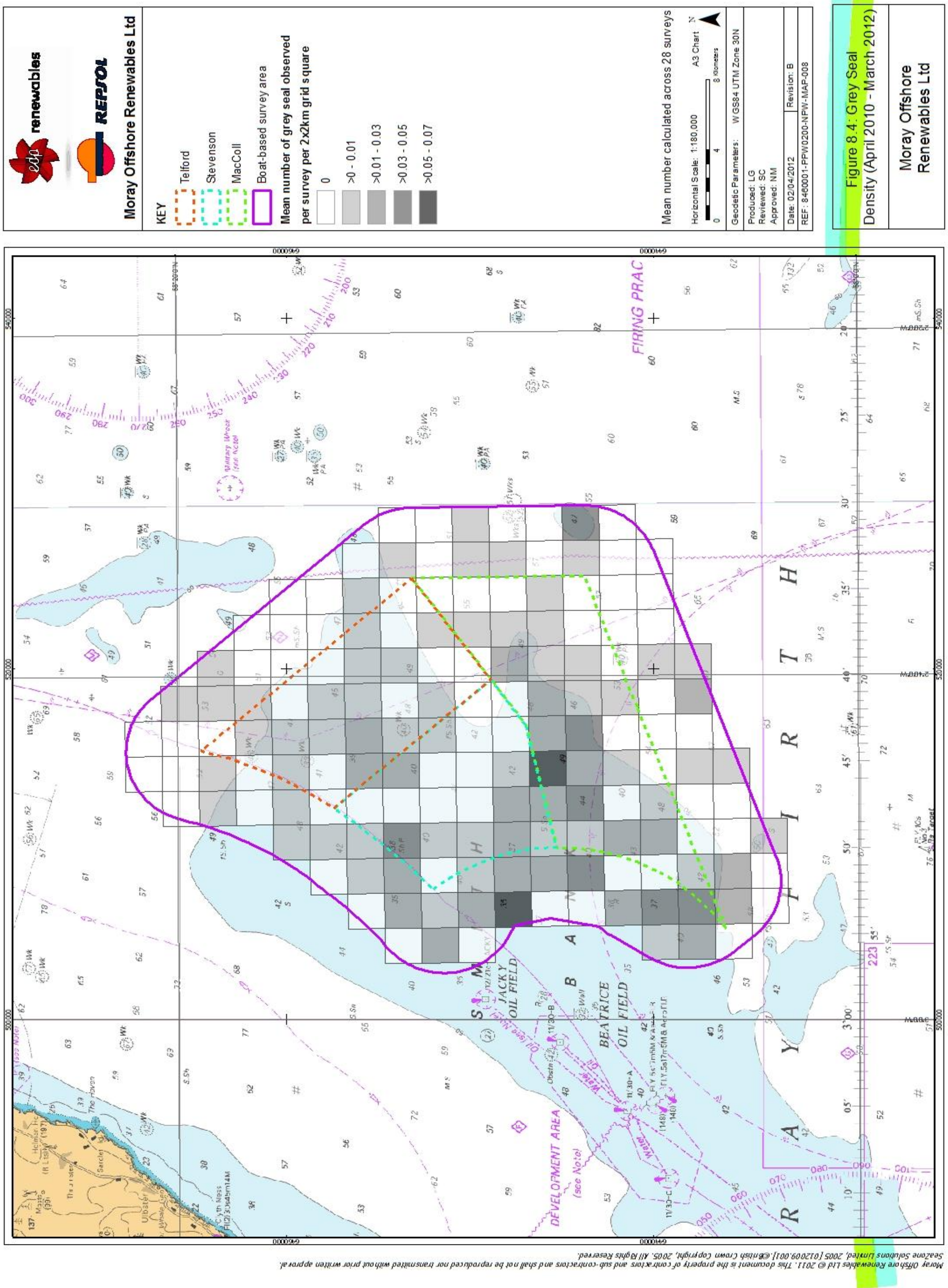

Figure 8.4: Density plots of grey seals observed during the boat-based surveys. Grey scale (light to dark) = 0; >0-0.01; 0.01-0.03; 0.03-0.05 and 0.05-0.07. Dotted orange line = Telford; dotted blue line = Stevenson and dotted green line = MacColl. Solid pink line = survey area.

The results of the distance sampling analysis are presented in Table 8.4 below. Two sets of analysis were performed, one on all seal sightings combined (Table 8.4a) and one of those identified as grey seals (Table 7.4b). For all seals combined a half normal detection function was used based on the lowest AIC, and for grey seals a hazard rate. All data was truncated at 400 m. Estimates of marine mammal densities (individuals per km^2) and population sizes including 95% confidence intervals (C.I.) are provided.

Sightings data were sub-divided according to which of the three proposed sites they occurred. Each site was allocated a proportion of the above abundance estimates based on the number of sightings within that site and are presented in Table 8.4c below.

Table 8.4a: Population and density estimates for all seals based on observations within the three proposed sites combined (Telford, Stevenson and MacColl) and buffer zone based boat surveys carried out between April 2010 and March 2012 (n = 263).

a) All seals	**Site**		**Buffer**	
	Estimate	**95% C.I.**	**Estimate**	**95% C.I.**
Population estimate	24	18-33	25	18-36
Density estimate (km^2)	0.08	0.05-0.11	0.07	0.05-0.10

Table 8.4b: Population and density estimates for grey seals only, based on observations within the proposed sites combined (Telford, Stevenson and MacColl) and buffer zone based boat surveys carried out between April 2010 and March 2012 (n = 157).

b) Grey Seal	**Site**		**Buffer**	
	Estimate	**95% C.I.**	**Estimate**	**95% C.I.**
Population estimate	15	10-22	15	10-22
Density estimate	0.05	0.03-0.07	0.04	0.03-0.06

Table 8.4c: Proportional population and density estimates for all seals combined and grey seals only, within each of the proposed Telford, Stevenson and MacColl sites.

