TECHNICAL REPORT ON PRE-CONSENT MARINE MAMMAL DATA GATHERING AT THE MORL AND BOWL WIND FARM SITES

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Report to MORL & BOWL

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EXECUTIVE OVERVIEW & KEY FINDINGS

The Moray Firth supports breeding populations of both harbour seals and grey seals, and sightings of at least fifteen species of cetaceans have been recorded in these waters. Recent work carried out for DECC, Marine Scotland, Oil & Gas UK and COWRIE has greatly enhanced our understanding of the occurrence of cetaceans in the vicinity of the MORL and BOWL windfarm sites. Nevertheless, following a review of the marine mammal data requirements for these offshore windfarm EIAs, it was agreed that there were several requirements either for additional data collection or more detailed analysis of existing data. The resulting work programme was developed in discussion with the developers and regulatory bodies, and has been conducted by the University of Aberdeen and SMRU Ltd at the University of St Andrews. Overall, the work programme has aimed to collect additional data that, in combination with existing data sources, can be used in Environmental Statements to address the following three objectives:

- ***Objective 1***: To characterise the sites with respect to the marine mammal species present; detail seasonality and year-to-year variability in occurrence.
- ***Objective 2:*** To assess the density of animals at the proposed sites.
- ***Objective 3:*** To assess the likelihood of exchange between local SACs and the proposed wind farm sites.

This main report describes the work carried out to address Objectives 1 and 2, and two additional Annexes describe work carried out by SMRU Ltd under Objective 3.

Key Findings from these studies were:

Objective 1- Characterisation & seasonal patterns

- Broad-scale deployments of echolocation detectors (C-PODs) in 2009 and 2010 showed that spatial variation in the occurrence of both porpoises and dolphins across the Moray Firth was consistent between years (Figure 3.11).

- The combined C-POD data set from 2009 and 2010 indicates that harbour porpoises were widely dispersed across the Moray Firth (Figure 3.12a), with porpoises typically detected on every day at sites in the vicinity of the MORL and BOWL windfarm sites. In contrast, C-PODs detected dolphins regularly in the inner Moray Firth and along the southern Moray Firth coast, less frequently in the central Moray Firth, and at intermediate levels in the vicinity of the MORL & BOWL sites (Figure 3.12b).

- Field comparisons confirmed that data from analogue (T-POD) and digital (C-POD) echolocation detectors were comparable (Figure 3.18), thereby providing a long time-series of data (2005-2010) that showed similar levels of occurrence of both dolphins and porpoises in the vicinity of the Beatrice demonstrator site over time (Figure 3.20).

- More intensive deployments of C-PODS on the BOWL (Section 3.6.3) and MORL (Section 3.6.4) sites have been made since May 2009, demonstrating that both porpoises and dolphins use these areas throughout the year. Seasonal fluctuations in the median number of hours per day that porpoises were detected in the BOWL (Figure 3.24) and MORL (Figure 3.27) sites.

- Whilst C-PODs provide important information on spatial and temporal variation in the occurrence of dolphins, they cannot currently be used to identify different dolphin species. Visual sightings of cetaceans from summer (April-October) boat-based and aerial surveys that were made over and around the BOWL and MORL sites in 2010 were collated, and maps of dolphin sightings from each survey team presented to provide information on the species of dolphins detected in the Outer Moray Firth.

- Aerial surveys using observers from NERI and WWT Consulting detected Risso’s dolphins, common dolphins and white-beaked dolphins in offshore waters, but bottlenose dolphins were only sighted within 10km of the southern Moray Firth coast (Figure 3.3). Boat based surveys conducted by Natural Power detected Risso’s dolphins, common dolphins and white-beaked dolphins and a single bottlenose dolphin over the MORL site (Figure 3.4). Boat based surveys over the BOWL site conducted by IECS reported a single encounter with a group of common dolphins, four encounters with groups of bottlenose dolphins, but no sightings of Risso's or white-beaked dolphins (Figure 3.5). A previous review of all historic data from the Outer Moray Firth found that all previous reported sightings around the BOWL and MORL sites were of Risso's dolphins, common dolphins and white-beaked dolphins (Thompson et al. 2010). These data highlight the difficulty of interpreting data collected from surveyors with different levels of experience, particularly where survey teams are selected for the primary purpose of detecting seabirds. Nevertheless, even if all visual species identifications are accepted, the majority of encounters with dolphins over the MORL and BOWL sites are likely to be species other than bottlenose dolphins.

Objective 2 – Density estimates

- Harbour porpoises were by far the most commonly encountered species in the Outer Moray Firth. Line-transect aerial surveys conducted in August and September were used to estimate the density of this species in different sample blocks in the Outer Moray Firth. Density within the sample block covering the MORL and BOWL sites was 0.81 porpoises per km^2 (Table 3.5), which is comparable with the highest density areas recorded in European waters during the broad-scale SCANS and SCANS II surveys.

- Spatial variation in the relative density of harbour porpoises across the Moray Firth was determined using over 1000 sightings from combined boat and aerial surveys in a habitat association model. Predicted values from the resulting GAMM were then scaled by the measure of absolute density from the aerial survey to predict the likely number of porpoises in each 4 x 4 km grid cell across the Moray Firth (Figure 3.8). These modelled distributions will underpin future assessments of the impact of disturbance and displacement for porpoises.

- There were too few sighting of dolphins to produce density estimates for individual species, but a combined estimate for all species showed that densities were low in offshore areas, but higher along the coast (Table 3.7). Presence only data from all available surveys conducted since 1982 were used within a classification tree to assess spatial variation in the likely species composition of dolphins encountered across the Moray Firth (Figure 3.15). These data, along with those from broader scale SCANS II data and regional estimates of bottlenose dolphin population size, will be used to underpin future assessments of the impact of disturbance and displacement for dolphins.

- VHF, Satellite and GPS-GSM data collected over two decades from 37 tagged harbour seals were integrated to model habitat association and predict relative densities of foraging seals across the Moray Firth by scaling to total population size (Annex 1, Figure 11). These modelled distributions will underpin future assessments of the impact of disturbance and displacement for harbour seals.

Objective 3 – Connectivity between the MORL & BOWL sites & SAC's

- Broad band acoustic recorders were deployed in the MORL and BOWL sites between July and October 2010, and whistle classification software developed by SMRU Ltd to assess the likelihood that dolphins in this area were bottlenose dolphin (that may be from the Moray Firth SAC) rather than other species such as Risso's dolphin, common dolphin or white-beaked dolphin. Comparable data were collected at a site within the Moray Firth SAC. Dolphins were recorded on eight occasions within the MORL and BOWL sites, and all encounters were classified at species other than bottlenose dolphins. In contrast, 79% of encounters within the SAC were of bottlenose dolphins (Annex II, Figure 7).

- Analysis of the combined VHF, Satellite and GPS-GSM telemetry dataset demonstrated that some harbour seals from the Dornoch Firth & Morrich More SAC are likely to spend time foraging within the MORL and BOWL sites (Annex I, Figure 11).

1. Background

The Moray Firth supports breeding populations of both harbour seals and grey seals, and sightings of at least fifteen 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. This work has lead to estimates of distribution, population size and trends for both harbour 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 BOWL's environmental impact assessments (Grellier & Lacey 2010), it was agreed that there were several requirements either for additional data collection or more detailed analysis of existing data. Not only are these data required to support consenting for both the BOWL and MORL developments, 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. The work has been co-ordinated by the University of Aberdeen, with key studies being carried out under sub-contract to SMRU Ltd at the University of St Andrews. Overall, the work programme has aimed to collect additional data that, in combination with existing data sources, can be used in Environmental Statements to address the following three objectives:

1. To characterise the sites with respect to the marine mammal species present; detail seasonality and year-to-year variability in occurrence.
2. To assess the density of animals at the proposed sites.
3. To assess the likelihood of exchange between local SACs and the proposed wind farm sites.

The 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 (eg. harbour porpoises and dolphins) within the development areas was required. These data can then be used to complement existing visual data (eg. Reid et al. 2003; Thompson et al. 2010a) and the data that will result from the boat-based seabird and marine mammal surveys being conducted by BOWL and MORL. 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).

The key requirement under Objective 2 was for robust region-specific density estimates of cetaceans in and around the BOWL and MORL 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 site. 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.

The key requirements under Objective 3 were for data to assess the likely connectivity between the BOWL and MORL 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 BOWL & MORL 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 the main body of this report, we describe the work carried out to address Objectives 1 and 2. Two additional reports cover work carried out by SMRU Ltd under Objective 3 are presented as annexes to this report; one assessing linkage with the bottlenose dolphin SAC and one assessing linkage with the harbour seal SAC.

2. Methodology

2.1 Visual surveys

2.1.1 Data sources

Primary data sets for this part of the study were collected by the University of Aberdeen through previous and ongoing surveys carried out in relation to the Beatrice Demonstrator Project and assessments 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 (on behalf of MORL) and 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.

2.1.1.1 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), they aimed 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 (Figure 2.1) during the summers of 2004 and 2005 (Table 2.1). 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 2.1. Days of survey effort carried out during the University of Aberdeen's boat-based surveys within the Moray Firth SAC.

Year	Month	# Survey Days
2004	August	2
2004	September	5
2004	October	3
2005	April	5
2005	May	4
2005	June	5
2005	July	1

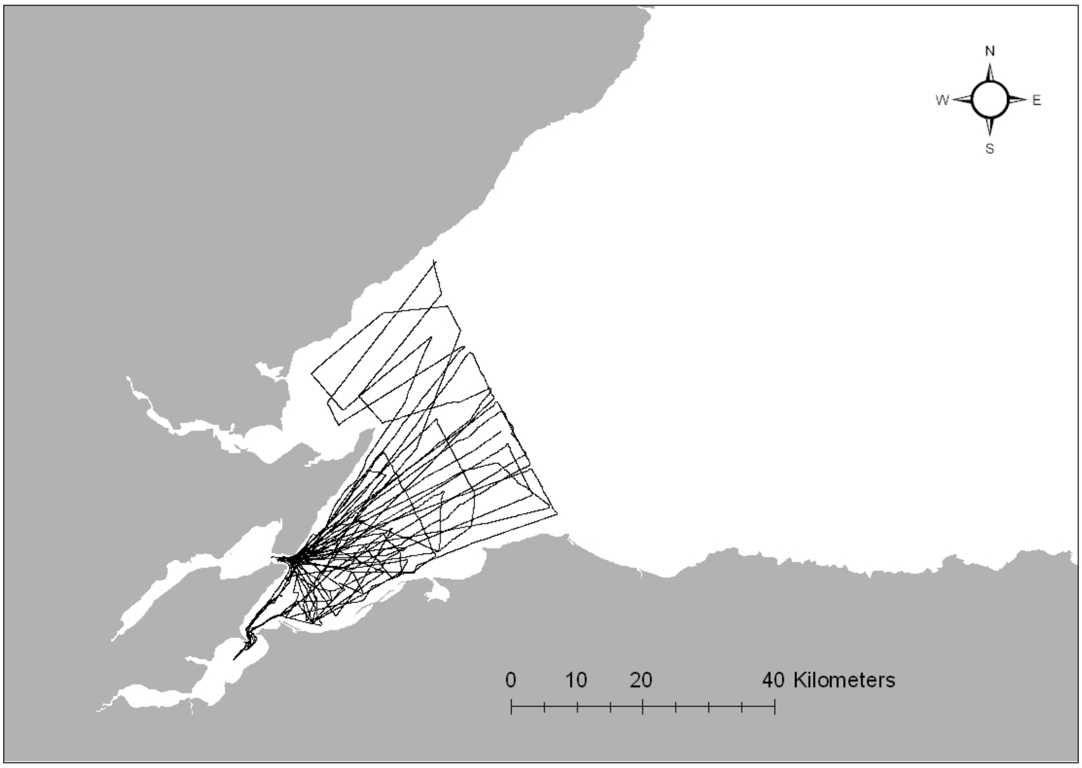


Figure 2.1. Map of the survey tracks used during the University of Aberdeen's boat-based surveys within the Moray Firth SAC.

2.1.1.2 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. 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 side, in the 180° arc ahead of the boat. Total survey distance was 1671 km.

Table 2.2. Days of survey effort carried out during the 2009 boat-based surveys.

Year	Month	# Survey Days
2009	June	5
2009	August	4
2009	September	3
2009	October	2

Figure 2.2. Map of total effort during the 2009 Univ of Aberdeen boat based surveys.

2.1.1.3 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 25x25km survey blocks as part of the 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 2.3).

Surveys followed the line-transect procedures used for SCANS and SCANS-II 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. Surveys that were incomplete, or 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 2.1.3.

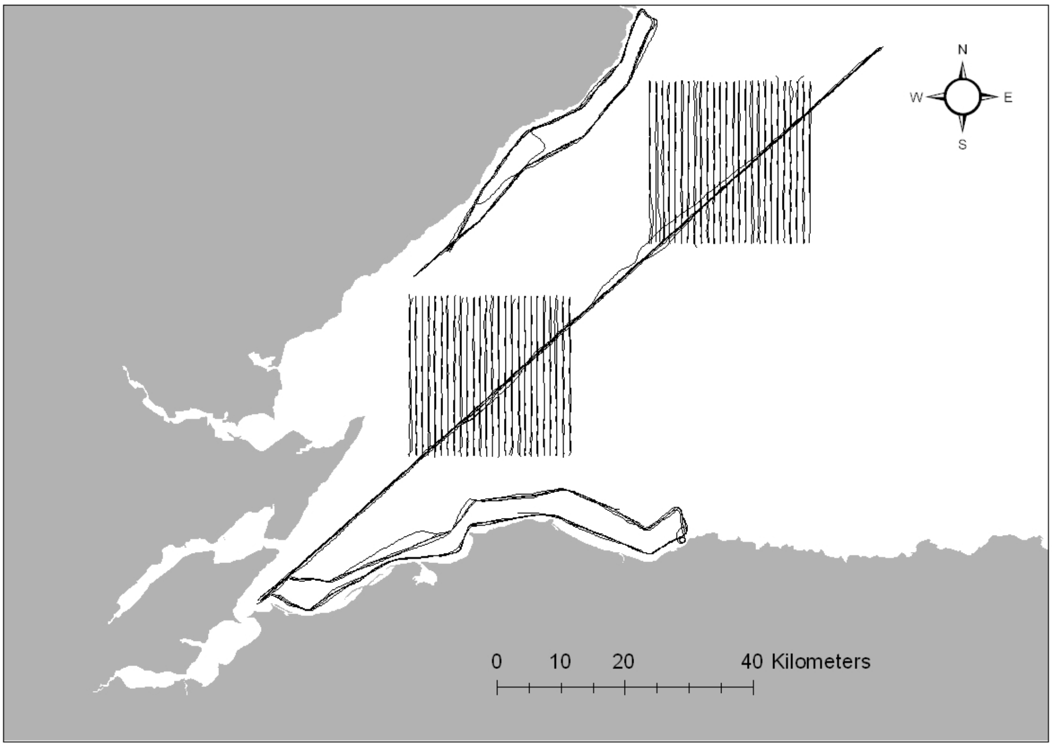


Figure 2.3. Map of survey tracks used during the 2010 aerial surveys

2.1.1.4 Natural Power surveys of MORL 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 MORL ES. Monthly surveys began in April 2010. 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 5m above sea level and travelled at approximately 10 knots on a series of standard transects (Fig 2.4).

Table 2.3. Days of survey effort carried out during the 2010 Natural Power surveys

Year	Month	# Survey Days
2010	April	3
2010	May	3
2010	June	3
2010	July	3
2010	August	6
2010	September	2
2010	October	4

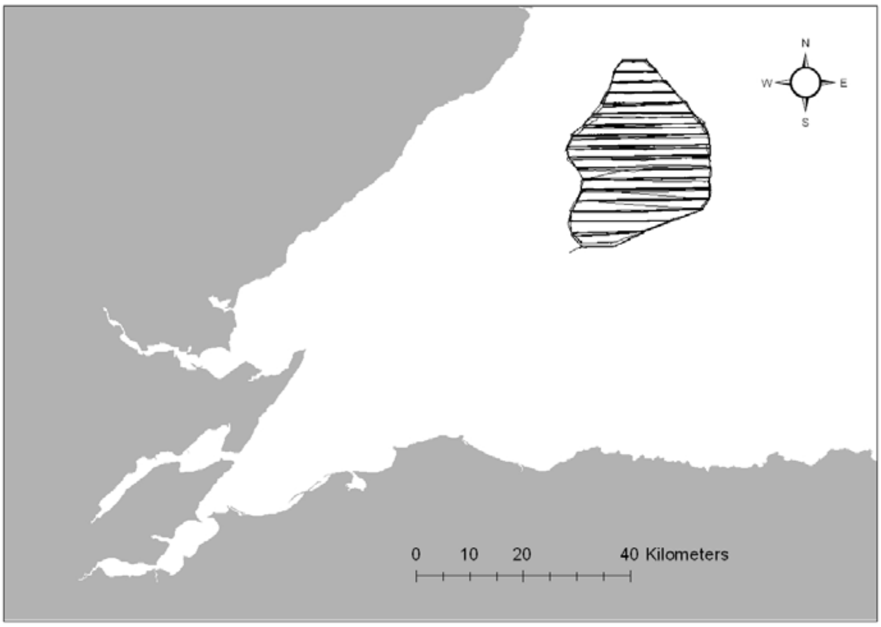


Figure 2.4. Map of survey tracks used for the MORL April to October 2010 surveys

2.1.1.5 IECS Boat surveys of 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, 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. The survey vessel was a converted lifeboat, with an observation height of approximately 3 m above sea level.

Table 2.4. Days of survey effort carried out at during the 2010 IECS surveys

Year	Month	# Survey Days
2010	April	4
2010	May	2
2010	June	2
2010	July	2
2010	August	2
2010	September	2
2010	October	0

Figure 2.5. Map of survey tracks used for the BOWL April to October 2010 surveys

2.1.2 Habitat association modelling

To assess habitat association of cetaceans, survey and habitat data were summarised across a 4x4 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 2.6). For depth, slope and distance to the coast, a mean value for every 4x4 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 with one 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, and a minimum mean depth of 5 m was therefore 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 4x4 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 2.7). 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.

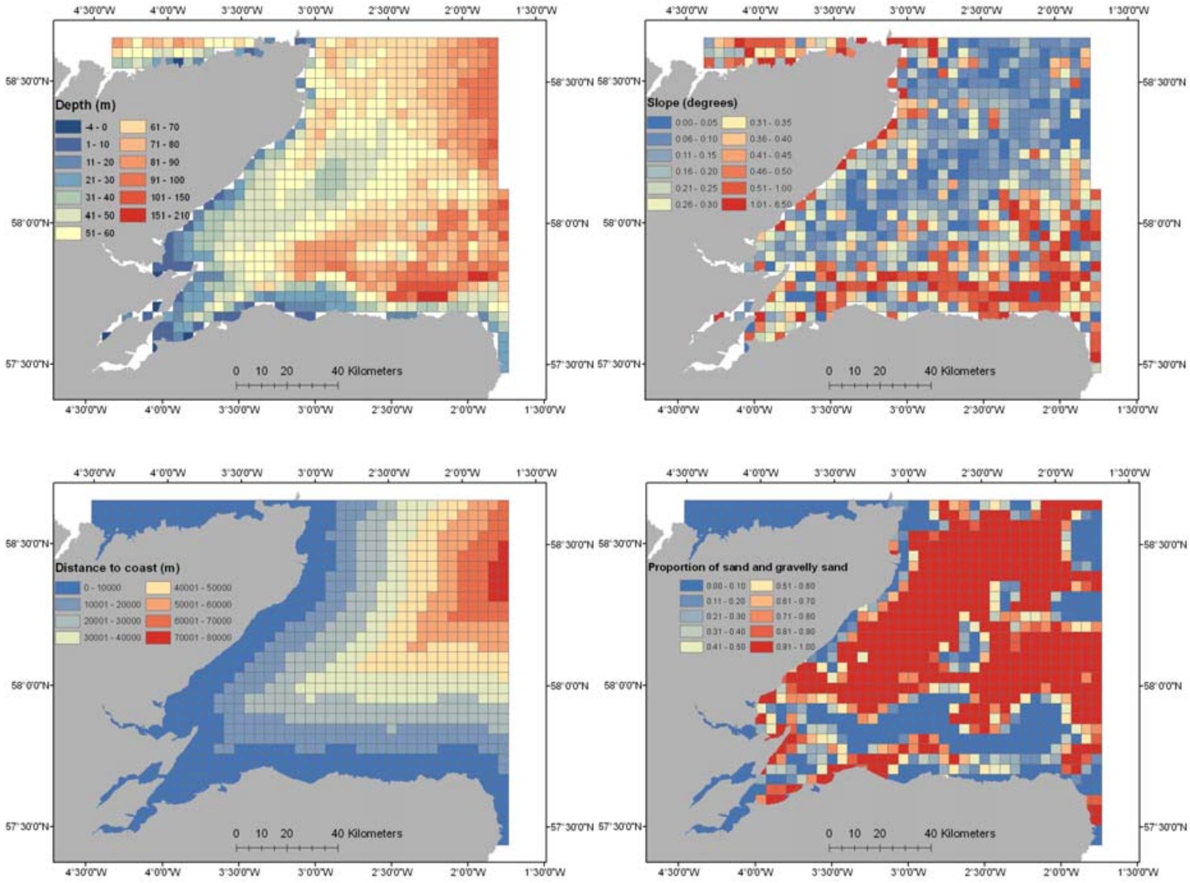


Figure 2.6. Habitat variables (depth, slope, distance to coast and sediment type) summarised over a 4x4 km grid.