All seals			
	MacColl	**Stevenson**	**Telford**
% observed	47.33	29.01	23.66
Population estimate	11.35	6.96	5.67
Density estimate	0.04	0.02	0.02
Grey seal			
	MacColl	**Stevenson**	**Telford**
% observed	53.16	26.58	20.25
Population estimate	7.97	3.99	3.04
Density estimate	0.26	0.13	0.10

8.3.3 Harbour porpoise

The most abundant species recorded during the boat-based surveys was harbour porpoise (Table 8.3) with 481 sightings totalling 835 individuals. The species was observed throughout the year, with two peaks in occurrence, one during the spring (April) and the other late summer (August and September; see Figure 8.5). This is consistent with other work conducted within the Moray Firth (Hastie *et al*., 2003a; Robinson *et al*., 2007; Eisfeld *et al*., 2009).

The harbour porpoise density plots suggest a fairly even distribution throughout the survey area with sightings being slightly more abundant towards the western edge of the survey area (Figure 8.6). The primary diet of harbour porpoise is sandeels and whiting, with sandeel being the preferred diet on the east coast of Scotland and during the summer (Santos & Pierce 2003; Santos *et al*., 2004). Results from sandeel surveys (Chapter 4.2: Fish and Shellfish Ecology) showed that the majority of sandeels were caught towards the western edge of the survey area, with only low numbers caught elsewhere; suggesting sandeels may not be porpoise's primary prey source within the Moray Firth.

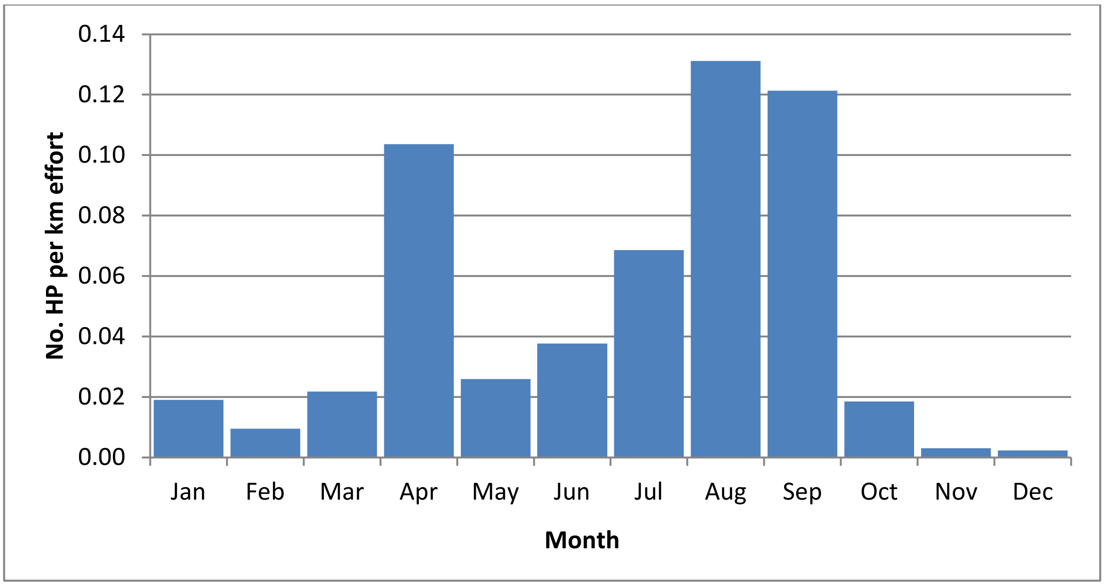

Figure 8.5: Mean number of harbour porpoise observed each calendar month during boat-based surveys conducted between April 2010 and March 2011 (n = 28).

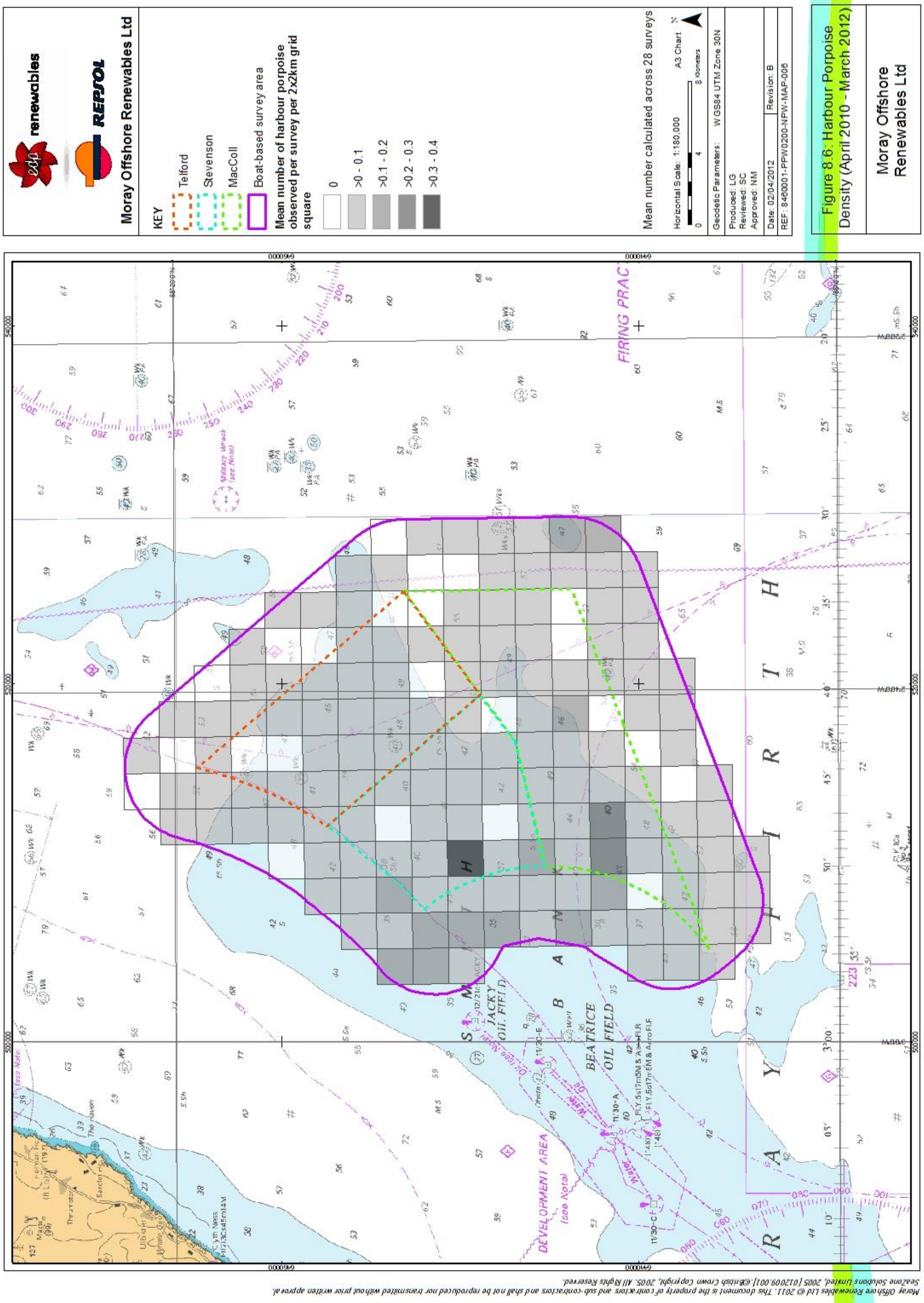

Figure 8.6: Density plots of harbour porpoise observed during the boat-based surveys. Grey scale (light to dark) = 0; >0-0.01; 0.01-0.02; 0.02-0.03 and 0.03-0.04. Dotted orange line = Telford; dotted blue line = Stevenson and dotted green line = MacColl. Solid pink line = survey area.

The results of the distance sampling analysis are presented in Table 8.5 below. A hazard-rate detection function was applied based on the lowest AIC. Estimates of marine mammal densities (individuals per km^2) and population sizes including 95% CI are provided. The analysis were repeated using the detection rate (0.22) calculated by the SCANS II surveys (Table 8.5b) to compensate for the potential number of animals present under water and therefore not available for detection.

Sightings data were sub-divided according to which of the three proposed sites they occurred. Each site was allocated a proportion of the above abundance estimates based on the number of sightings within that site and are presented in Table 8.5c below. The estimates adjusted for g(0) were used for this as it was felt this represented a more realistic estimate.

Table 8.5a: Population and density estimates for harbour porpoise based on observations in the proposed sites (Telford, Stevenson and MacColl) and buffer zone boat surveys carried out between April 2010 and July 2011 (n = 433).

Harbour porpoise	Site		Buffer	
	Estimate	95% C.I.	Estimate	95% C.I.
Population estimate	47	37-59	49	37-67
Density estimate	0.16	0.23-0.20	0.14	0.10-0.19

Table 8.5b: Population and density estimates for harbour porpoise based on observations in the proposed sites (Telford, Stevenson and MacColl) and buffer zone boat surveys, adjusting for g(0) = <1.

Harbour porpoise	Site		Buffer	
	Estimate	95% C.I.	Estimate	95% C.I.
Population estimate	214	170-270	224	167-302
Density estimate	0.72	0.57-0.91	0.63	0.47-0.85

Table 8.5c: Proportional population and density estimates for harbour porpoise within each of the proposed Telford, Stevenson and MacColl sites.

Harbour porpoise (adjusted for g(0))			
	MacColl	**Stevenson**	**Telford**
% observed	45.21	35.37	19.41
Population estimate	96.75	75.69	41.54
Density estimate	0.33	0.26	0.14

8.3.4 Dolphin species

A total of four species of dolphin were recorded between April 2010 and March 2012 (Table 8.3). These were (in order of abundance) common dolphin, white-beaked dolphin, Risso's dolphin and bottlenose dolphin (Figure 8.7).

There has been three sightings of **common dolphin** (64 individuals), with another two sightings (July 2010) also thought to be this species. All sightings occurred between June and August 2010 (Figure 8.7). No sightings of common dolphin were recorded during 2011. This species was previously considered rare in the northern North Sea but a number of sightings have been recorded in the Moray Firth in recent years (Robinson *et al*., 2010). The location of the sightings can be found in Figure 8.9.