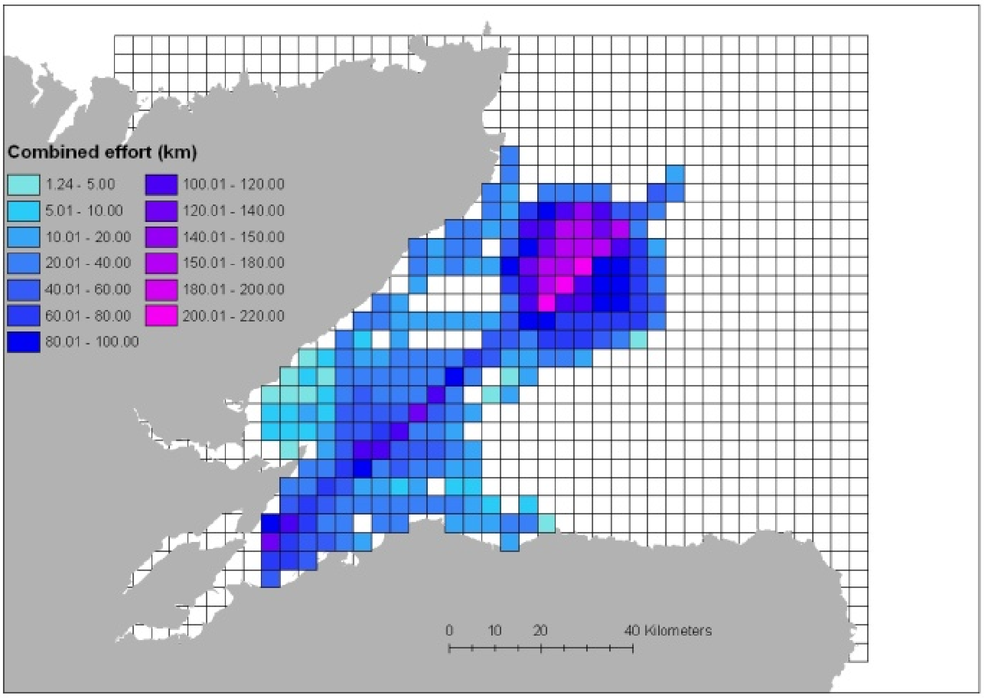


Figure 2.7 The total amount of survey effort in each 4 x 4 km cell.

2.1.2.1 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 4x4 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 pseudoreplication caused by including some cells more than once. The initial model included depth, the proportion of the 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 overdispersed 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.

2.1.2.2 Dolphin model

Although there were insufficient data to produce habitat association models for individual dolphin species, we were able to use these 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, we developed this analysis to assess the likelihood that any dolphins encountered in offshore areas (see results in section 3.4) were bottlenose dolphins. Habitat and other spatial variables (eg distance to coast) were recorded at each of the locations where visual sightings 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.

We used available sightings of dolphins that were identified to species within the Moray Firth between 1982 and 2010. Several datasets described in Thompson et al. (2010a) were used, in combination with the four datasets described in section 2.1.1. Datasets without counts of animals or with poor locational precision were excluded from the analysis. In total, eight datasets were included (Table 2.5).

Individual dolphin sightings were used in the classification tree. Each sighting was assigned the habitat values averaged over the 4x4 km grid cell that it was seen within. These were the same habitat values used in the porpoise model, described in section 2.1.2.1. 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.

Table 2.5. 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

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.

2.1.3. 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 each 25 x 25km, with the control block (Figure 2.8, Block B) covering a large part of the BOWL and MORL development areas.

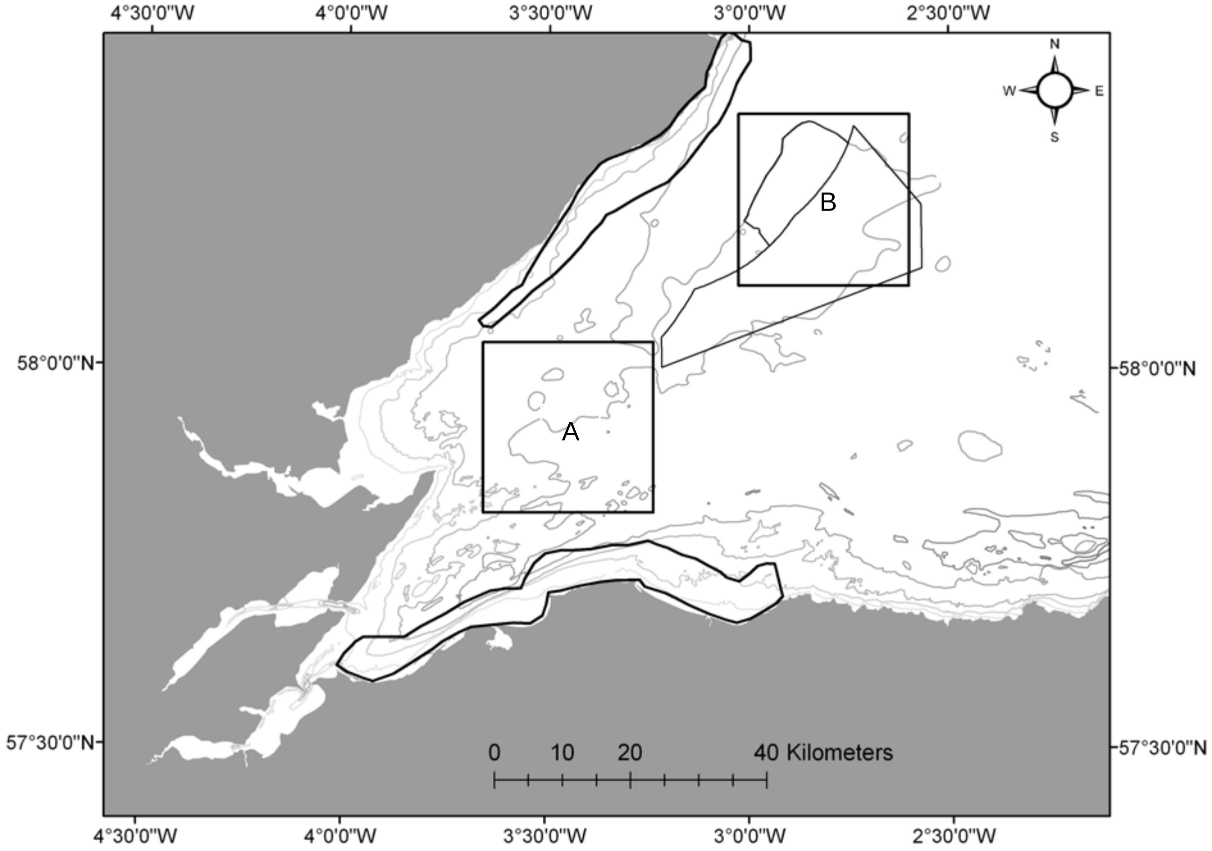


Figure 2.8. A map of the Moray Firth showing the position of the aerial survey blocks in relation to the location of the MORL and BOWL sites.

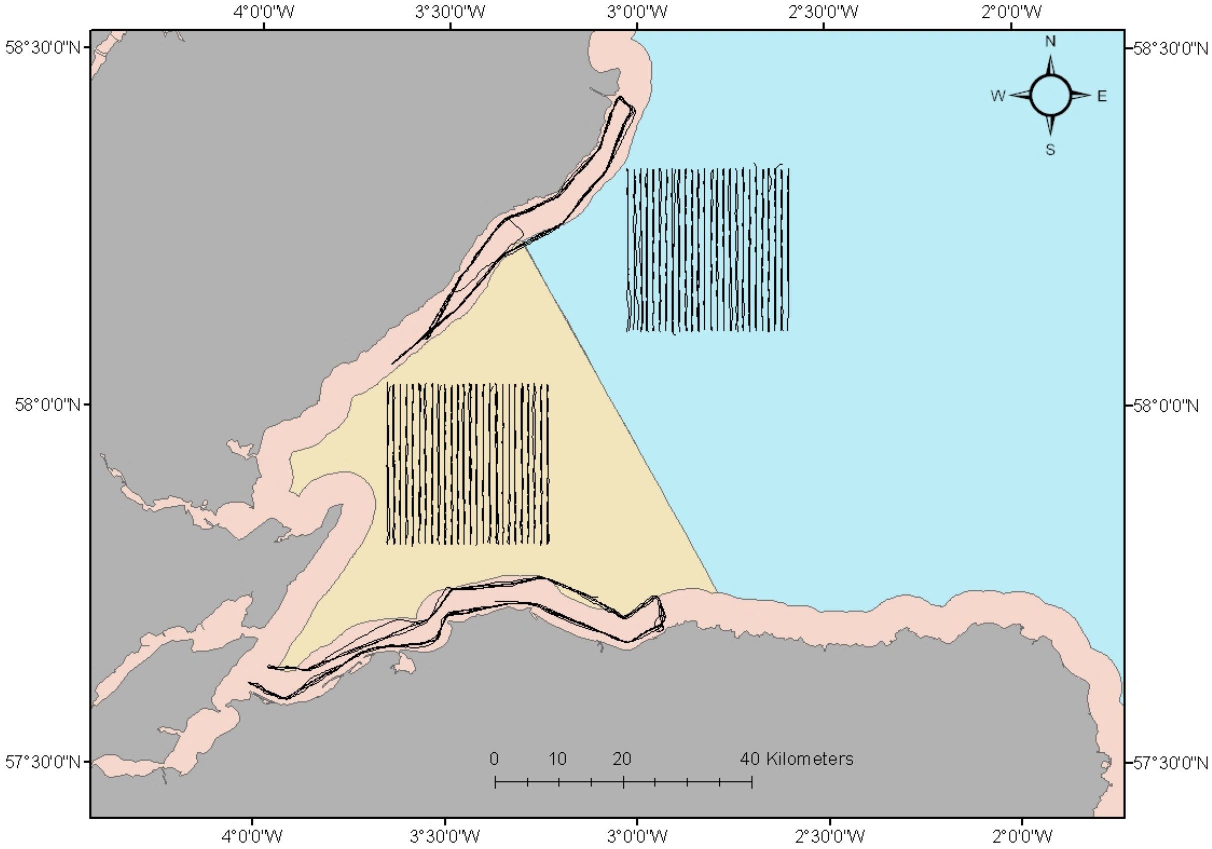


Figure 2.9. Map showing the total aerial survey effort used in the calculations of density and the regions used to estimate abundance (pink = coastal; yellow = central Moray Firth; blue = outer Moray Firth).

As outlined in section 2.1.1.3, aerial surveys 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 2.9). On the coastal transects, the aeroplane flew parallel to the coast at a distance of 1 km offshore, returning on a parallel transect 5km offshore. The two blocks and transect were surveyed 9 times, the north coast route 6 times and the south coast survey route 5 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.

Observers followed protocols developed for SCANS and SCANS-II aerial surveys to collect data. 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 trackline 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. g(0), the detection probability on the track line, is equal to 1 (Thomas *et al*. 2009). Data collected in studies such as this fail to meet this assumption in two ways, and this must 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, we produced a single detection function for all dolphins, and used this to provide an estimate of density and abundance for all pooled dolphins of all species. Ongoing work is exploring whether this dataset can be used to produce robust estimates of density of the individual dolphin species. In the meantime, 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 5km of land, a central Moray zone and an outer Moray Firth zone (Figure 2.9).

2.2 Passive acoustic monitoring

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 6 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 200m around the T-POD (Tougaard *et al.*, 2006), whereas field studies indicate that bottlenose dolphins can be detected at distances up to 1200m (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.

2.2.1 Data sources

2.2.1.1 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. First, at a site near the Beatrice Demonstrator turbines, and secondly, at a site 40km to the south near Lossiemouth (Figure 2.10). Our 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 & 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, we deployed both a C-POD and a T-POD at 14 of the moorings used during the 2010 field season (see Section 2.2.1.3). In each case, the two devices were cable tied side by side at the same position on the mooring.

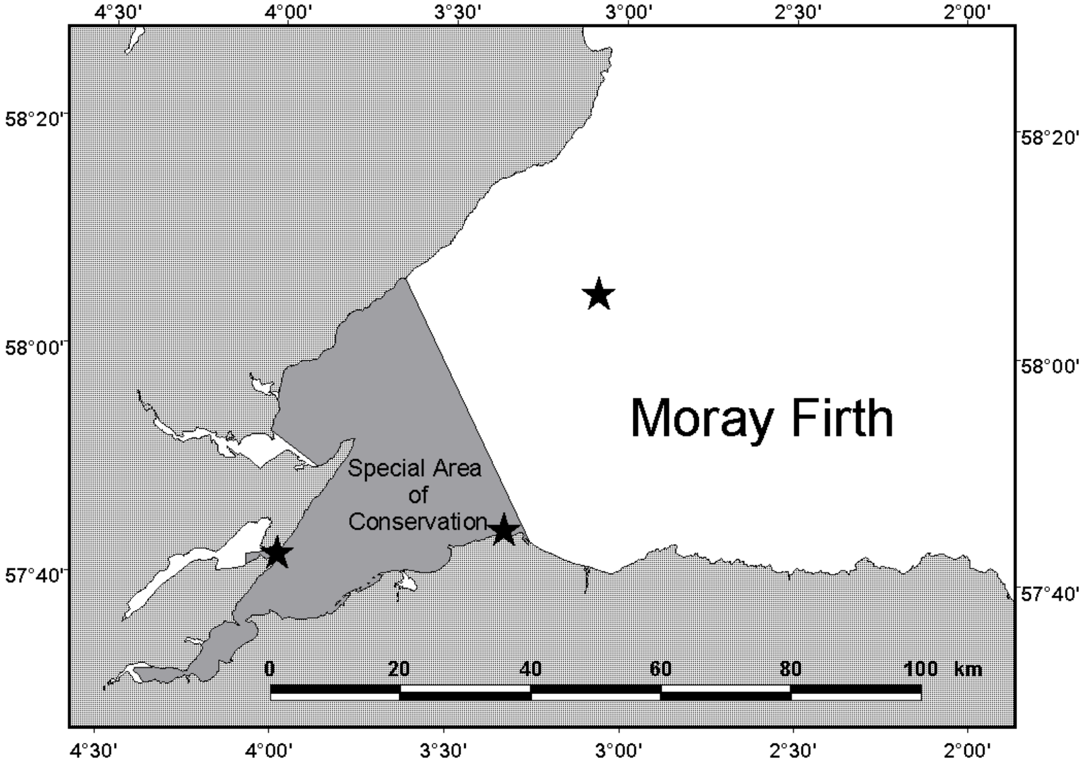


Figure 2.10. Sites used for passive acoustic monitoring during the Beatrice Demonstrator study, 2005-2007. From Bailey et al. 2010.

2.2.1.2 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 windfarm 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 2.11) 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.

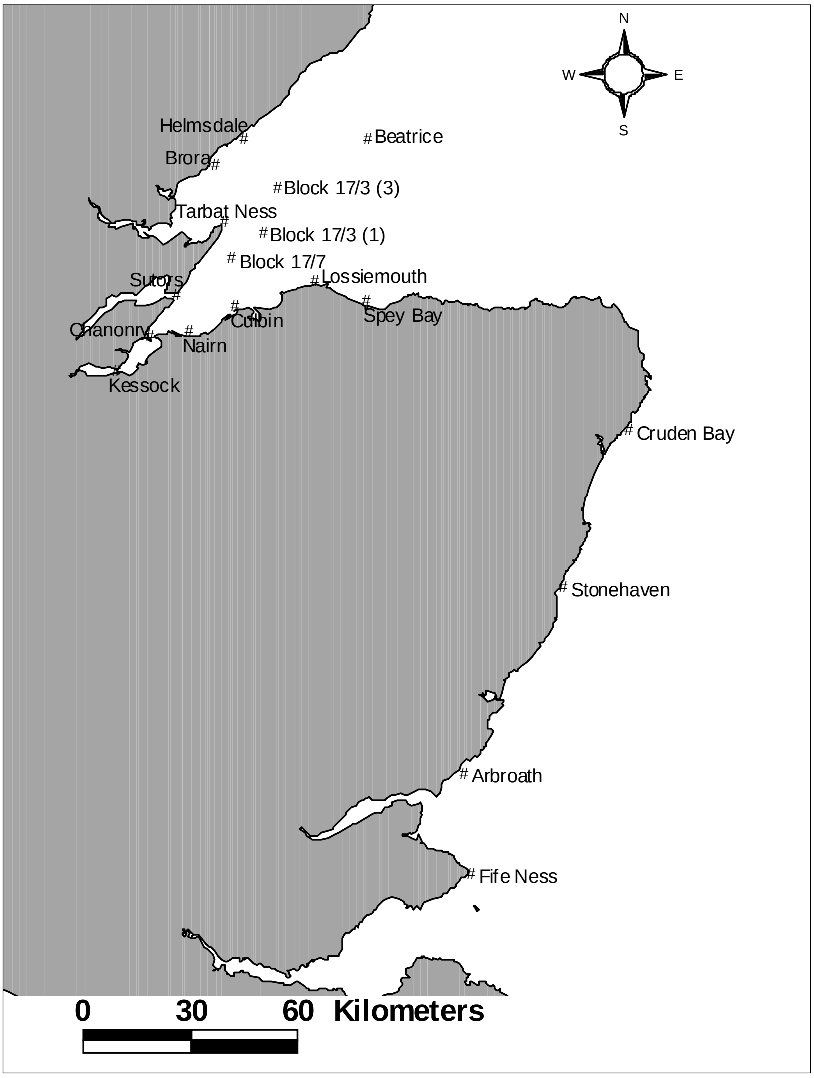


Figure 2.11. Sites used for passive acoustic monitoring during SNH and SEERAD funded studies 2006-2009. From Thompson et al. 2011b

2.2.1.3 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 2.12). All primary deployments were made using C-PODs. For a subset of moorings in 2010, we paired a C-POD with a T-POD to provide data for a comparison of detection rates for the two devices.

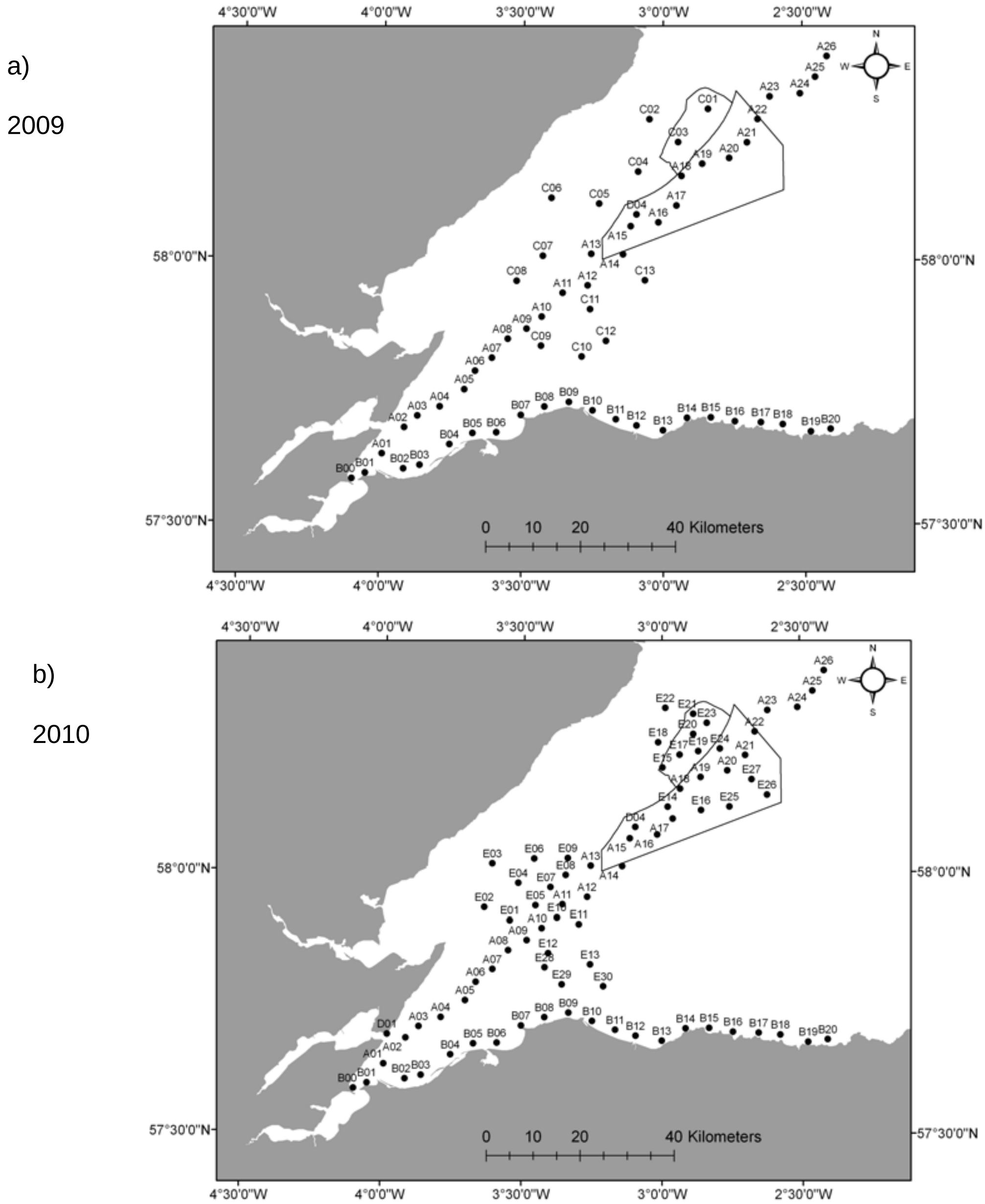


Figure 2.12. Sites used for passive acoustic monitoring during DECC funded studies in a) 2009 and b) 2010

2.2.1.4 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, BOWL and MORL contracted the University 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 6 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 2.13.