In total, 18 **white-beaked dolphins** were recorded during the surveys, with an additional six animals identified as either white-beaked or white-sided dolphin (*Lagenorhynchus* species).

Lagenorhynchus species were first observed in October 2010 when four animals (two sightings) were recorded (Figure 8.7): the first sighting of a single animal was thought to be a white-sided dolphin but sighting was too brief for confirmation; and the second group where thought to be white-beaked dolphins, but were too far away to confirm. Another sighting of two individuals occurred during November 2011, thought to be white-beaked dolphins but were heading away at speed preventing positive identification.

In January 2011, six individual groups of dolphins where observed, 18 animals in total, all positively identified as white-beaked dolphins. Of these, three groups (nine individuals) appeared to be travelling while the remaining dolphins exhibiting foraging behaviour with large numbers of feeding gulls observed in the same area. Sightings positively identified as white-beaked sightings all occurred in the deeper waters along the eastern edge of the survey area (Figure 8.8).

A single **Risso's dolphin** was observed during the October 2010 survey, on the bow of the vessel at the same as a *Lagenorhynchus* sighting ahead. The animal stayed with the boat for about a minute and was seen twice surfacing in the wake of the vessel. The location of the sighting can be found in Figure 8.8.

A single **bottlenose dolphin** was observed on the very first day of surveying in April 2010. The animal was observed exhibiting foraging behaviour for several minutes in close proximity to the vessel allowing confirmation of species identification. The animal was observed at the western edge of the survey area (Figure 8.8). While bottlenose dolphins are regularly seen in the Moray Firth, they are primarily associated with coastal waters of the southern and inner Moray Firth (Wilson *et al*., 1997; Hastie *et al*., 2003b; Robinson *et al*., 2007).

An additional 60 **unidentified dolphins** have also been recorded (see Figure 8.8), with 45 of these observed during July 2010 and thought most likely to be common dolphins.

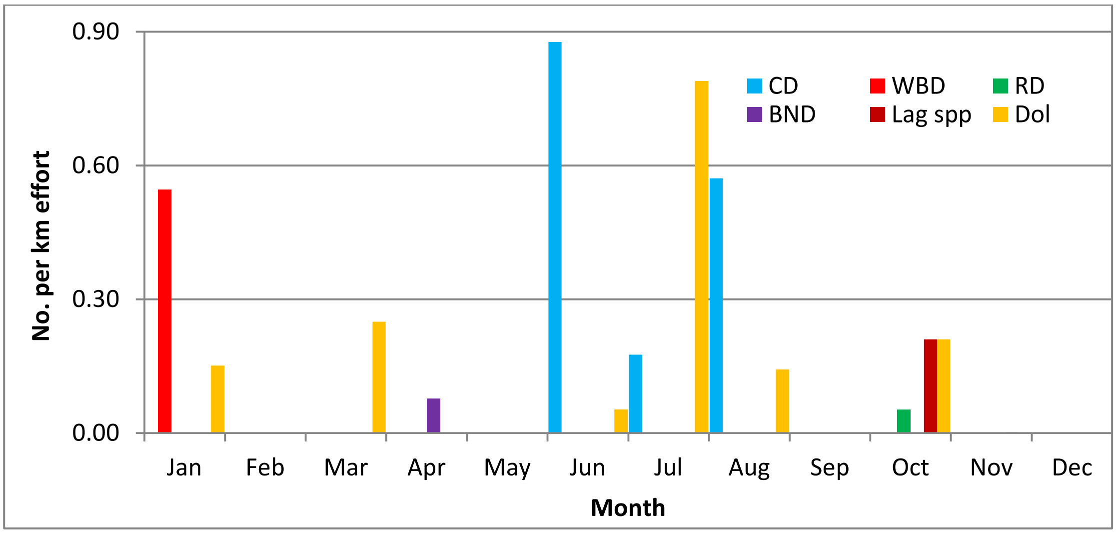

Figure 8.7: Months in which dolphin species were recorded, expressed as the mean number of individuals per km of survey effort. CD = common dolphin; WBD = white-beaked dolphin; RD = Risso's dolphin; BND = bottlenose dolphin; Lag species = *Lagenorhynchus* species (white-beaked or white-sided); Dol = unidentified dolphin species.

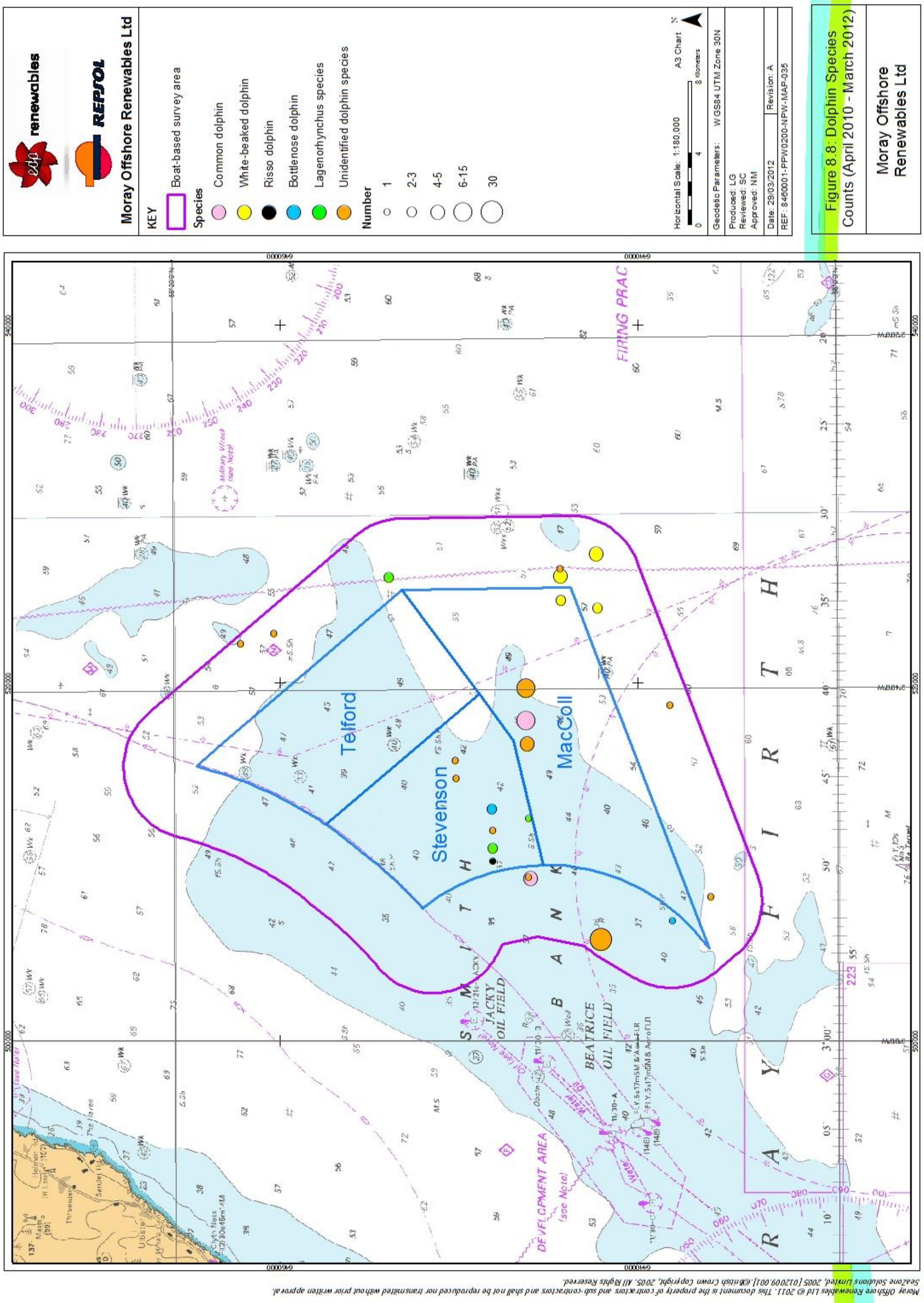

Figure 8.8: Location of dolphins recorded during the boat-based surveys. Pink = common dolphin; yellow = white-beaked dolphin; black = Risso dolphin; blue = bottlenose dolphin; green = *Lagenorhynchus* species; orange = unidentified dolphin species. Pink line represents the survey area including buffer;

8.3.5 Minke whale

In total, 49 minke whales were recorded between April 2010 and March 2012. The peak in sightings occurred in August and no animals were observed between November and March (Figure 8.9).

A density plot showing their distribution can be found in Figure 8.10. Many of these sightings were associated with other marine mammals (such as seals and harbour porpoise) and/or with feeding birds. As with the harbour porpoise, the sandeel is a primary prey species for the minke whale (Haug *et al*., 1997; Lindstrom *et al*., 2002; Pierce *et al*., 2004) along with sprat and herring. The results from sandeel surveys conducted for this ES (see Chapter 4.2: Fish and Shellfish Ecology) suggest this distribution of minke whale is related to prey availability.

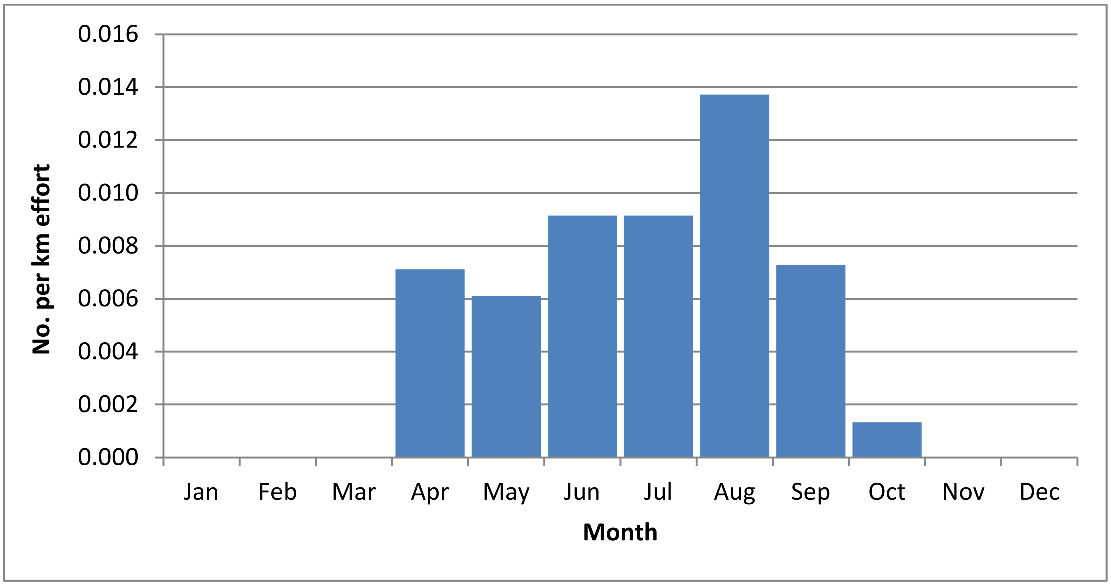

Figure 8.9: Mean number of minke whale recorded each calendar month during boat-based surveys conducted between April 2010 and July 2011 (n = 28).