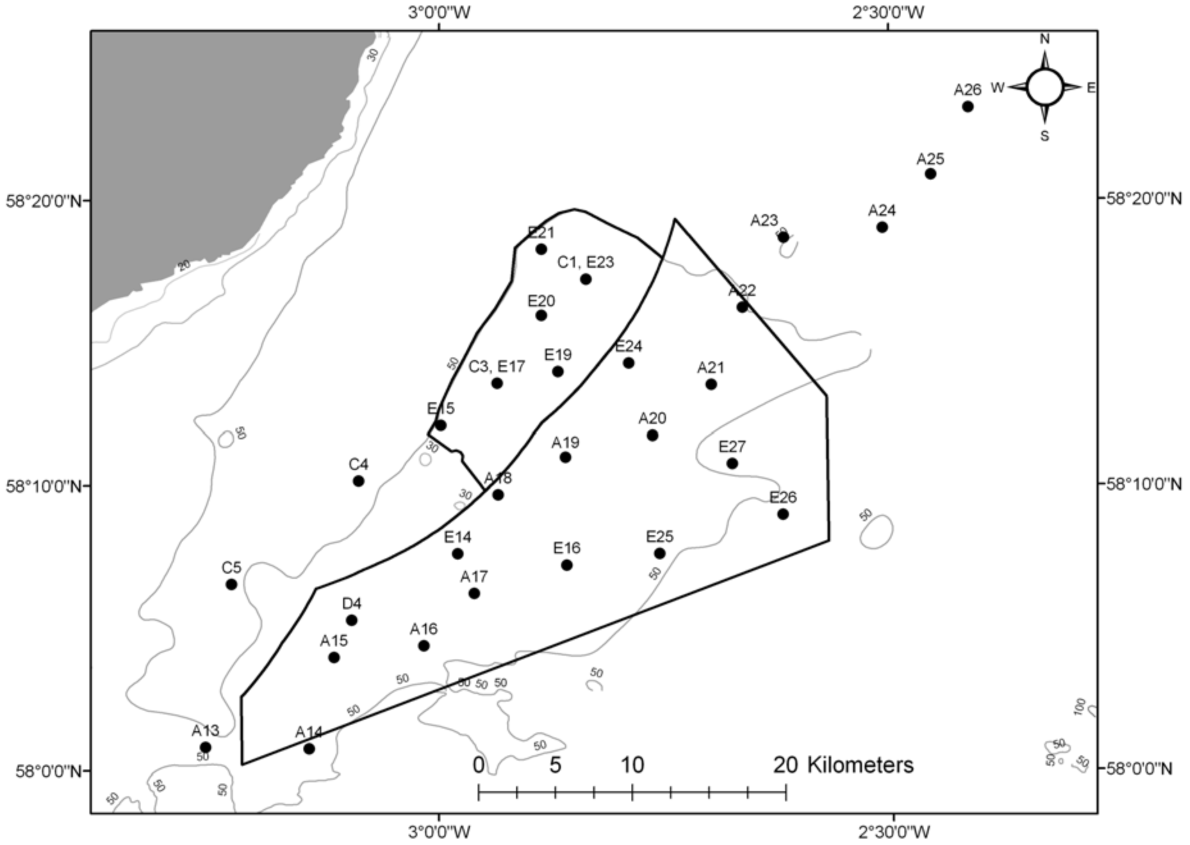


Figure 2.13. Sites at which T-PODs or C-PODs have been deployed within or close to the MORL and BOWL development areas.

2.2.2 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 6 successive scans within different user-defined frequencies, logging detections for periods of up to 5 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 our studies, we used Version 4 and Version 5 T-PODs 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 we set a target frequency of 50 kHz and a reference frequency of 70 kHz on three of the channels. For porpoises, we set a target frequency of 130 kHz and reference of 92 kHz on the three other channels. 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. We used the category "CET ALL", 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.

2.2.3 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 1-2 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, we used only CetHi and CetMod detections to estimate the number of hours that either porpoises or dolphins were detected at each sampling site on each day.

Because of greater levels of fishing effort in the outer Moray Firth, we modified the mooring design used previously in inshore areas. In this study, we used moorings with a single riser from a 100 kg or 150 kg weight, and a larger surface Dhan buoy with radar reflector and flag (Figure 2.14). 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.

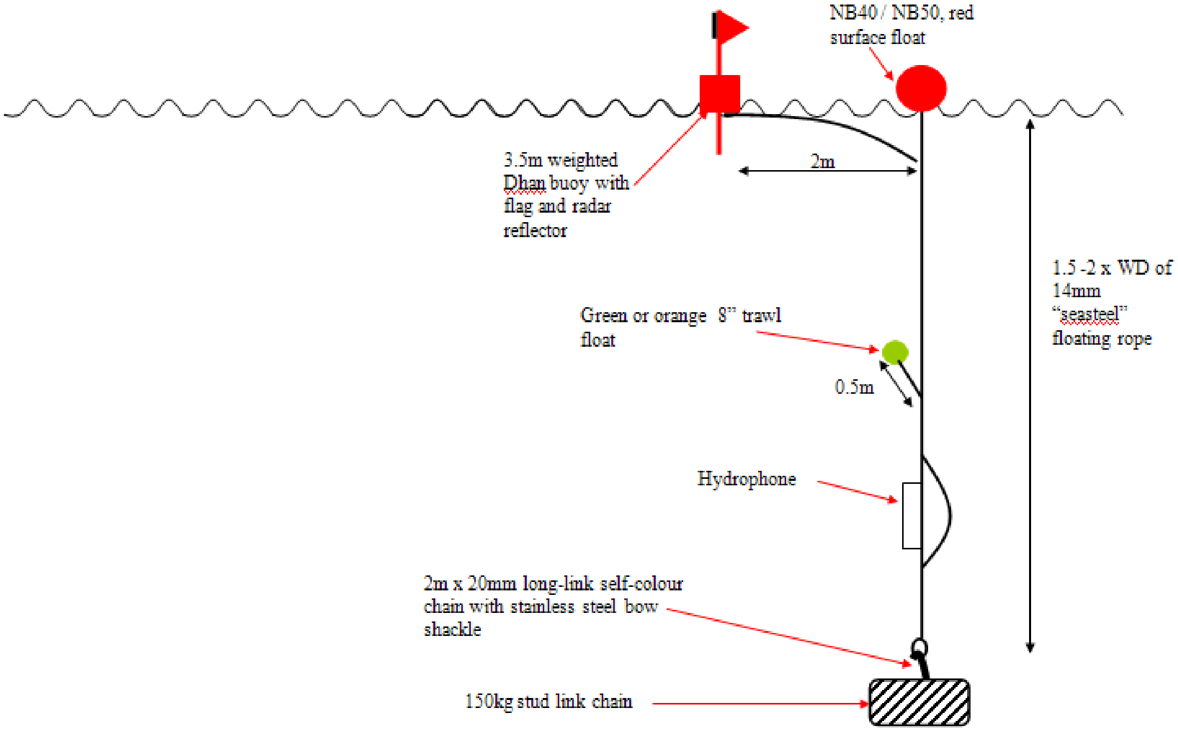


Figure 2.14. Single riser mooring design with Dhan buoy used to suspend PoDs in the water column

3. Results

3.1 ***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 2.1 (Table 3.1).

Table 3.1. Number of sightings of cetaceans recorded during each of the different visual survey programmes.

Species	2.1.1.1 AU SAC	2.1.1.2 AU Boat	2.1.1.3 AU Aerial	2.1.1.4 MORL	2.1.1.5 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

Maps presenting raw data on the distribution of all sightings of harbour porpoises and dolphins are shown in sections in Figures 3.1 – 3.5. In both these figures and in Table 3.1, we include all those sightings where the different survey teams were confident about species identification.

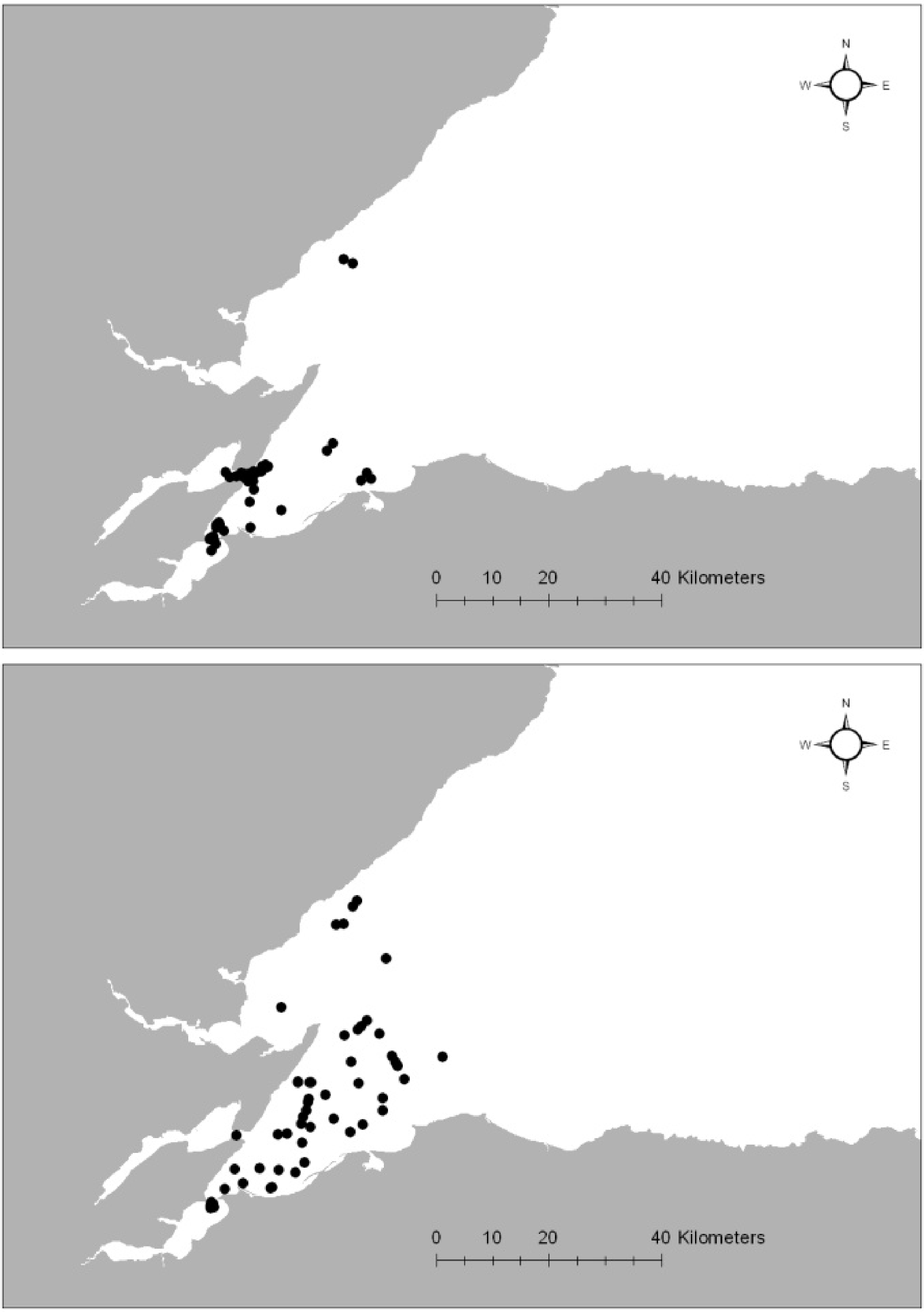


Figure 3.1. Sightings of a) dolphins and b) harbour porpoises made during the University of Aberdeen surveys within the Moray Firth SAC. All sightings of dolphins on these surveys were reported as bottlenose dolphins.

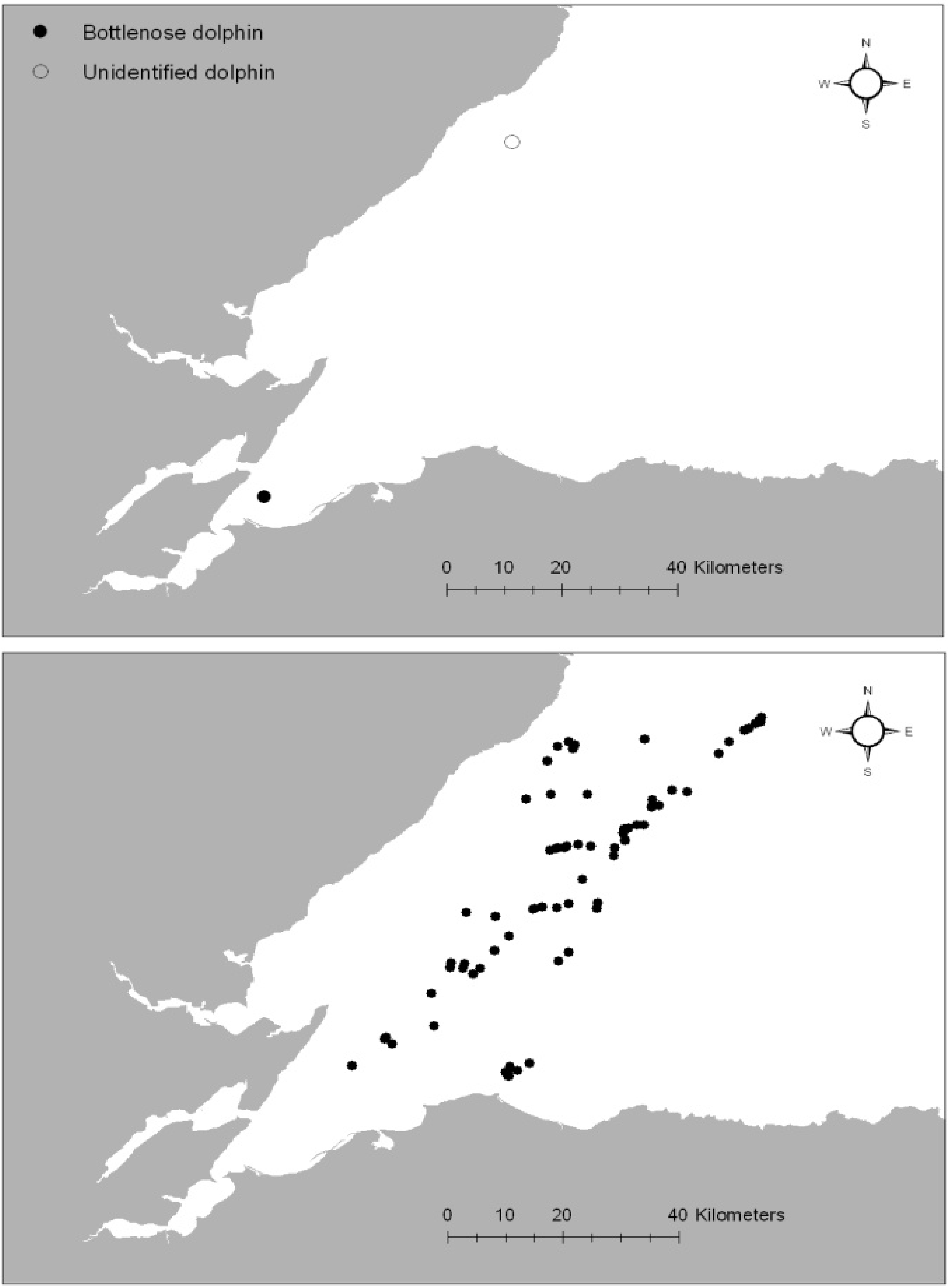


Figure 3.2. Sightings of a) dolphins and b) harbour porpoises made during the University of Aberdeen's 2009 boat based surveys in the Outer Moray Firth.

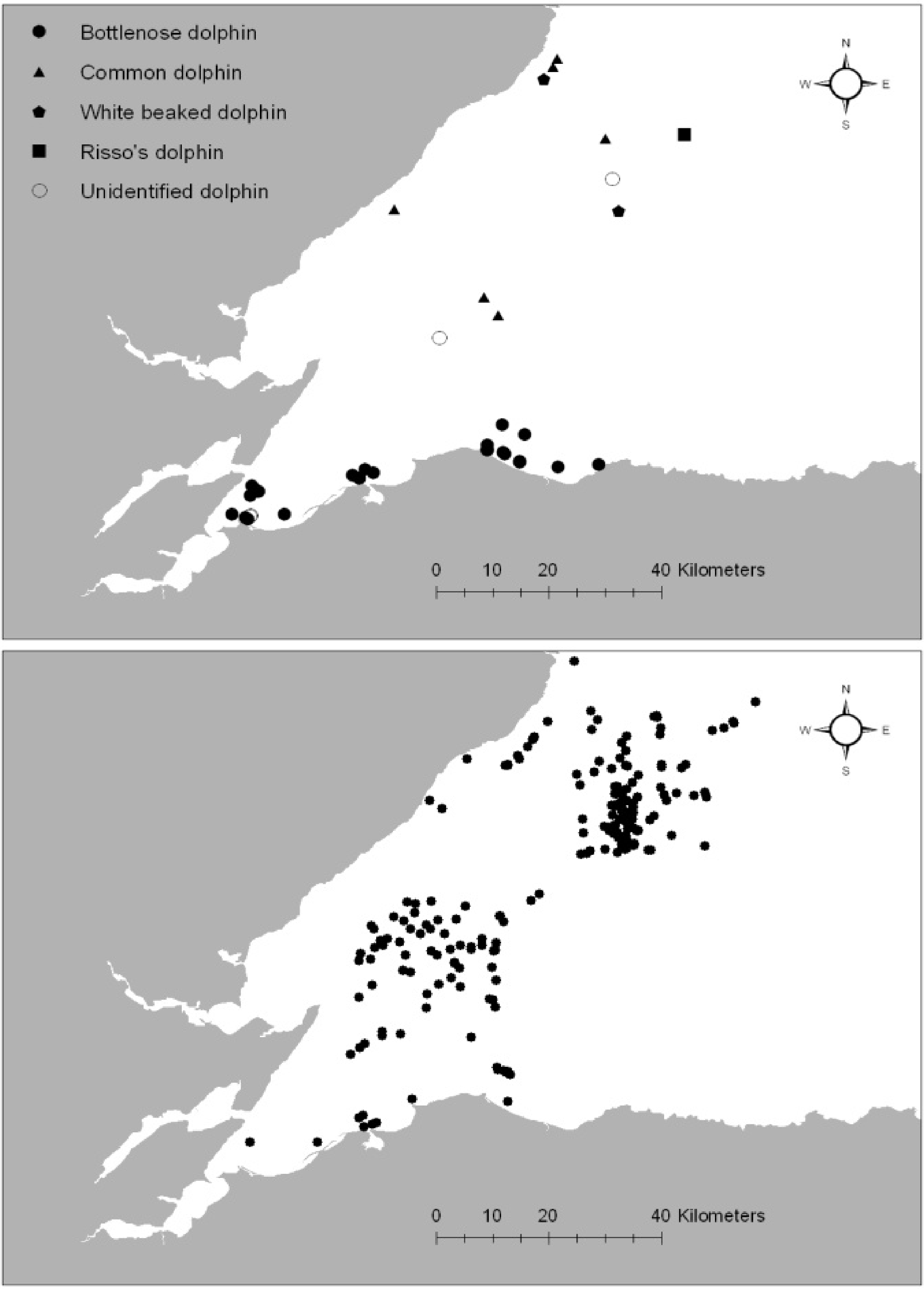


Figure 3.3. Sightings of a) dolphins and b) harbour porpoises made during the University of Aberdeen's 2010 aerial surveys of the Outer Moray Firth.

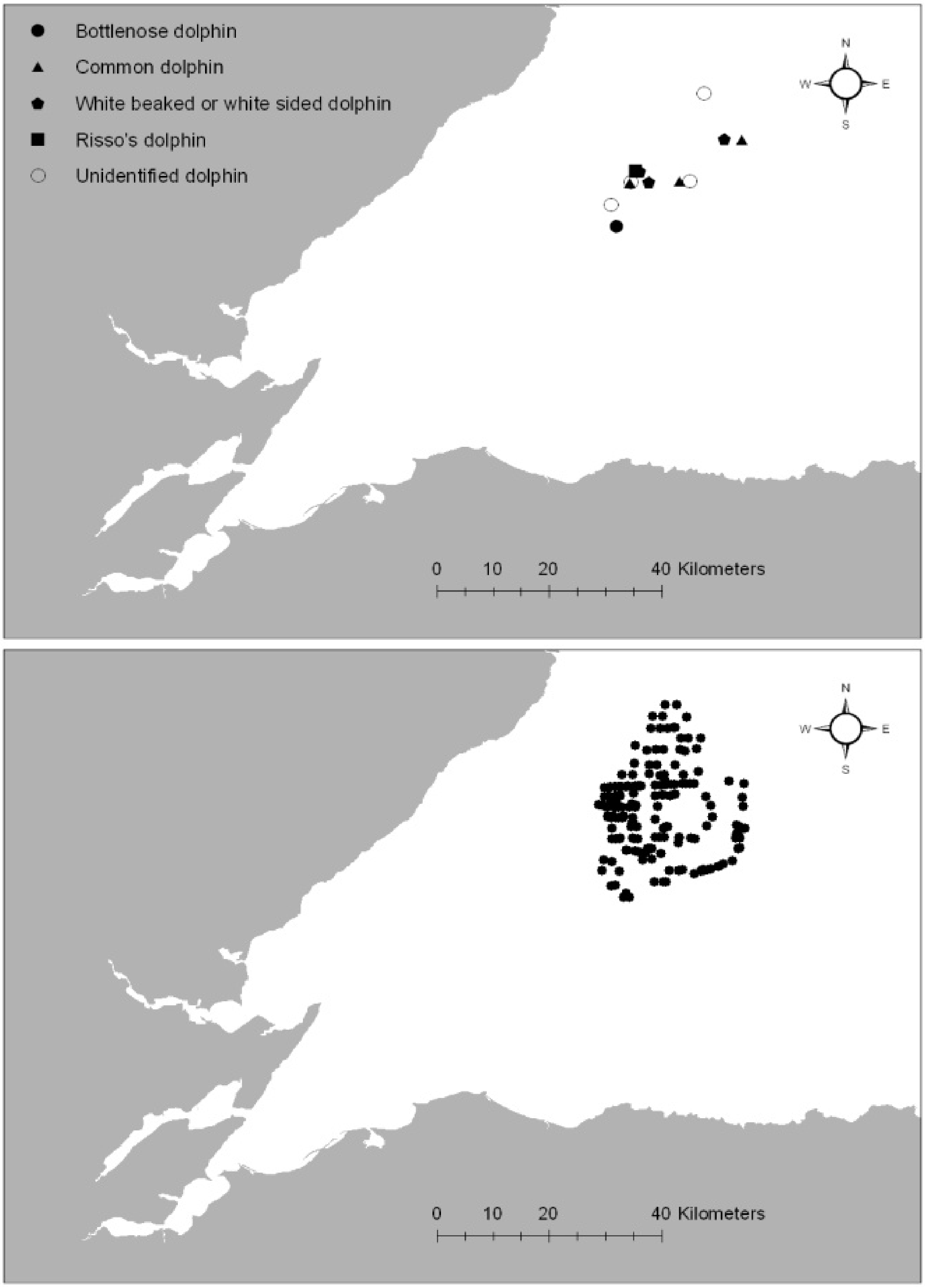


Figure 3.4. Sightings of a) dolphins and b) harbour porpoises made during Natural Power boat surveys of the MORL site between April and October of 2010.