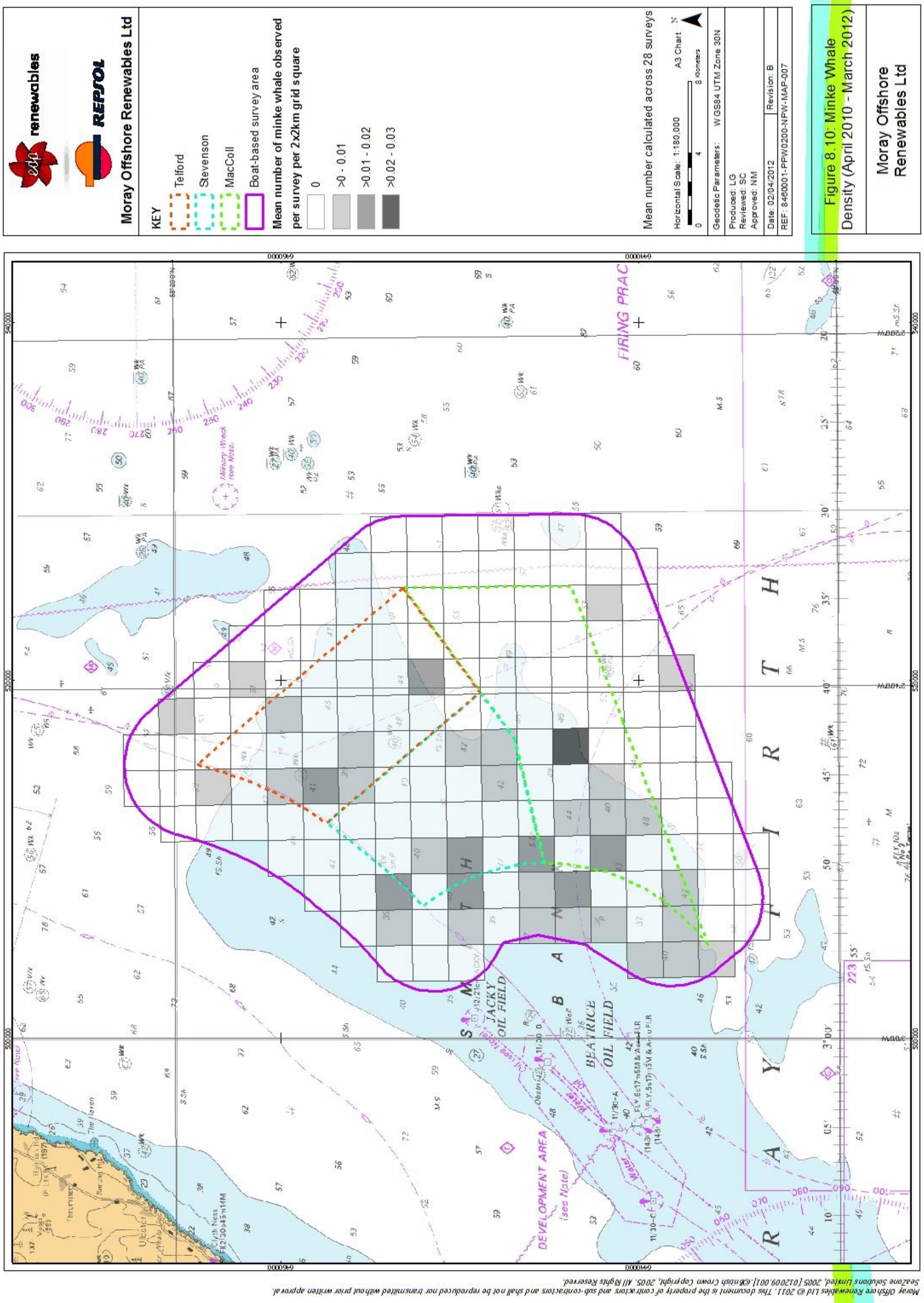

Figure 8.10: Density plots of minke whales observed during the boat-based surveys. Grey scale (light to dark) = 0; >0-0.01; 0.01-0.02 and 0.02-0.03. Dotted orange line = Telford; dotted blue line = Stevenson and dotted green line = MacColl. Solid pink line = survey area.

The results of the distance sampling analysis are presented in Table 8.6a below. Estimates of marine mammal densities (individuals per km^2) and population sizes including 95% CI are provided. A half normal detection function was chosen based on the lowest AIC. The analysis were also performed using the detection rate (0.55) calculated by the SCANS II surveys (Table 8.6b) to illustrate the potential number of animals present under water and therefore not available for detection. In comparison to the harbour porpoise analysis, this did not change the estimates greatly although the small sample size needs to be taken into consideration when interpreting these results.

Because minke whales were only recorded between April and September in both years the surveys were conducted, the distance analysis was repeated using only the survey effort conducted during these months (i.e. 14 surveys instead of 28). No measureable differences were found between the different estimates (see values in brackets in Tables 8.6 a and b).