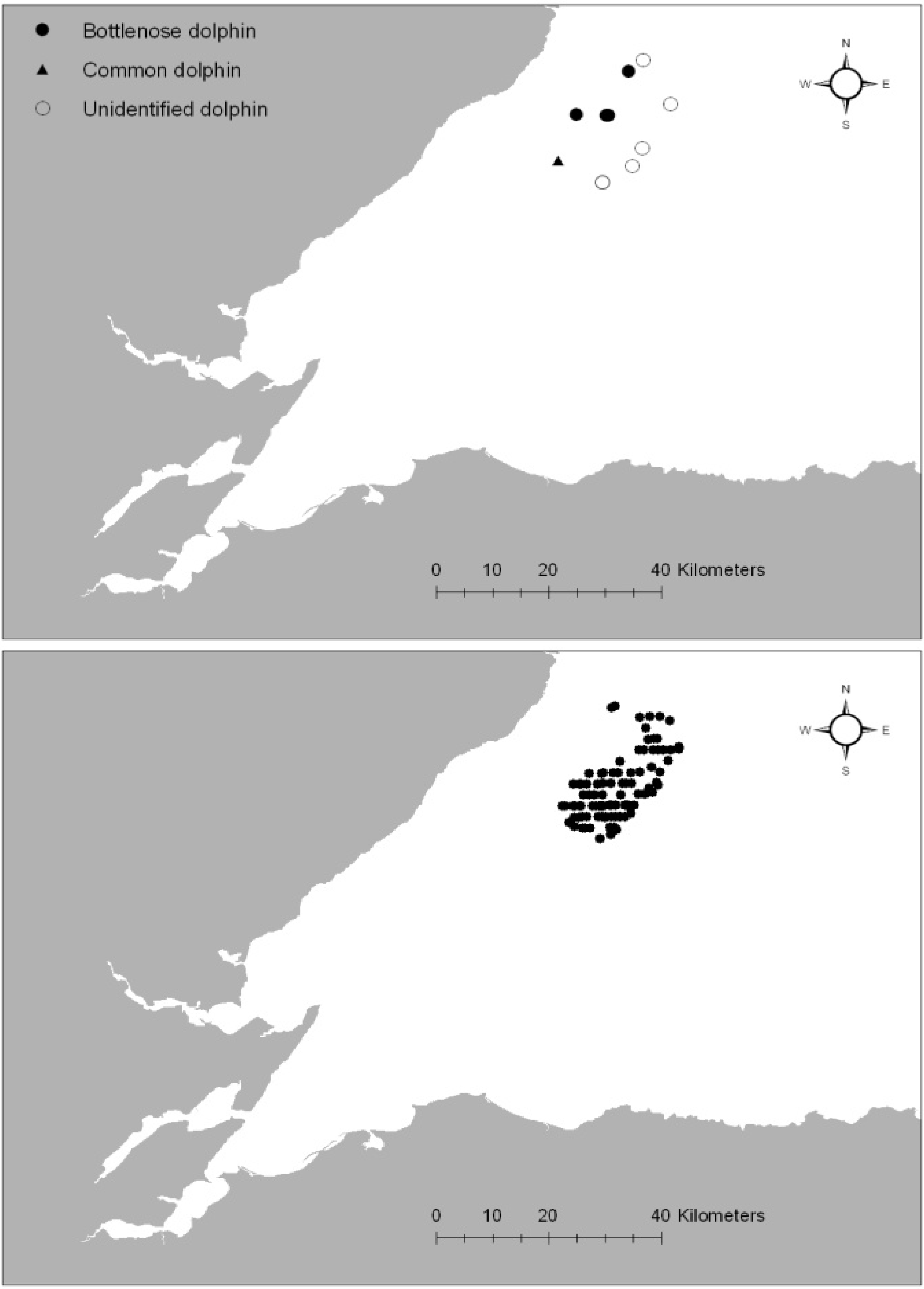


Figure 3.5. Sightings of a) dolphins and b) harbour porpoises made during IECS boat surveys of the BOWL site between April and October 2010.

3.2 ***Modelling harbour porpoise habitat association & distribution***

Models were based on over 1000 sightings of porpoises from the five different surveys (Table 3.2)

Table 3.2. 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.

Table 3.3. 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 shape of the 2D smoother (Figure 3.6) 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.

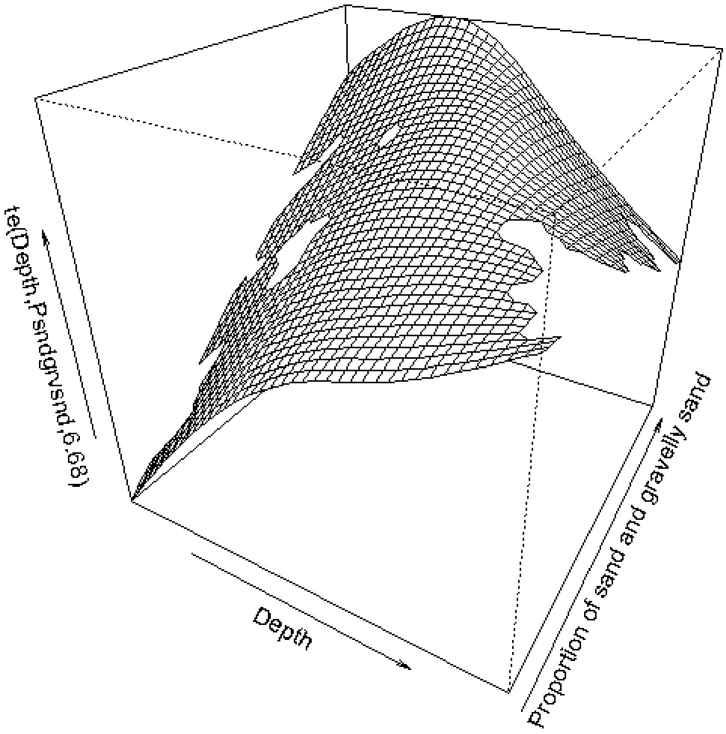


Figure 3.6. Two dimensional smoother used in the porpoise habitat association model to described the relationship with both depth and the proportion of the sediment made up of sand and gravelly sand.

The results of this model were then used to predict spatial variation in the relative abundance of porpoises across the Moray Firth. The predicted number of porpoises in each 4x4 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 3.7a shows the predicted number of porpoises encountered in different parts of the Moray Firth for a standard 1km of survey effort, and Figure 3.7b shows the standard error of this prediction for each cell. Although cell identify 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 2.7) are the most uncertain (Figure 3.7b). This is particularly so for deep water areas due to the interaction with depth and sediment type (Figure 3.6), and the lack of survey effort in waters deeper than 80m. In this report, we therefore do not make predictions for any cells where water depth is greater than 120m, and the higher uncertainty for the cells with depths in the range 75-120m 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 3.5). This was based on the highest quality data from the 98 4 x 4 km cells that overlapped the two 25 x 25km survey blocks (Figure 2.8). 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 3.7a). The resulting values provide an indication of the number of porpoises likely to be present in each 4 x 4 km cell (Figure 3.8).

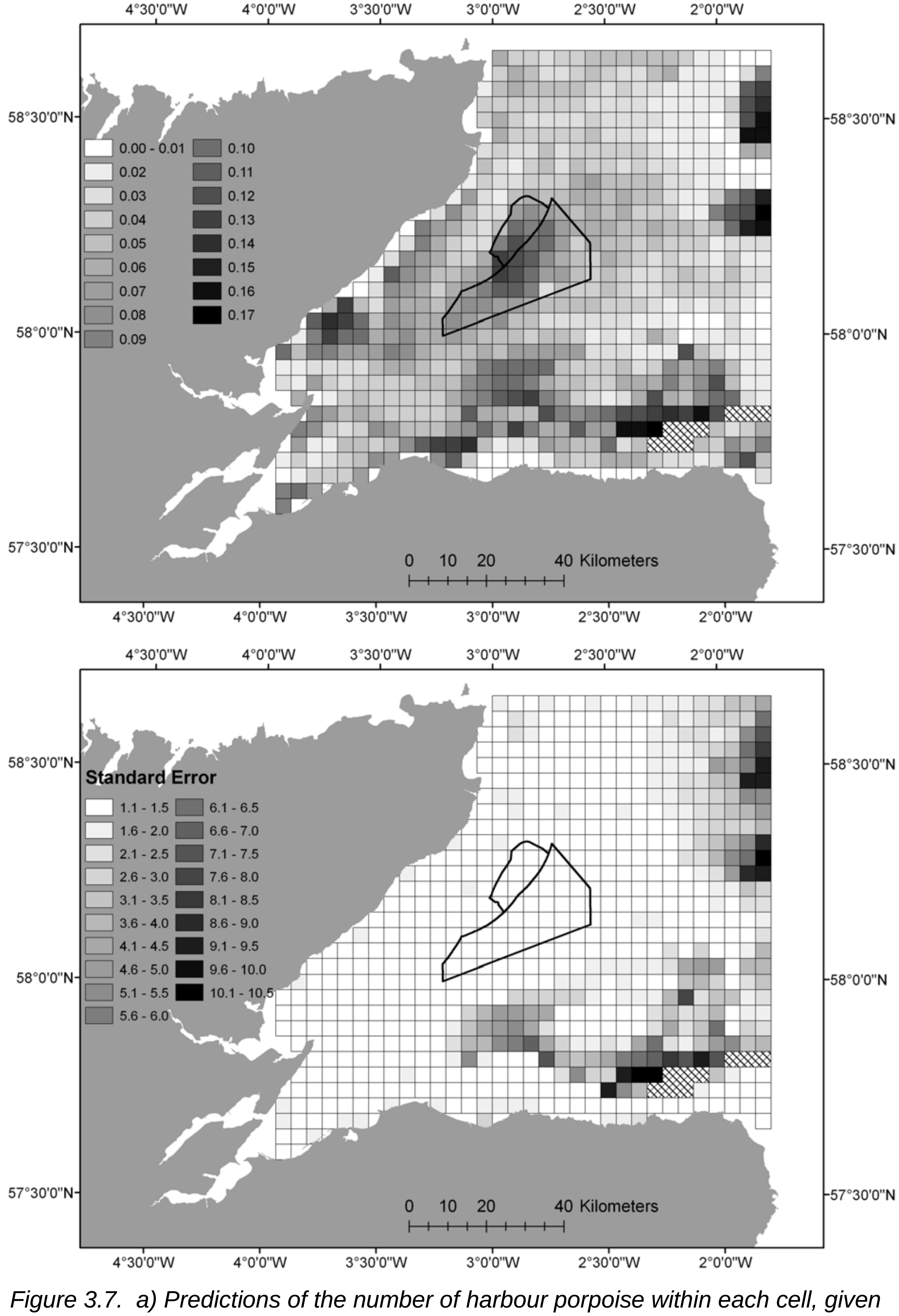


Figure 3.7. a) Predictions of the number of harbour porpoise within each cell, given 1 km of effort. b) Standard errors around predicted values in each cell.

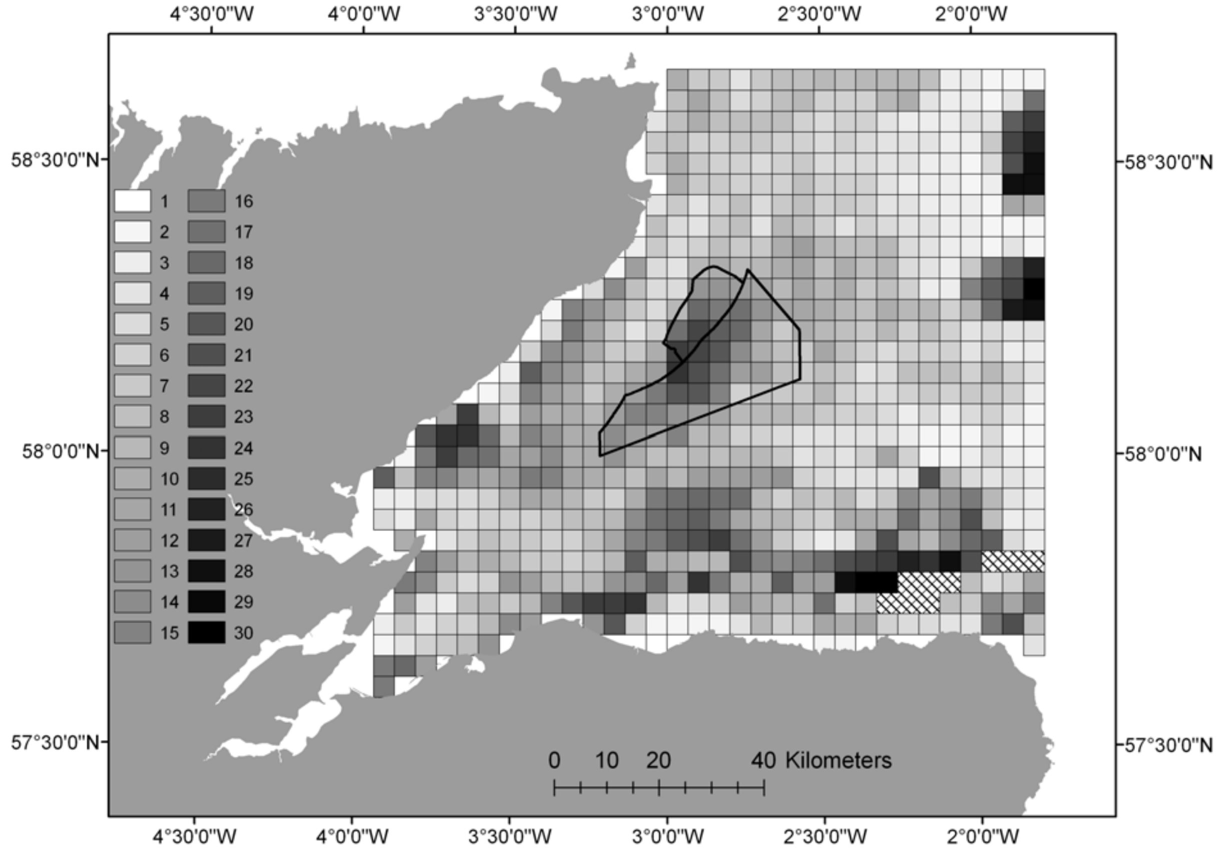


Figure 3.8. The predicted number of harbour porpoises in each cell. Values are based upon measures of relative abundance derived from the habitat association modelling (Fig 3.7), scaled according to estimates of absolute abundance from aerial line transect surveys (Table 3.4), and extrapolated to other areas according to predicted relative abundance (Fig 3.7).

3.3 ***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 2.12). 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 2.12). 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 windfarm sites (Figure 3.9). 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 3.10).

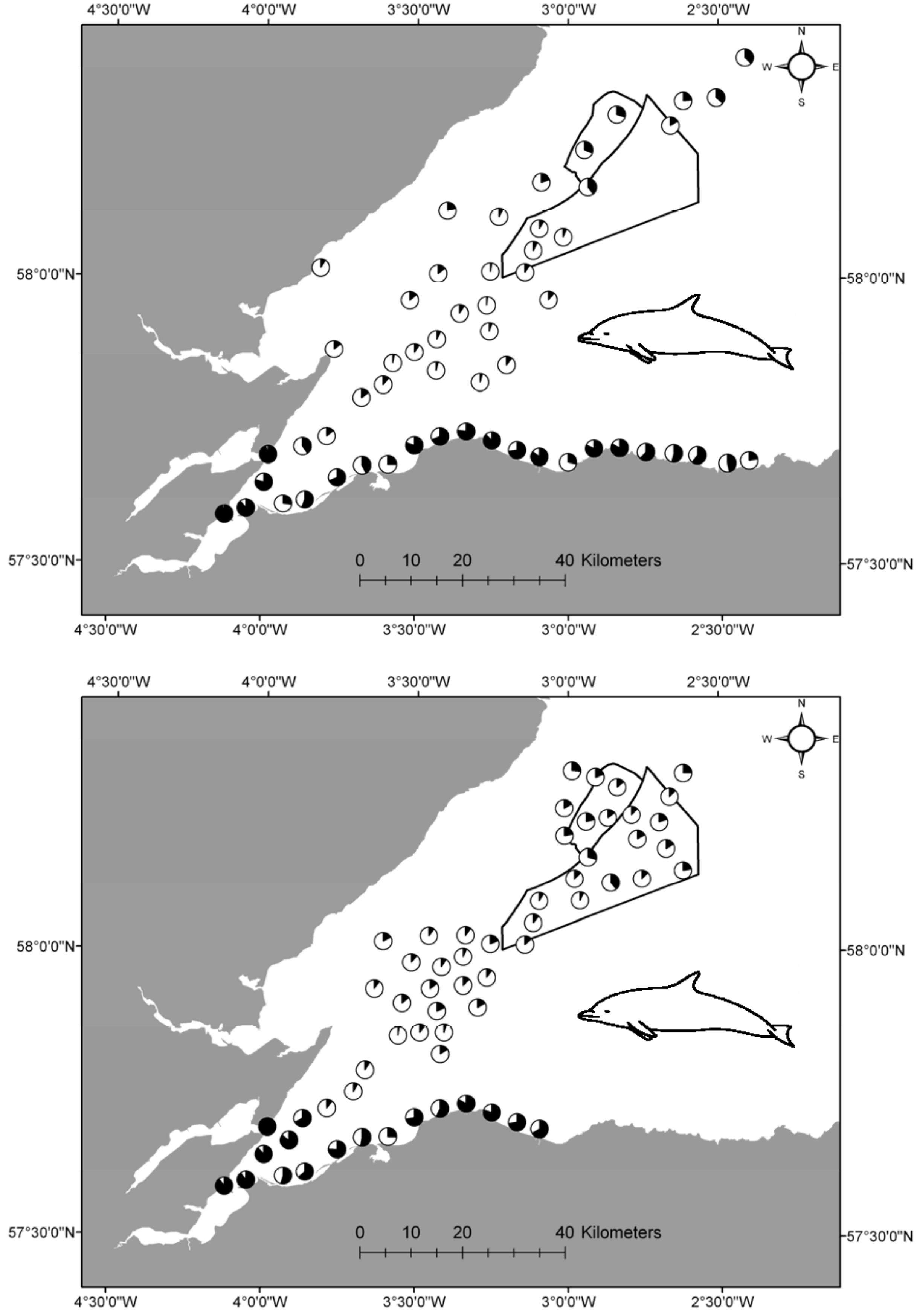


Figure 3.9. Proportion of days that dolphins were detected a) in 2009 and b) in 2010 at each PAM site. Figures are updated versions of those presented in Thompson et al. 2010a and Thompson et al. 2011a.

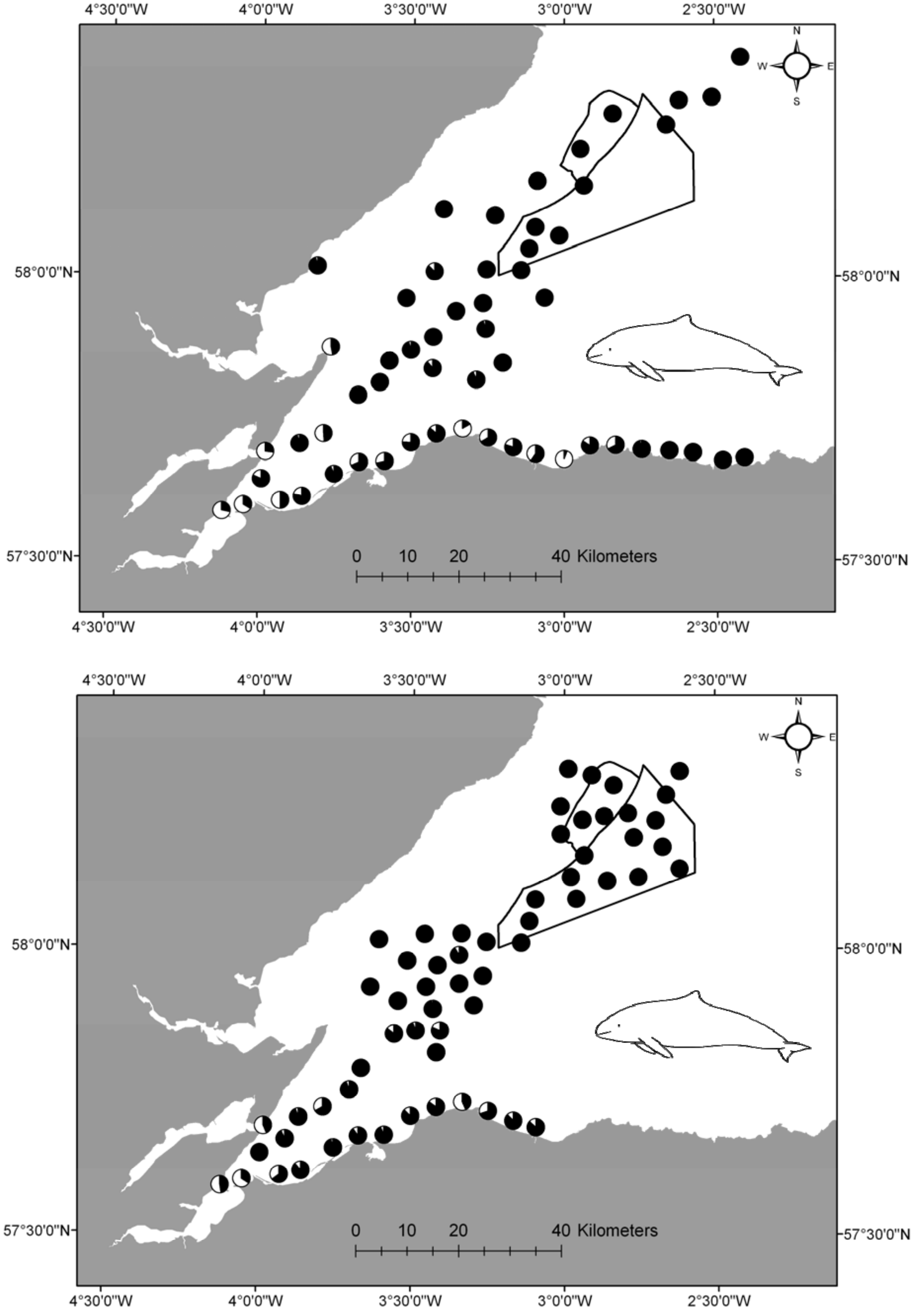
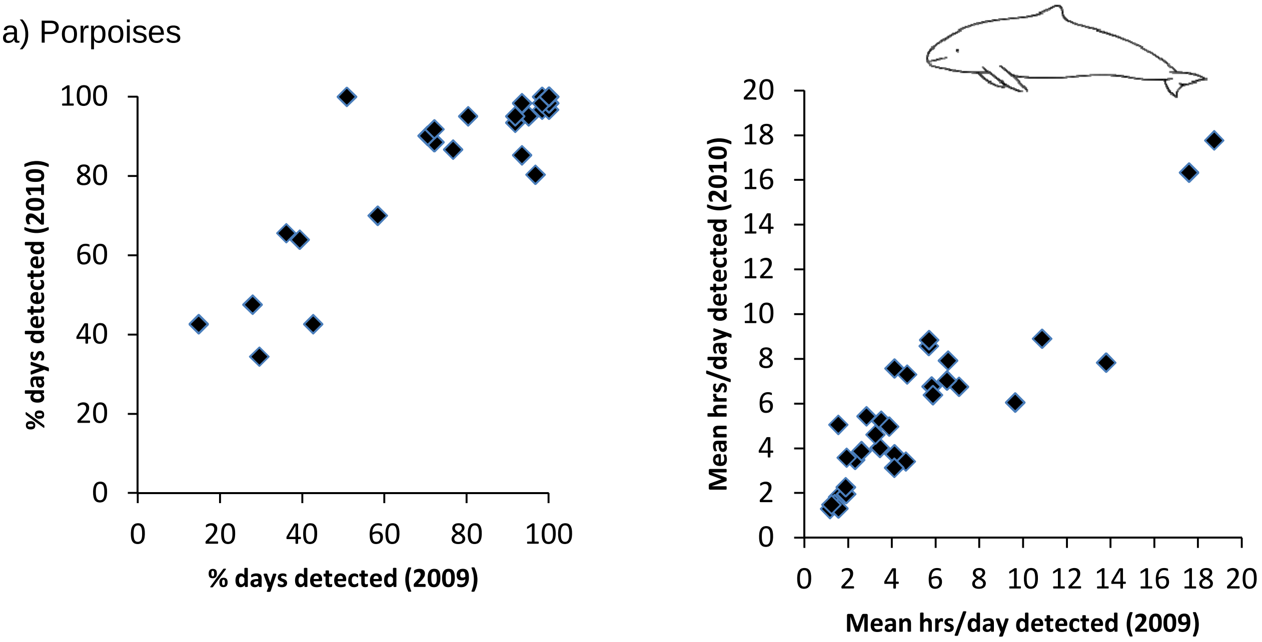


Figure 3.10. Proportion of days that porpoises were detected a) in 2009 and b) in 2010 at each PAM site. Figures are updated versions of those presented in Thompson et al. 2010a and Thompson et al. 2011a.

a) Porpoises



b) Dolphins

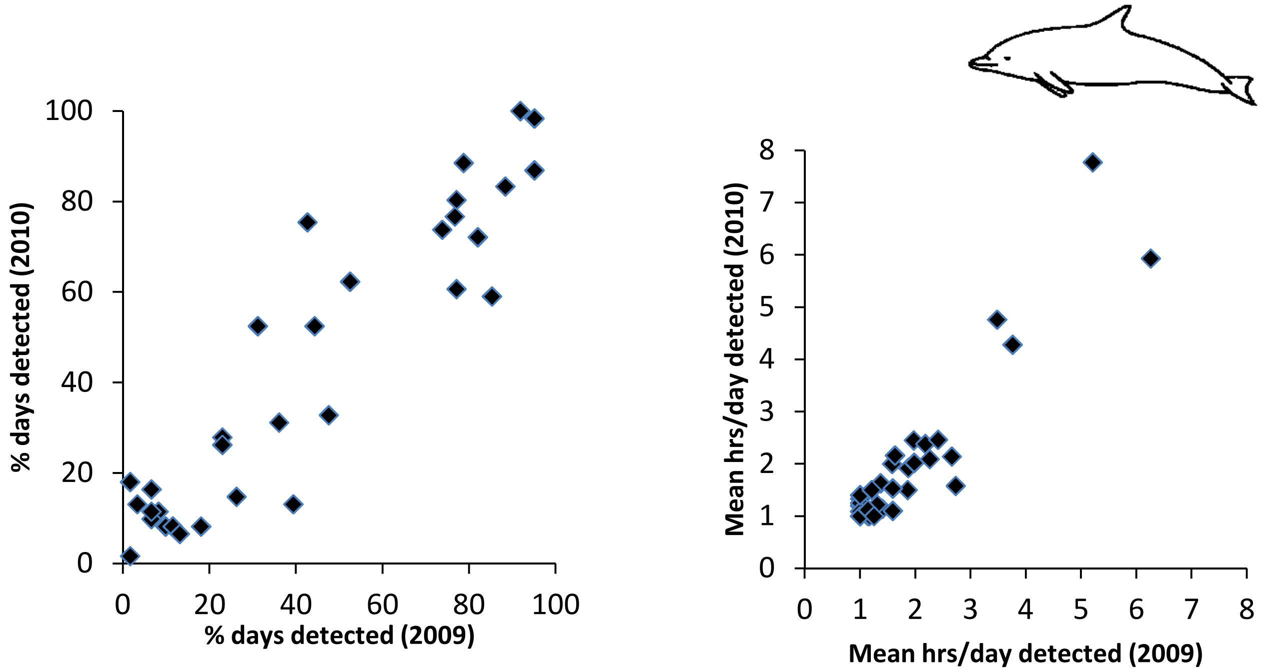


Figure 3.11. Comparison of the percentage of days that a) porpoises and b) dolphins were detected at 33 sites that were monitored in both 2009 and 2010. Also presented are the mean number of hours that animals were present on those days on which detections were made. Data are from August and September only. Figures are taken from Thompson et al. 2011a.

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 3.11 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, we pooled data 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 3.12).

At offshore sites, porpoises were present on almost all sampling days (Figure 3.12). To provide finer scale information on variation in the occurrence of porpoises around the windfarm sites, we therefore estimated 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 (Figure 3.13).

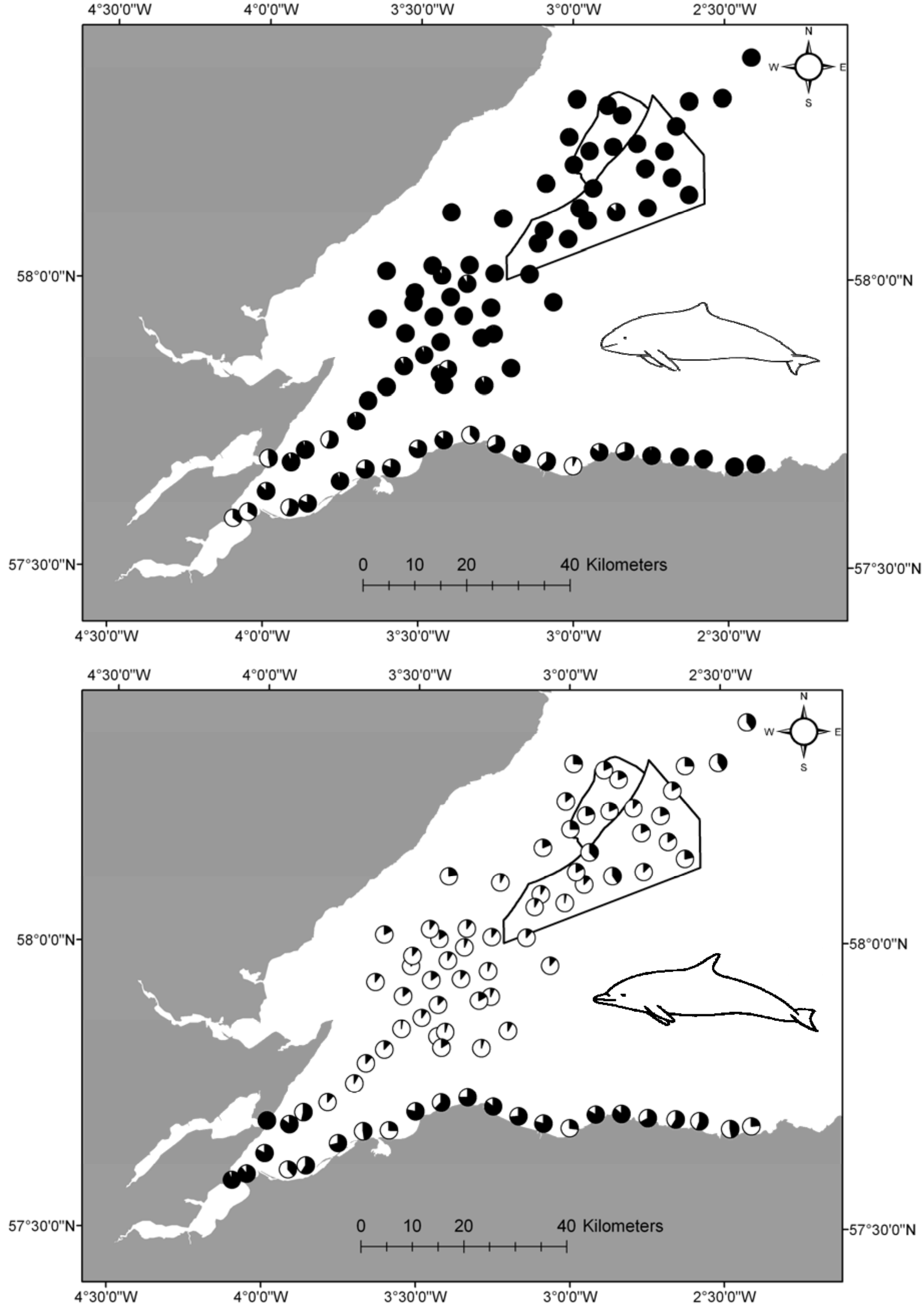


Figure 3.12. Spatial variation in the occurrence of a) porpoise and b) dolphins in the summers (April-Oct) of 2009 and 2010. Figures show the proportion of days that animals were detected on C-PODs at each sampling location, using pooled data from Thompson et al. 2010a and 2011a.

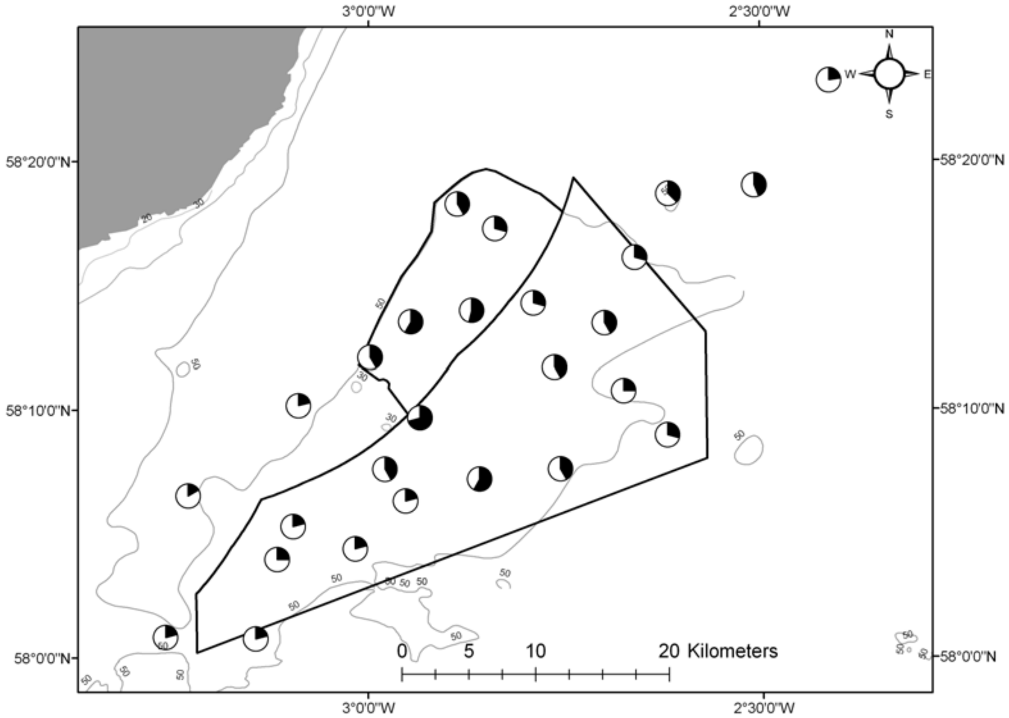


Figure 3.13. Fine-scale spatial variation in the occurrence of porpoises in and around the BOWL and MORL development sites. Data are from the summers (April-Oct) of 2009 and 2010. Pie-charts for each sampling site represent the median number of hours that porpoises were detected each day during the sampling period (April –Oct of 2009 and 2010).

3.4 ***Using classification tress to model spatial variation in the 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 3.4, Figure 3.14).

Table 3.4 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

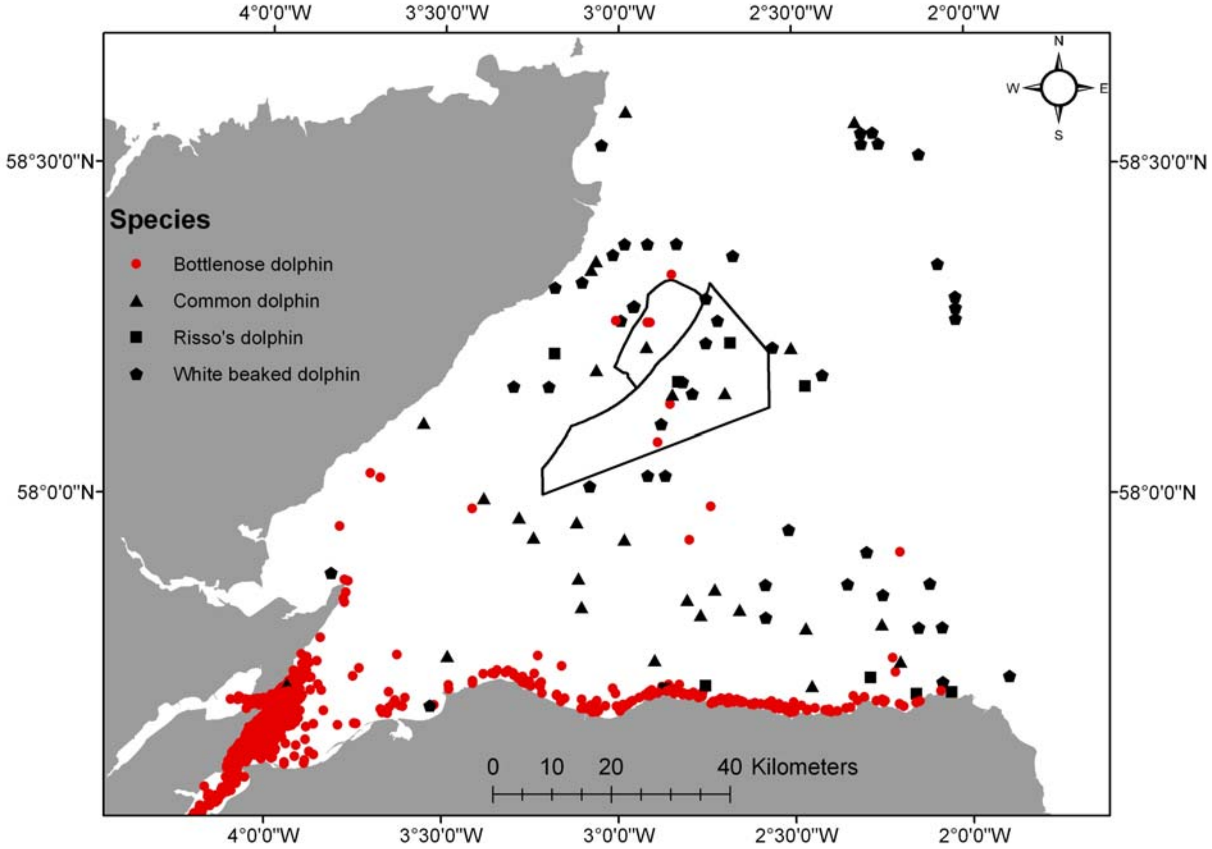


Figure 3.14. Sightings of dolphins from all data sources used in the classification tree.

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 3.15a). However, including the series of encounters 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 acoustic work (see Annex II), we suggest 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 3.15b). Data on the likely presence of bottlenose dolphins are also presented separately in Figure 3.16.

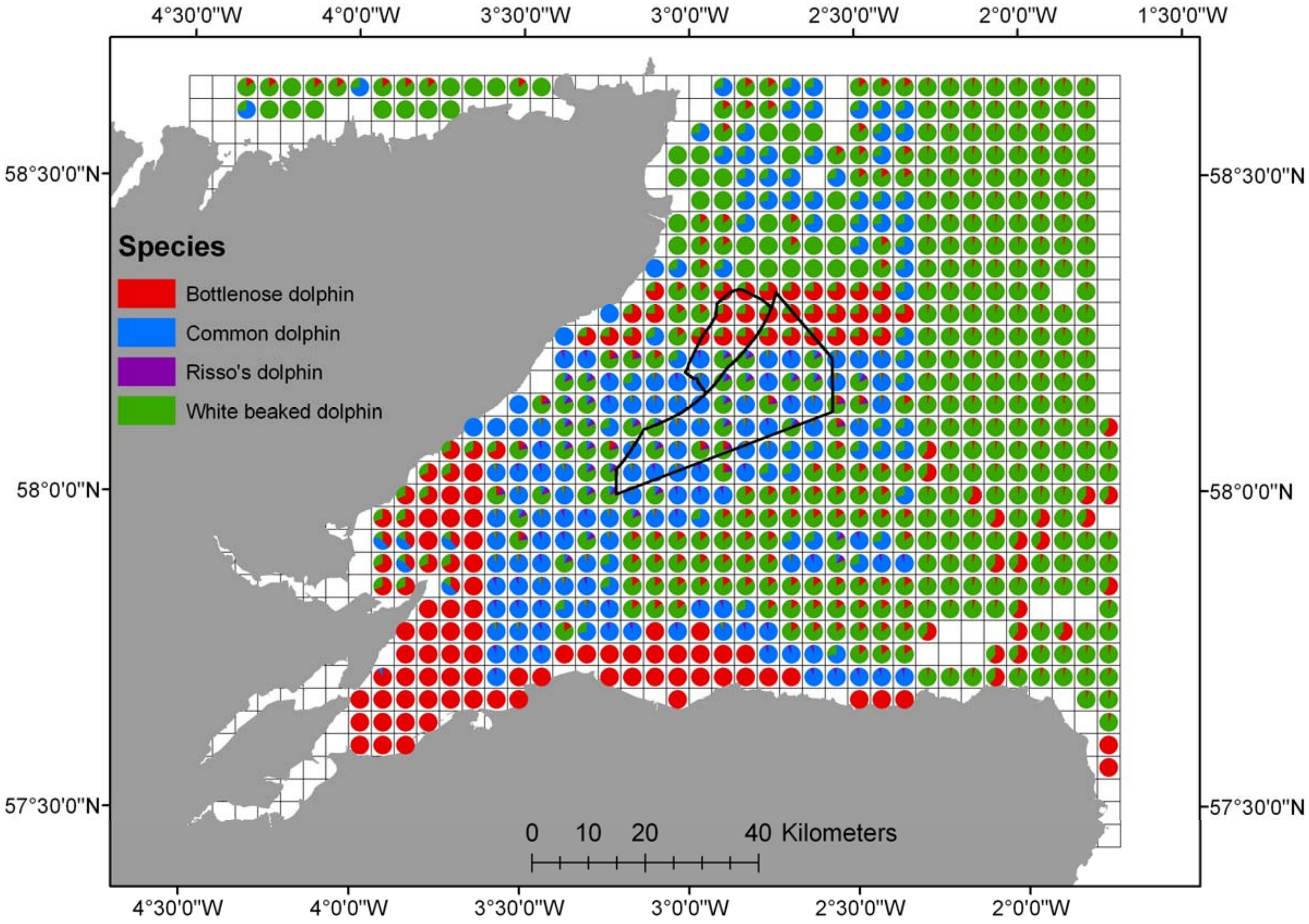


Figure 3.15a Prediction of the dolphin species composition within each4x4 km grid cell, using all data.