Sightings data were sub-divided according to which of the three proposed sites they occurred. Each site was allocated a proportion of the above abundance estimates based on the number of sightings within that site and are presented in Table 8.6c below. The estimates adjusted for g(0) were used for this as it was felt this represented a more realistic estimate.

Table 8.6a: Population and density estimates for minke whales based on observations in the proposed sites (Telford, Stevenson and MacColl) and buffer zone during boat surveys carried out between April 2010 and March 2012 (n = 40). Values in brackets represent the analysis conducted using only effort between April and September.

Minke whale	**Site**		**Buffer**	
	Estimate	**95% C.I.**	**Estimate**	**95% C.I.**
Population estimate	2 (2)	1-3 (1-3)	2 (2)	1-3 (1-3)
Density estimate	0.006 (0.006)	0.004-0.009 (0.004-0.009)	0.004 (0.004)	0.002-0.008 (0.002-0.008)

Table 8.6b: Population and density estimates for minke whales based on observations in the proposed sites (Telford, Stevenson and MacColl) and buffer zone during boat surveys based on g(0) = <1. Values in brackets represent the analysis conducted only using effort between April and September (n = 14).

Minke whale	Site		Buffer	
	Estimate	95% C.I.	Estimate	95% C.I.
Population estimate	3 (3)	2-5 (2-5)	3 (3)	1-5 (2-5)
Density estimate	0.01 (0.01)	0.007-0.02 (0.007-0.02)	0.008 (0.008)	0.004-0.015 (0.004-0.015)

Table 8.6c: Proportional population and density estimates for harbour porpoise within each of the proposed Telford, Stevenson and MacColl sites.

Minke whale (adjusted for g(0))			
	MacColl	Stevenson	Telford
% observed	38.10	58.57	33.33
Population estimate	1.14	0.86	0.99
Density estimate	0.004	0.004	0.003

8.4 Other whale species

There have been two sightings of **killer whale** during the boat-based surveys: the first sighting (May 2010) was of three animals (one male) seen at distance, while the second sighting (June 2010) was of six animals crossing the bow of the vessel. This second sighting was divided into what appeared to be two male-female-juvenile sub-groups (see Image 8.4).

In November 2011, a **sperm whale** was observed logging at the surface. In addition, seven **unidentified whales** have been recorded, all between April and September, with six of these thought most likely to be minke whales. The location of all of these sightings can be found in Figure 8.11 below.

Image 8.4: One of the male-female-juvenile killer whale groups recorded in May 2010. Picture taken by Tim Sykes.