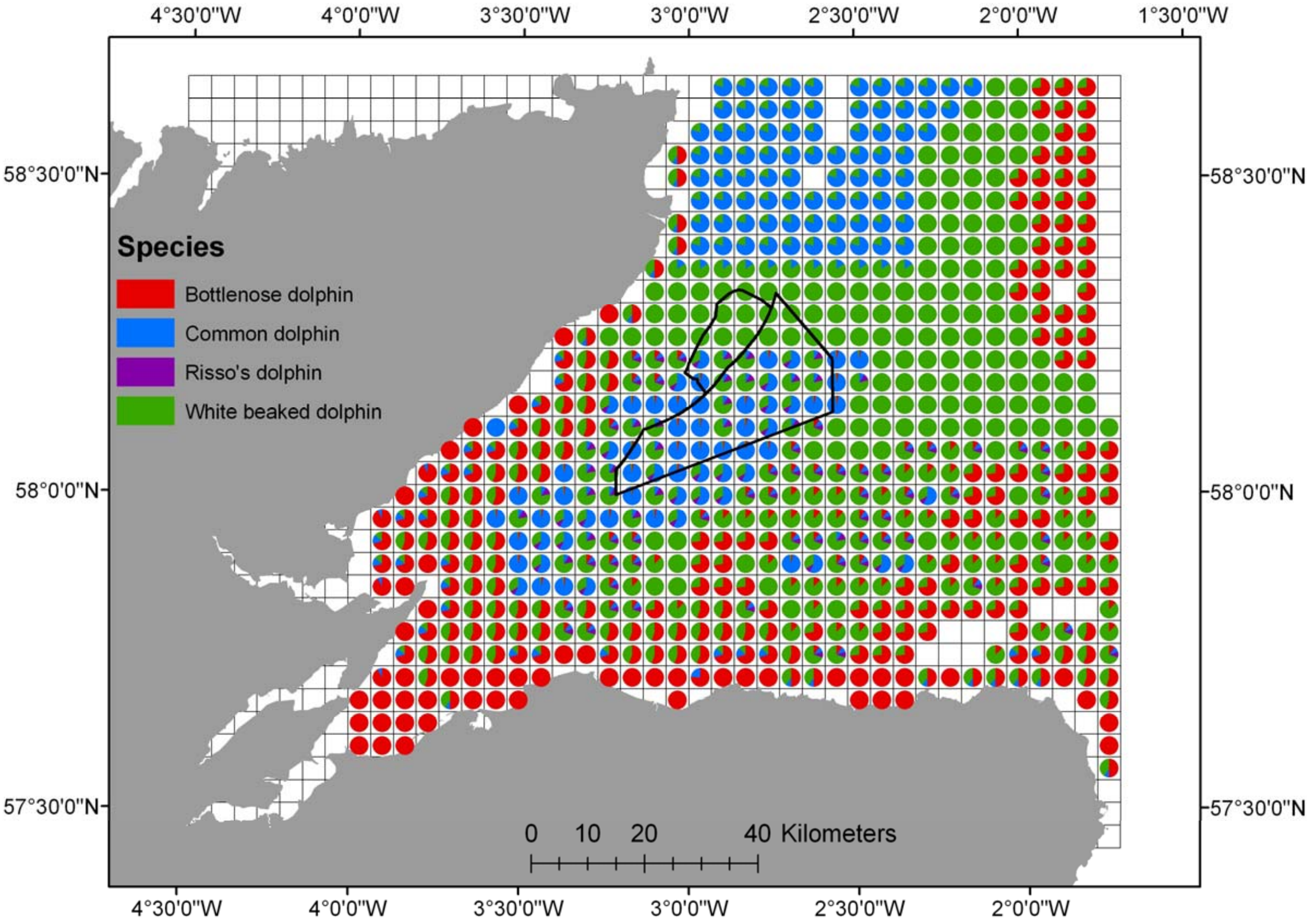


Figure 3.15b. Prediction of the dolphin species composition within each4x4 km grid cell, using all data except for the IECS/BOWL dataset

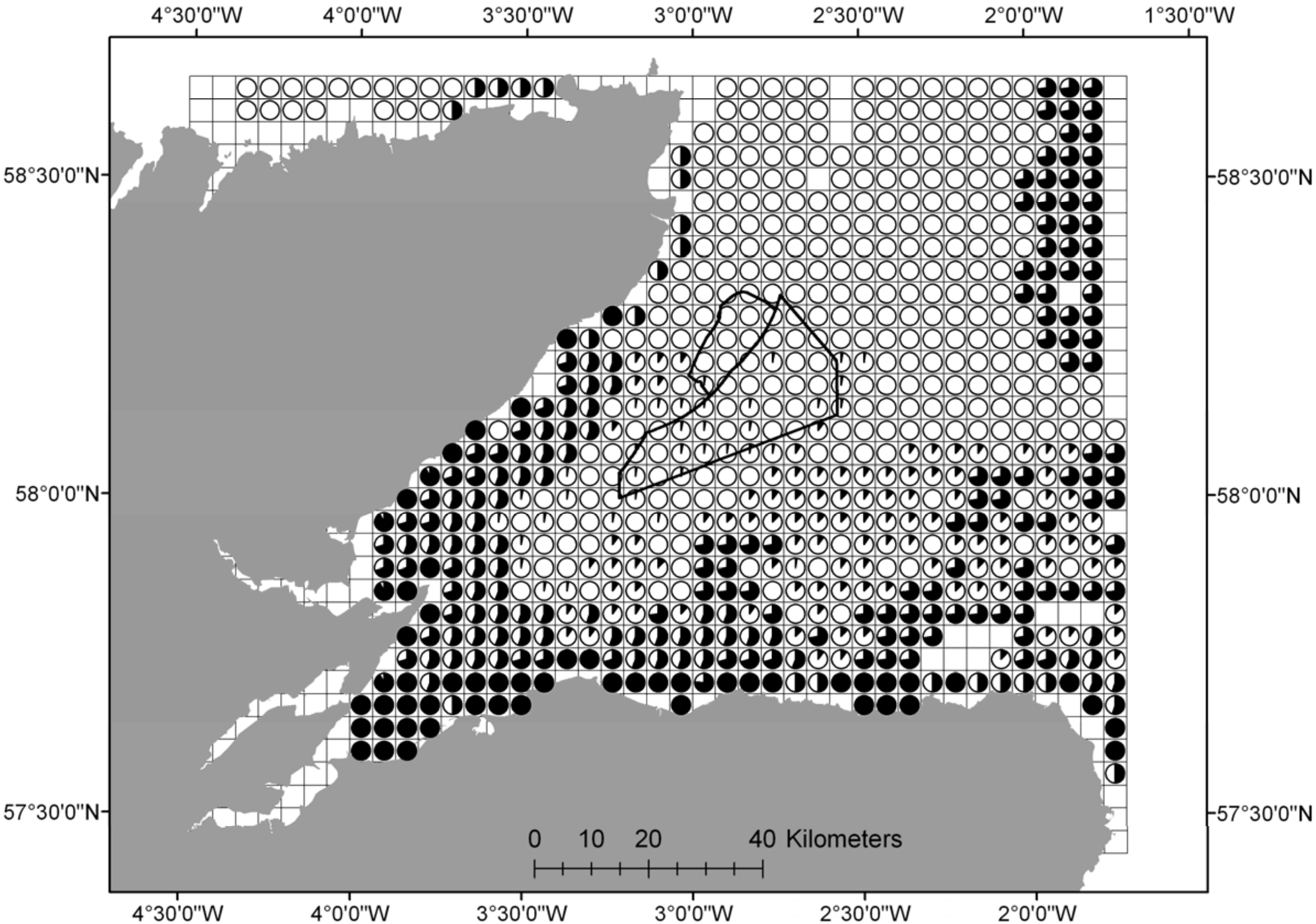


Figure 3.16. Prediction of the likelihood that dolphins encountered in each 4x4 km grid cell are likely to be bottlenose dolphins. Data are as for Figure 3.15b, but presented as bottlenose dolphin (black portion of pie chart) vs all other species.

3.5 **Estimation of density**

3.5.1. Harbour porpoise density

There were 230 sightings of harbour porpoises, representing 350 individuals, during the aerial line transect surveys shown in Figure 3.17. Density estimates were made both for the entire survey area, and for sub-areas (Table 3.5). 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 3.6).

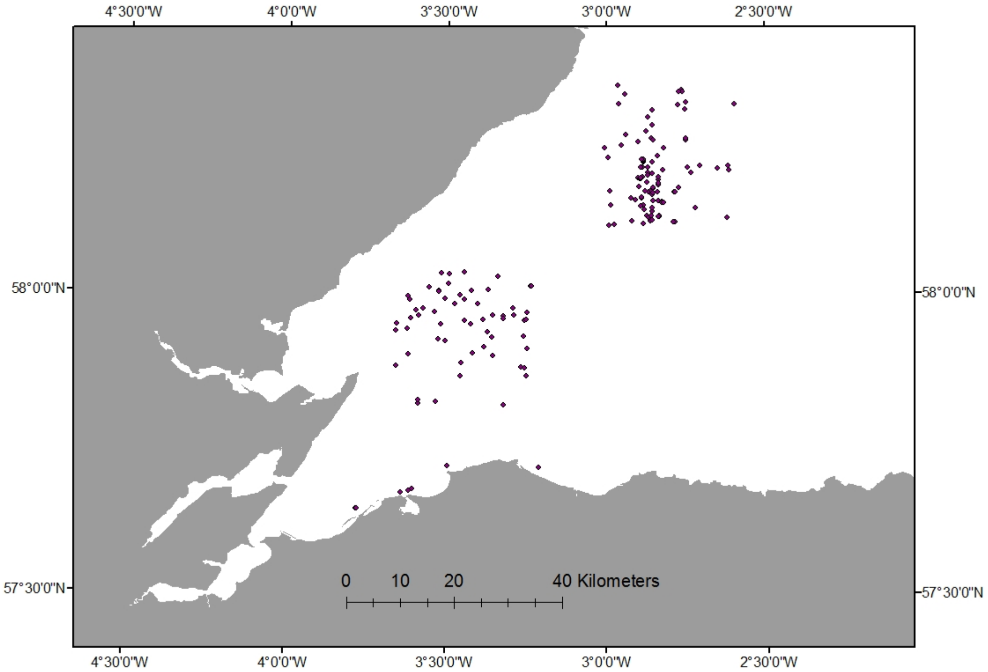


Figure 3.17. Locations of sightings of harbour porpoise made during the aerial line transect surveys in August and September 2010.

Table 3.5. Estimates of porpoise density (individuals per km^2) 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

Table 3.6. Estimates of the number of individual porpoises present in the BOWL and MORL sites are based on data from Block B (see Table 3.5).

Site	Area (km^2)	Number of porpoises	95% confidence range
BOWL Site	121	98	55-178
MORL Site	520	422	234-765

3.5.2 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 our 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 3.7) to estimate the combined abundance of all dolphin species (Table 3.8). Nevertheless, viewed in conjunction with results from the classification tree (Figure 3.15 and 3.16), 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 windfarms. This is especially so given that estimates are likely to be positively biased given our 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 km^2) and bottlenose dolphins (0.011 individuals per km^2) for area J are similar to estimates obtained in this study.

Table 3.7. Estimates of dolphin density (individuals per km^2) 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 3.8 Estimates of the number of individuals present in different regions (see 2.9) within the Moray Firth based on the estimated density in the sample blocks within each of those regions (see Table 3.7).

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

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

3.6.1. 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 3.18a) and specifically for the Beatrice Demonstrator site where there had been a time series of data using both types of device (Figure 3.18b).

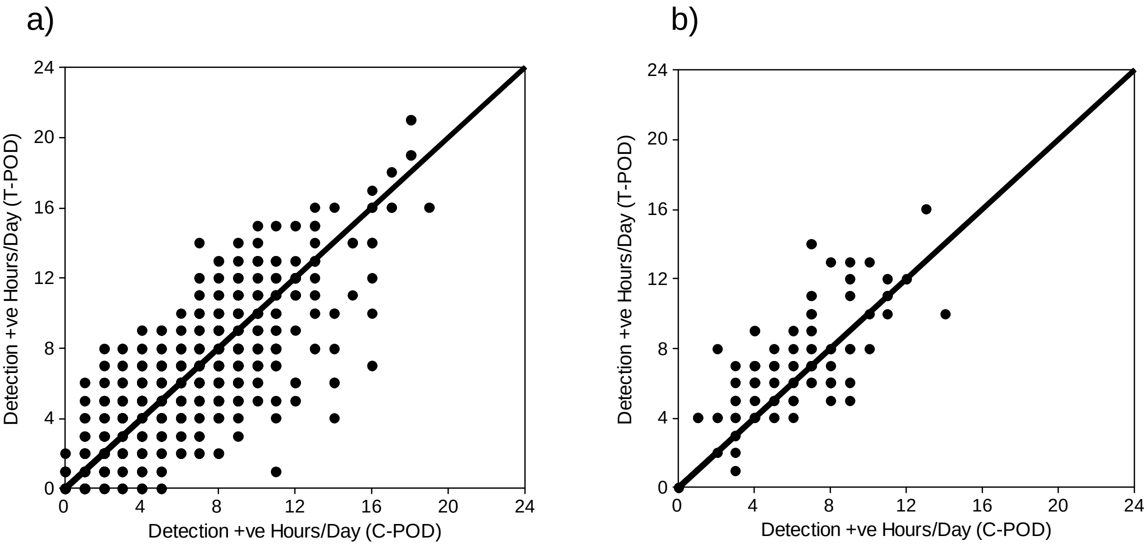


Figure 3.18. Comparison of the number of hours per day that porpoises were detected on paired T-PODs and C-PODs in 2010; a) for all nine paired devices (see Table 3.7) b) data for the Beatrice Demonstrator site. The line shown on each figure represents a 1:1 relationship.

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 3.19a). 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 3.19b).

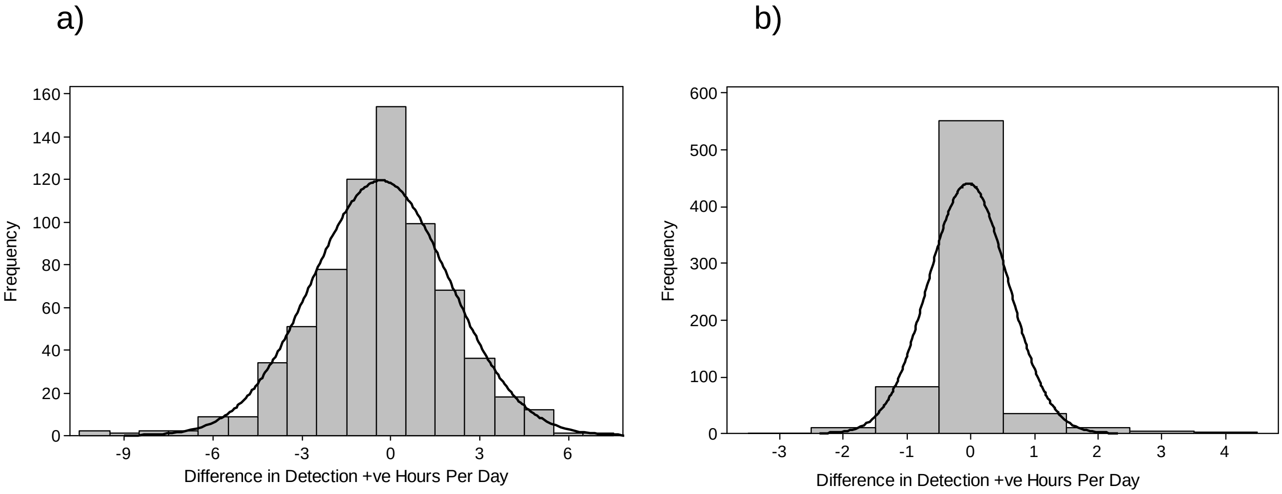


Figure 3.19. Differences in the number of hours that a) porpoises and b) dolphins were detected on the nine matched pairs of T-PODs and C-PODs (see Table 3.7 for sample sizes).

Table 3.9. 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

3.6.2. 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 3.10), but these data provide a unique opportunity to explore longer-term temporal change in the occurrence of dolphins and porpoises at an offshore site.

Table 3.10. The number of T-PODs and C-PODS 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							■		

Overall, porpoises were detected on most (> 93%) days that T-PODs or C-PODs were deployed at this site, whereas dolphins were detected only rarely (< 6% of deployment days) and this pattern was consistent across all five years in which data were collected (Figure 3.20). 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) (Fig 3.21). The median number of hours that porpoises were detected on each day was also consistent across years (Figure 3.22).

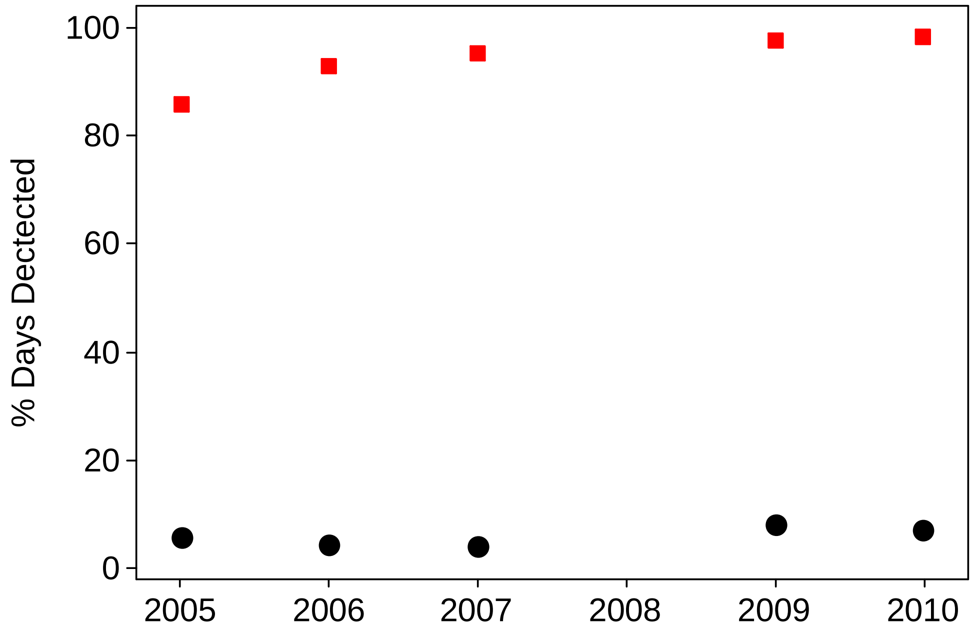


Figure 3.20. Annual values for the % of days that porpoises (squares) and dolphins (circles) were detected at the PAM site near the Beatrice Demonstrator. See Fig 2.10 for the site location and Table 3.8 for sample sizes.

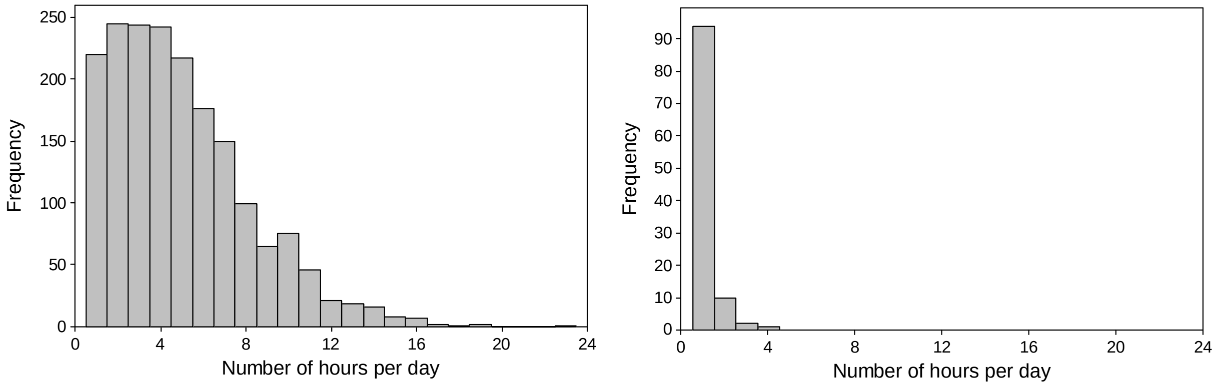


Figure 3.21 . Frequency histograms for the number of hours that a) porpoises and b) dolphins were detected on those days in which there was at least one detection. (Data are from the entire period 2005-2010).

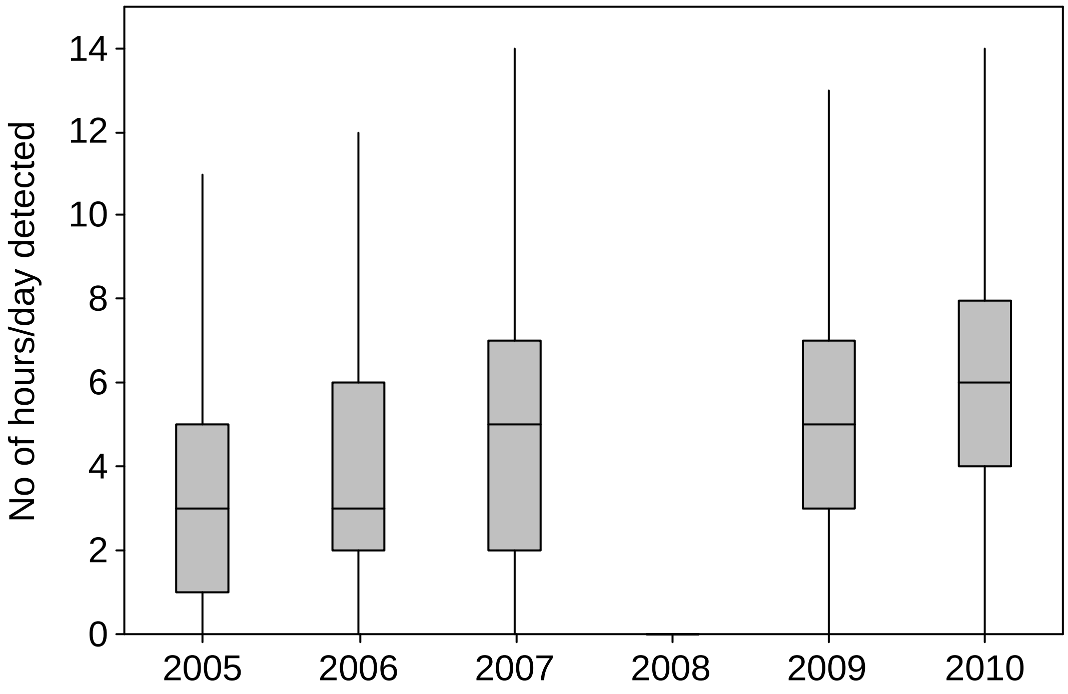


Figure 3.22. Annual estimates in the median number of hours per day (with IQ ranges) that porpoises were detected at the PAM site near the Beatrice Demonstrator.

3.6.3. 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 3.11). 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 3.23). However, the median number of hours that porpoises are detected does appear to vary seasonally, with peaks in the winter and late summer (Figure 3.24). Not only were porpoises detected almost daily, but they were typically present for many hours each day. In contrast, dolphins were generally detected form only one or two hours a day, even on those few days that they were detected (Figure 3.25).

Table 3.11. 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 but not yet recovered.

	BOWL			MORL		
	2009	2010	2011	2009	2010	2011
Jan		2	5		2	8 (6)
Feb		2	5		2	8 (6)
Mar		2	5		1	8 (6)
Apr		2			1	(14)
May		2		1	1	(14)
Jun		2		6	1	(14)
Jul	2	5		6	13	
Aug	2	5		6	13	
Sep	2	5		6	12	
Oct	2	5		6	12	
Nov	2	5		6	9	
Dec	2	5		3	8 (6)	

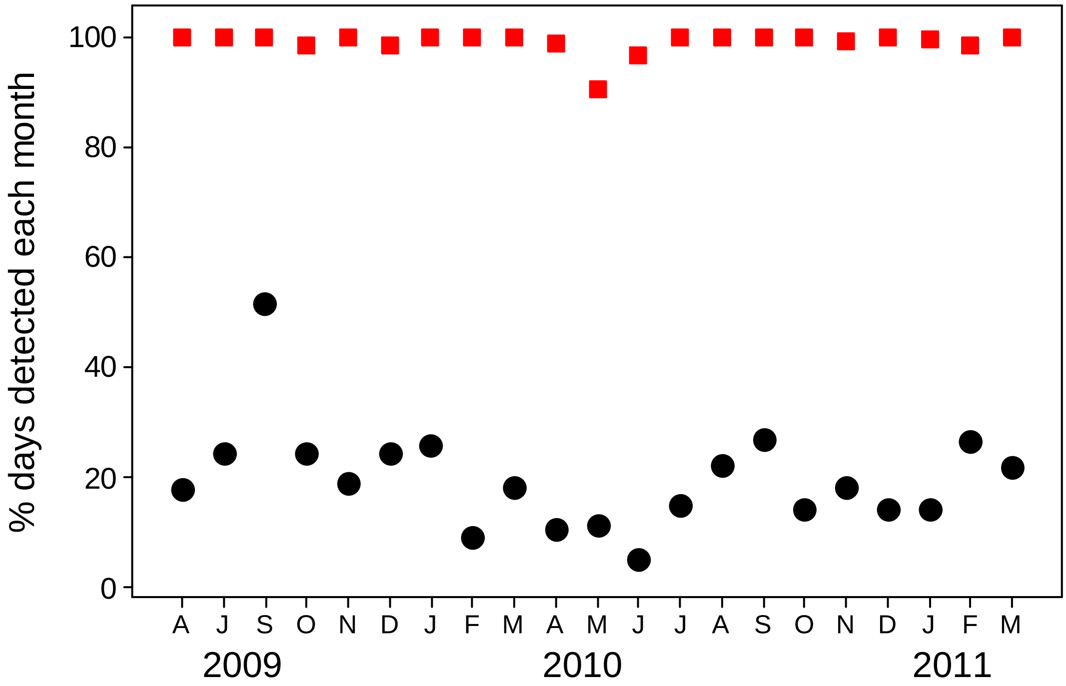


Figure 3.23. Monthly values for the % of days that porpoises (squares) and dolphins (circles) were detected at site within the BOWL development area. See Table 3.8 for sample sizes.

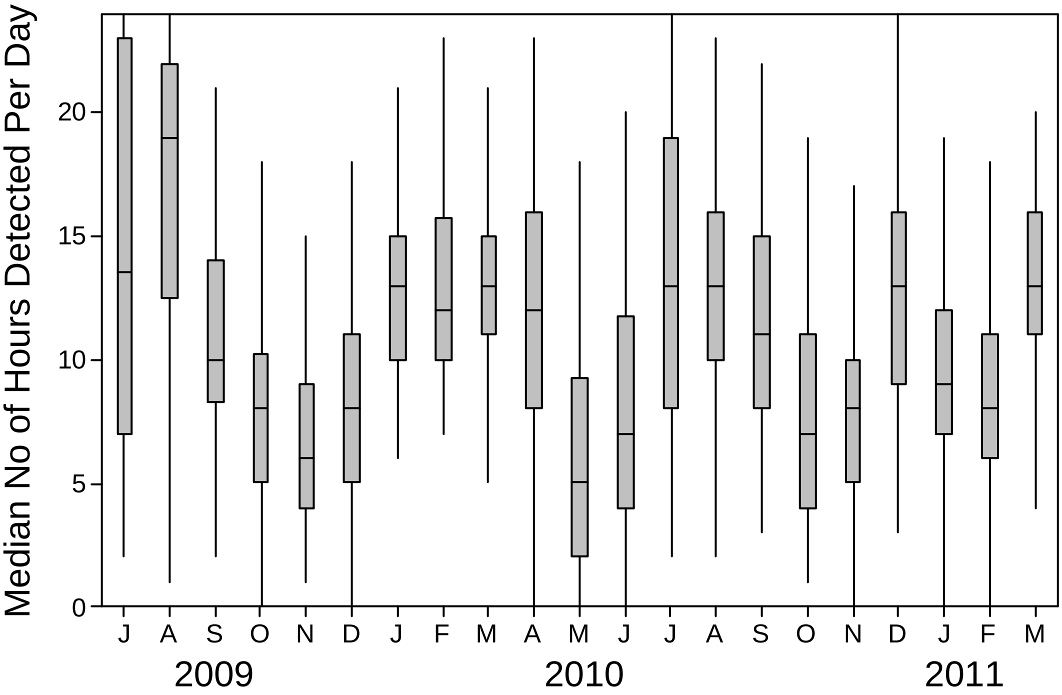


Figure 3.24. Monthly variation in the median number of hours per day that porpoises were detected on C-PODs within the BOWL development area. Sample sizes are provided in Table 3.8.

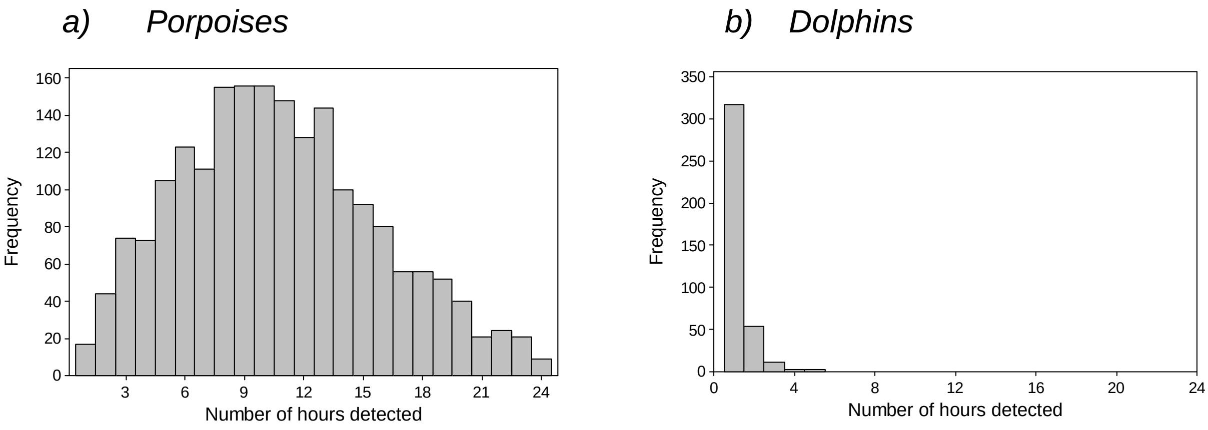


Figure 3.25. Frequency histograms showing the number of hours that a) porpoises and b) dolphins were detected on C-PODs from the BOWL site. Data are from 2009-2011, and only include those days on which any animals were detected.

3.6.4. Seasonal variability in C-POD detections within the MORL site.

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 3.11). 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 3.26). 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 (Figure 3.27 & 3.28). In contrast dolphins were typically only detected for one or two hours on those days that they were recorded on the site (Figure 3.28).

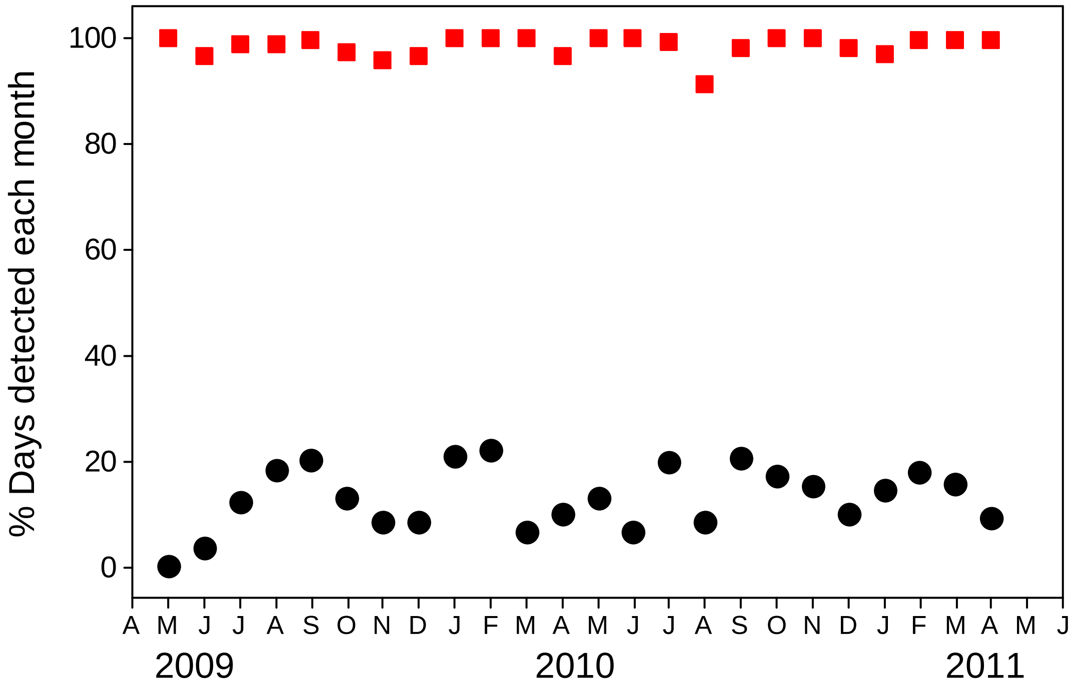


Figure 3.26. Monthly values for the % of days that porpoises (squares) and dolphins (circles) were detected at site within the MORL development area. See Table 3.9 for sample sizes. Data from 8 sites for Dec 2010 to March 2011 are included, and additional devices will be collecting data until June 2011.

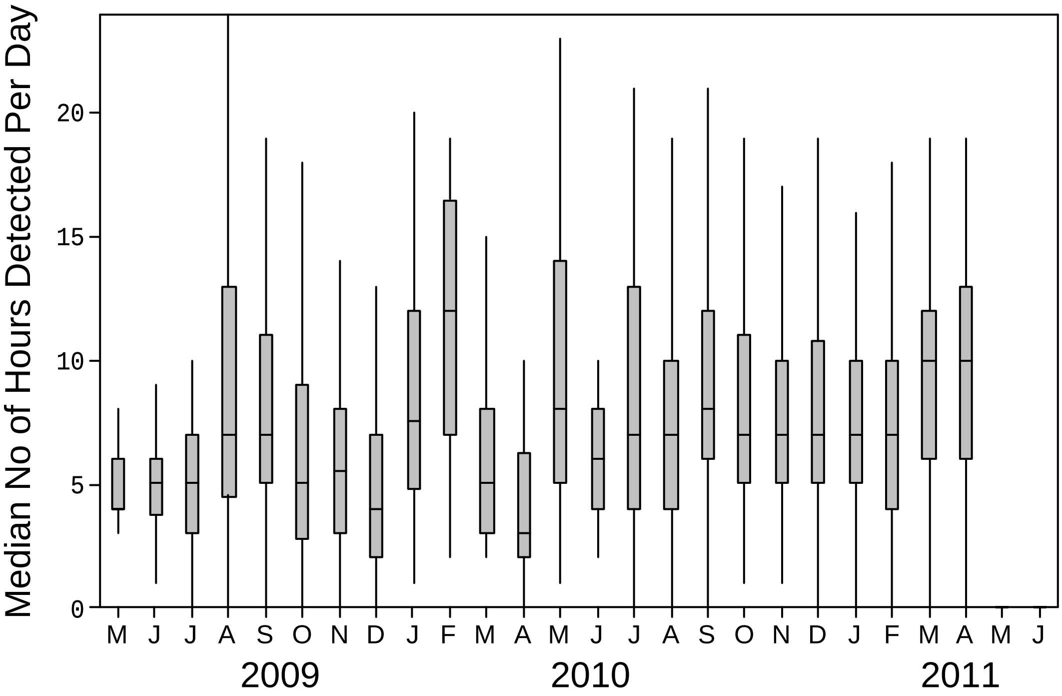


Figure 3.27. Monthly variation in the median number of hours per day that porpoises were detected on C-PODs within the MORL development area. Sample sizes are provided in Table 3.8. Additional data for the period Dec 2010 to June 2011are currently being collected.

a) Porpoises *b) Dolphins*

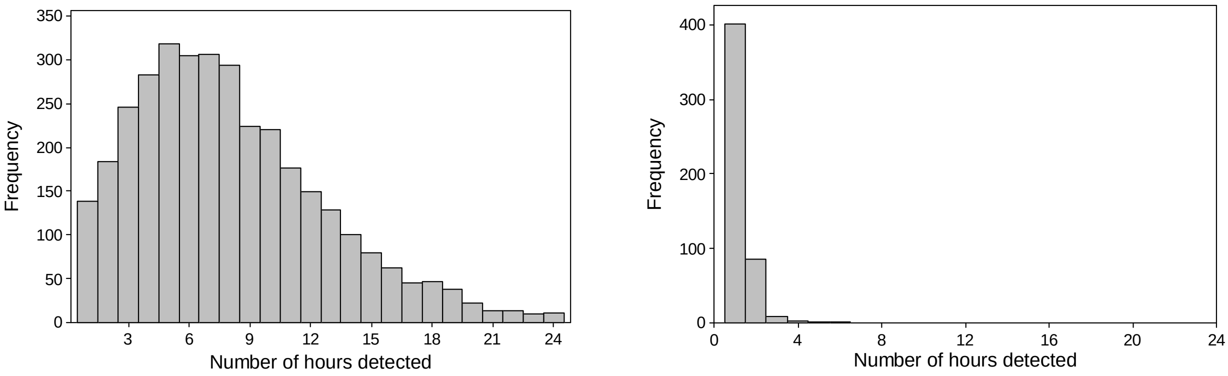


Figure 3.28. Frequency histograms showing the number of hours that a) porpoises and b) dolphins were detected on C-PODs from the MORL site. Data are from 2009-2011, and only include those days on which any animals were detected.

4. 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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ANNEX I

TECHNICAL REPORT ON HARBOUR SEAL TELEMETRY AND HABITAT MODEL

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Report to MORL & BOWL

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 windfarm sites is in the Loch Fleet National Nature Reserve (NNR), and the next nearest is in the Dornoch Firth (Figure 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 August moult were also carried out to explore how observed variations in natural environmental conditions 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). The pattern of population change is markedly different to that seen in areas affected by mass mortalities from the 1988 and 2002 phocine distemper virus outbreaks (Harkonen et al. 2006), and the factors driving harbour seal declines in Scottish waters remain 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 limit 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 assess the 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 pinnipeds such as grey seals that stay ashore during the breeding season.

A key requirement for the MORL and BOWL EIA's is an assessment of the connectivity between the proposed windfarm sites and protected species in locals SACs. In the case of harbour seals, this requires information both on the origin of those seals that may be encountered on the windfarm 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 Moray Firth harbour seals are therefore well characterised, and it was not considered necessary at this stage 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, we describe how we use a Bayesian State Space Modelling (SSM) approach to integrate tracking data from multiple tag types and standardize position estimates while accounting for location error. We then use the standardized tracking data set 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, we present the latest information on abundance trends in the Dornoch Firth and Loch Fleet.

2. Methodology

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 1) and tagged between 1989 and 2009 (Table 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 their hair on the head or neck. Capture and handling techniques are described in Thompson et al. (1992).

Table 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**

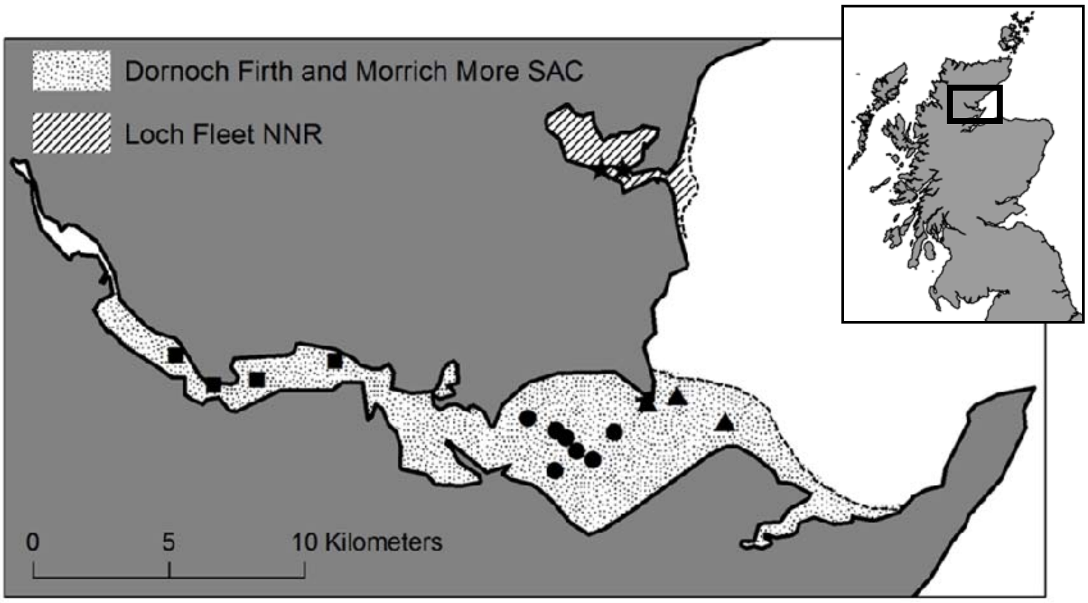

Figure 1. *A map showing the location of harbour seal haul-out sites in the Dornoch Firth and Loch Fleet (taken from Cordes et al. 2011).*

2.1.1 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 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).

2.1.2 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 (Scotland) between 2004 and 2007 (Table 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).

2.1.2 GPS GSM telemetry

GPS GSM tags combine a GPS (Global Positioning System) sensor with a mobile phone GSM (Global System for Mobile Communications) 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 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 are also 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).

2.1.3 State Space Modelling

The state-space modelling 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, 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 we therefore only retained those daily positions that had a corresponding VHF location to ensure that there were no spurious SSM locations.

2.2 Habitat association modelling

The 95% credible limits for each SSM position were used to estimate the uncertainty in all positions (Figures 2 and 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 haulout 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. 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 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 haulout, 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 3, 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 0 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).

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 haulout in units of 5 km. Since we were using grid cells of 4 km, 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. Since this can vary between seasons and sexes, this was repeated using only data from the summer breeding period (April to July). The model was performed using the contributed R package geepack version 1.0-17 (Yan & Fine 2004).