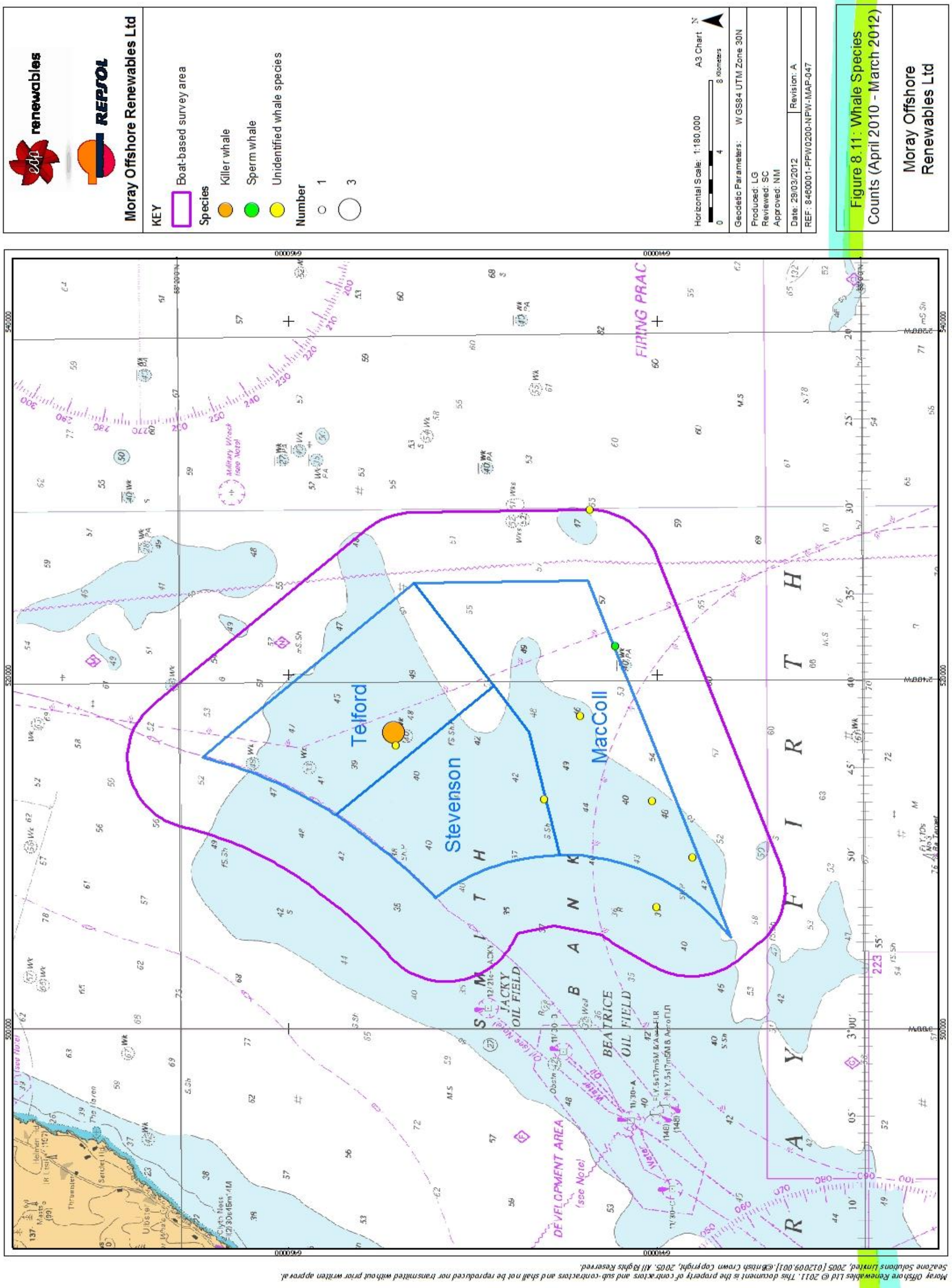

Figure 8.11: Location of whale species recorded during the boat-based surveys. Orange = killer whale; green = sperm whale; yellow = unidentified whale. Pink line represents the survey area including buffer; Blue line the three proposed sites (Telford, Stevenson and MacColl). Blue line = proposed sites; pink line = survey area.

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9. Summary

Data collected during the boat-based surveys corroborated the outputs from the habitat association models, and density estimates were in line with those calculated during the SCANS II surveys.

9.1 Harbour seal

Harbour seal is the commonest seal species observed within the Moray Firth, with parts of the Inner Moray First designated a SAC for their protection. Counts made during the breeding season indicate a decline in numbers within the SAC in recent years but an increase in numbers across the Moray Firth as a whole. Tagging studies found the highest rates of occurrence for the harbour seal were within 30 km of their haul-out sites. Habitat association models highlighted areas of preferred habitat, primarily within the inner firth plus some areas close to the proposed developments in the north-eastern part of the Firth. Some preference was also shown for small areas of the south-east Firth in the vicinity of the proposed land-fall sites. Modelling suggests some areas can possibly holding up to 0.5 animals per km^2. To date, only six animals have been confirmed as a harbour seal during the boat-based surveys within the proposed sites although large numbers of seals are not identified to species level.

9.2 Grey seal

Telemetry studies suggest that grey seals regularly travel between the Moray Firth and haul-out sites outside the area. Areas with the highest usage within the Moray Firth included the Dornoch and Pentland Firths. Lower levels of usage (between one and five animals per 4 km grid square) were estimated for the proposed sites combined and confirmed by the boat-based surveys. Areas of low usage are also predicted for the proposed land-fall sites.

Of the three proposed sites, grey seals were more abundant in the proposed MacColl site, accounting for about half of the animals recorded during the boat-based surveys. The data for all seals (including those not identified to species) showed a similar pattern. This distribution appears to mirror that for sandeels, suggesting seal distribution is related to prey distribution.

9.3 Harbour porpoise

Passive acoustic monitoring indicates that harbour porpoise can be found throughout the Moray Firth. Harbour porpoise habitat models showed a preference for intermediate depths with increasing levels of sand and gravel, such as the Smith Bank. The boat-surveys provide evidence for this association, with the highest numbers of porpoises recorded in the south-east part of the survey area. Numbers predicted in the models for coastal areas were low in comparison suggesting no conflict with the proposed land-fall sites.

Density estimates from boat-based surveys at the proposed sites combined (0.16 animals/km^2) were slightly lower than those predicted for the Moray Firth by the SCANS II surveys (0.4-0.6 animals/km^2), although when g(0) is adjusted to allow for missed sightings this estimate rises to 0.72 animals/km^2, more in line to those predicted by SCANS. Those densities predicted using analysis of aerial data were higher still with 0.81 porpoises per km^2 predicted for the area that includes the MORL R3 zone. It should be noted however, that these aerial surveys coincide with the months during which the highest number of porpoise were recorded during the boat-based surveys (refer to Figure 8.5).

As with seals, harbour porpoise were more abundant in the proposed MacColl site, accounting for just under half of the animals recorded during the boat-based surveys. The proposed Telford site contained the fewest number of sightings.

9.4 Bottlenose dolphins

A resident population of bottlenose dolphins can be found within the Moray Firth, for which as SAC has been designated. Passive acoustic monitoring indicates that dolphins (various species) can be found throughout the Moray Firth.

The EAR data suggest that those dolphins recorded in the vicinity of the proposed developments are unlikely to be bottlenose dolphins, with this species being restricted to coastal waters (including the proposed land-fall site areas). This observation is supported by only a single bottlenose dolphin being positively identified during the two years of boat-based surveys, with this animal being observed in the buffer zone to the west of the proposed sites (i.e. side closest to the coast).

An overall dolphin density (any species) of 0.066 animals per km^2 was calculated for the Moray Firth with densities in the vicinity of the proposed sites (any dolphin species) predicted to be low. Dolphin presence between the three individual sites appears to be fairly even with only a single dolphin being identified as a bottlenose during the boat-based surveys.

9.5 Other cetacean species

Of the other cetacean species observed within the Moray Firth, the minke whale is the most abundant. They have been shown to prefer sandbanks, as was shown by their distribution recorded during the boat-based surveys. The SCANS II surveys estimated 0.022 animals per km^2 for the Moray Firth, Orkney and Shetland combined, higher than the 0.01 animals per km^2 calculated from the boat-based surveys for the proposed sites, although the small sample size needs to be taken into account when interpreting these results.

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