2.3 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 4km 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 be occurring in each cell at any one moment in time. Currently we do not formally incorporate uncertainty into this estimate. Instead, the estimate is conservative in two ways. First, we used the average population estimate of 1653 from 1993 (from Thompson et al. (1997), when the population was at a peak compared with current numbers (see results). Second, we assumed that all seals might be foraging at sea at the same time. However, a sub-set of the population are hauled out on every low tide through 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. Results

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 2), indicating consistency in habitat use between tagging methods and over the 20 year period. The majority of locations occurred near the haulout 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), 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.

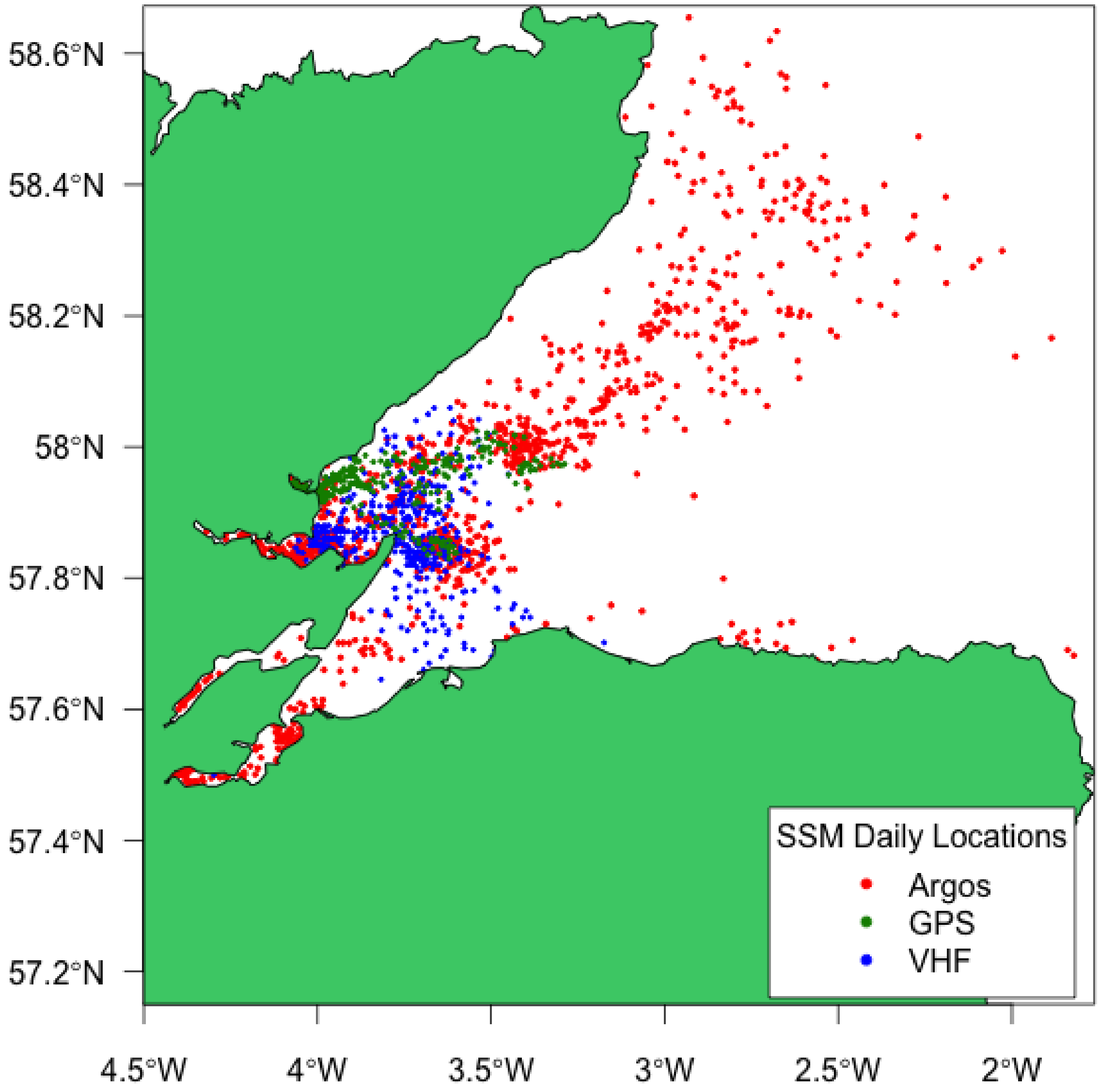

***Figure 2:** a) Daily seal SSM locations derived from Argos satellite (red), GPS GSM (green), and VHF (blue) positions (circles).*

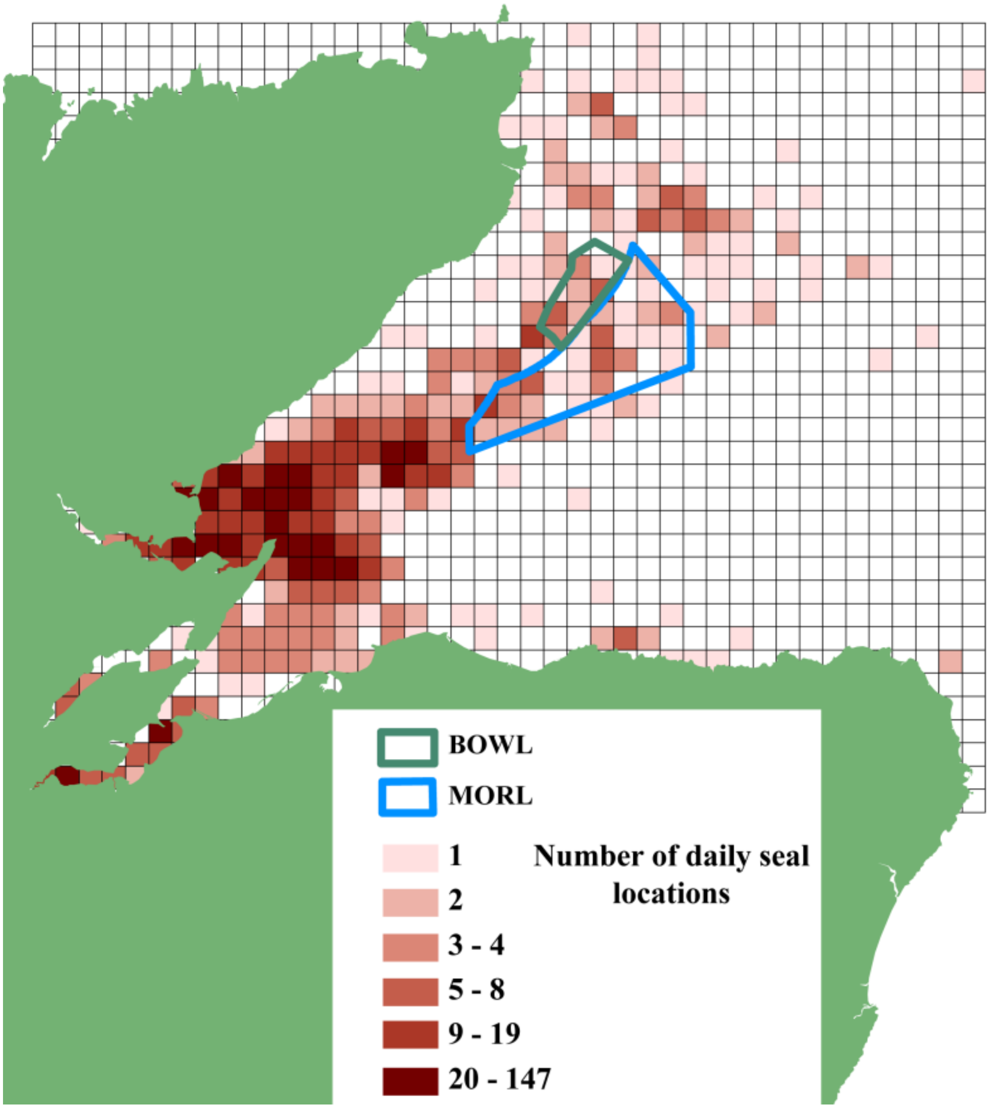

__Figure 3:__ Number of daily SSM harbour seal locations within 4 x 4 km grid cells (colour coding based on the quantile distribution) with the proposed BOWL and MORL wind farm sites overlaid.

3.2 Presence-absence GAM

The results of the presence-absence GAM showed that depth, slope and distance to nearest haulout were significantly related to the probability of harbour seal presence, but sediment type was not (Table 2). The probability of seal occurrence was highest at intermediate depths (approximately 15-50 m) and decreased with increasing seabed slope (Figure 4). The probability of seal presence was highest within 30 km of the nearest haulout 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 northeastern part of the Moray Firth, including the MORL and BOWL sites (Figure 5).

Table 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 haulout and seabed sediment type (reference level: sand, marine sediment).

Smoother term:	*edf*	*Chi-square*	*P value*	*Overall deviance explained*
Depth	*4.30*	*61.06*	*< 0.001**	*35.2%*
Slope	*1.51*	*24.83*	*< 0.001**	
Distance to nearest haulout	*6.47*	*16.48*	*0.021**	
Parametric coefficients:	*Estimate*	*Z value*	*P value*	
Intercept	*-1.64*	*-6.24*	*< 0.001**	
Sediment – Sand, marine, gravelly	*0.55*	*1.96*	*0.051*	
Rock or gravel	*-0.50*	*-1.41*	*0.160*	
Sand, marine, muddy or mud, marine, sandy	*0.16*	*0.39*	*0.693*	

edf, estimated degrees of freedom

* denotes statistical significance at 5% level

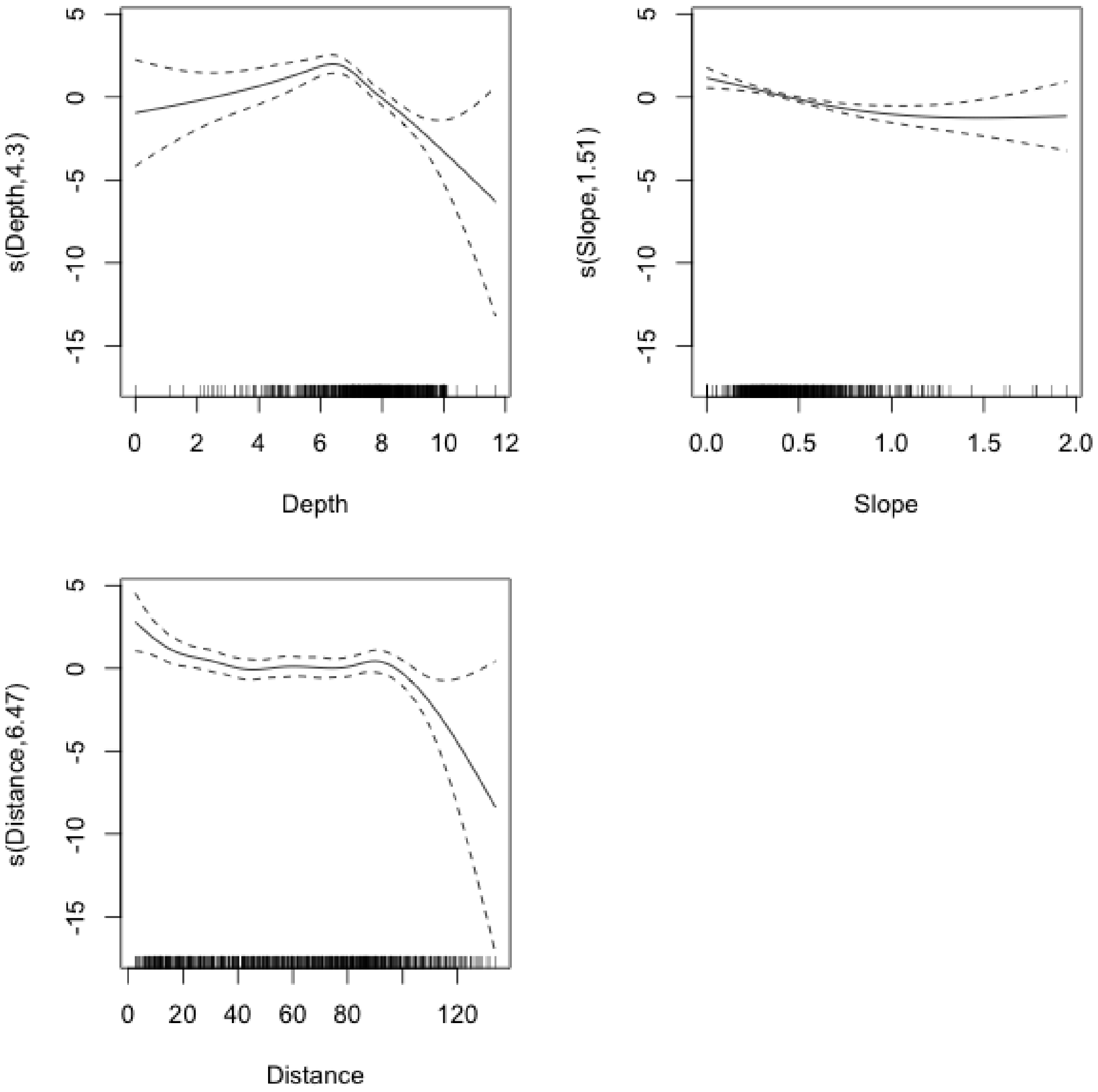

Figure 4: GAM smoothing curves for square root of water depth (m), square root of seabed slope (degrees), and distance to nearest haulout (km) in relation to probability of seal presence.

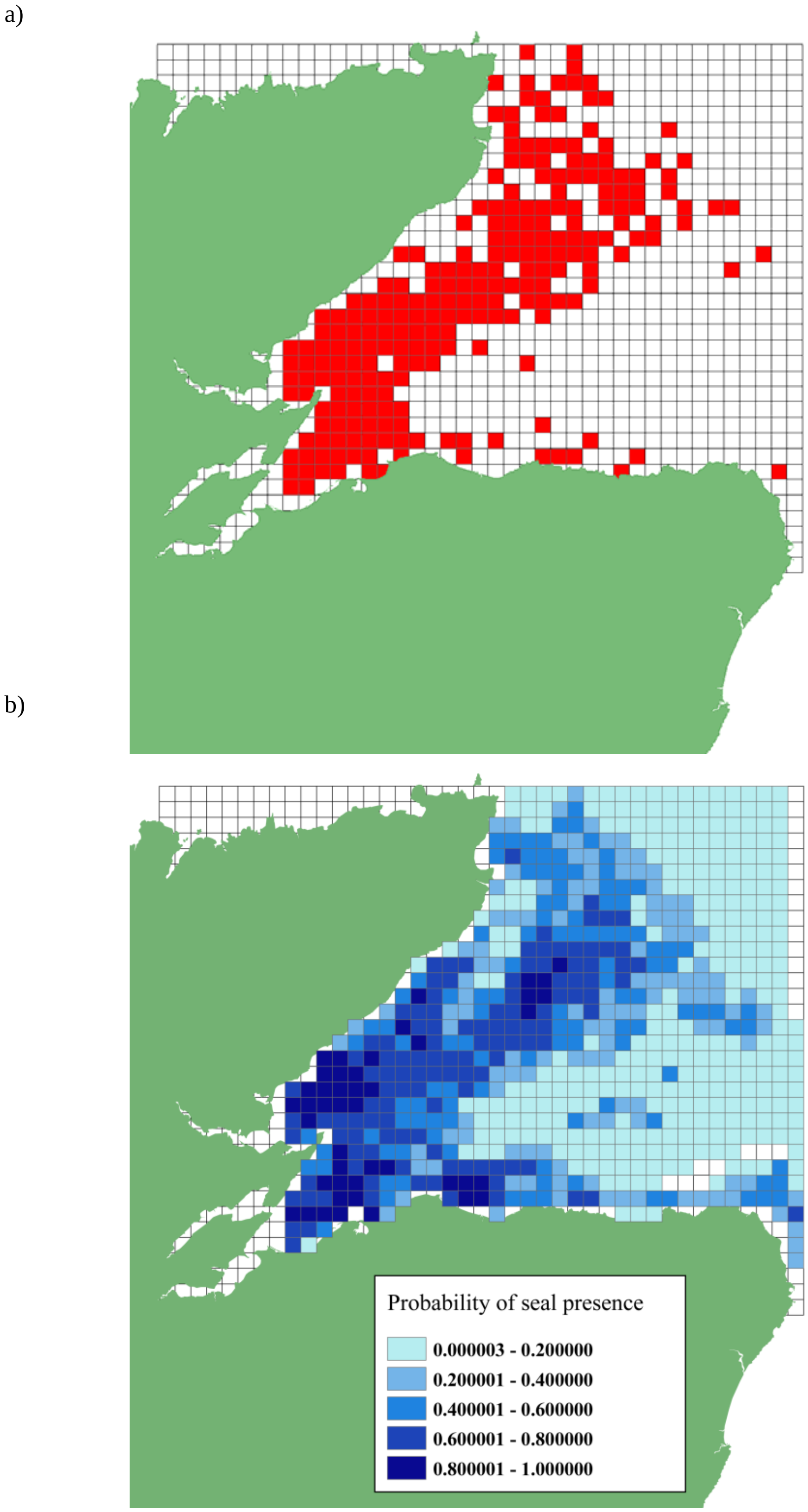

Figure 5: a) Seal presence from SSM daily positions in 4 x 4 km grid cells shown in red, b) GAM predicted probabilities of seal presence (white cells indicate no data), The BOWL (green) and MORL (blue) sites are overlaid.

3.3 Summer presence/absence GAM

Depth and slope were significantly related to the probability of harbour seal presence, but distance to nearest haulout and sediment type were not (Table 3). The probability of seal occurrence was highest at intermediate depths (approximately 15-50 m) and decreased with increasing seabed slope (Figure 6). The probability of seal presence was highest within 30 km of the nearest haulout 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 7).

Table 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 haulout 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 haulout	*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

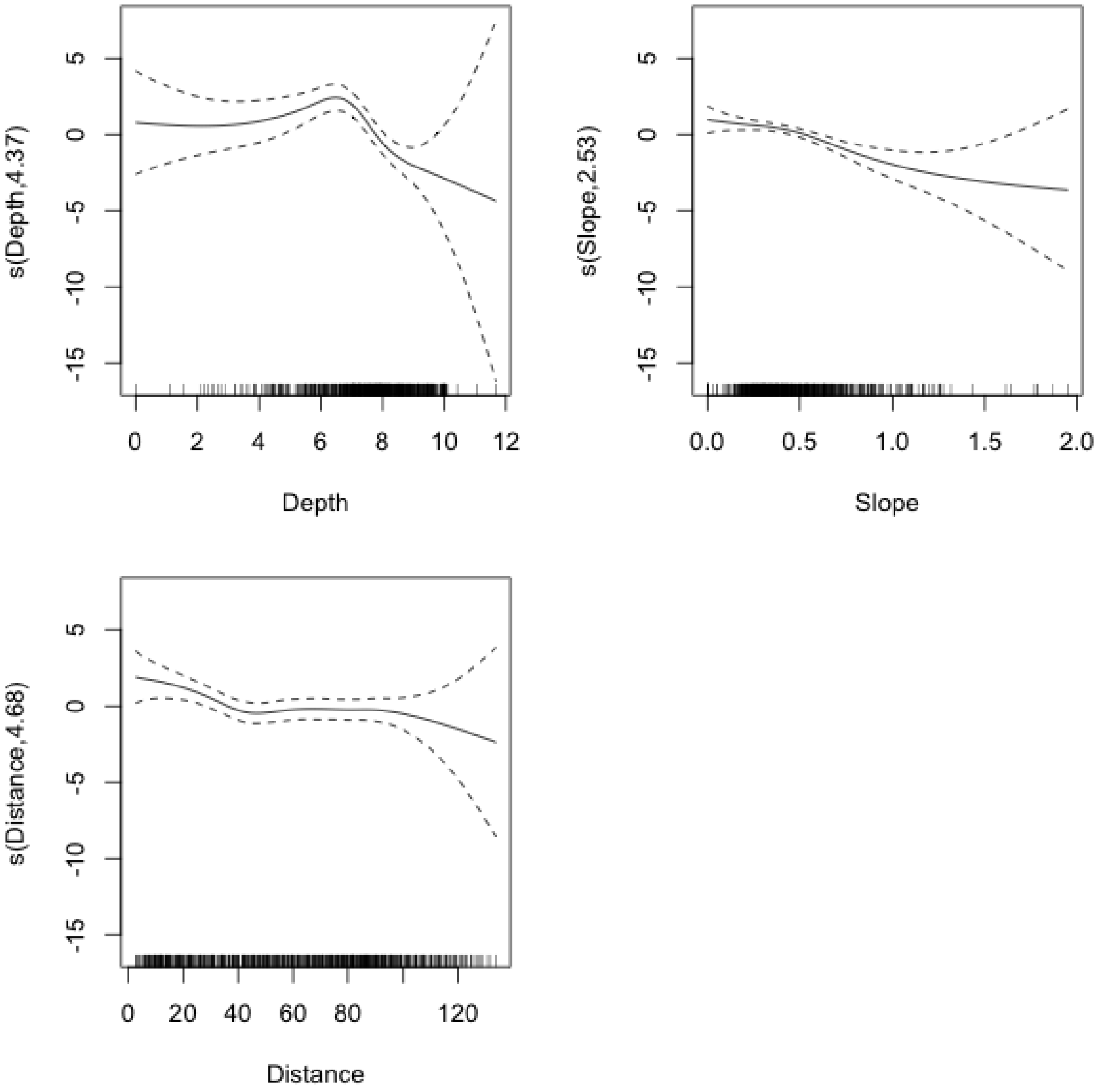

Figure 6: *GAM smoothing curves for square root of water depth (m), square root of seabed slope (degrees), and distance to nearest haulout (km) in relation to probability of seal presence during the summer breeding period (April to July).*

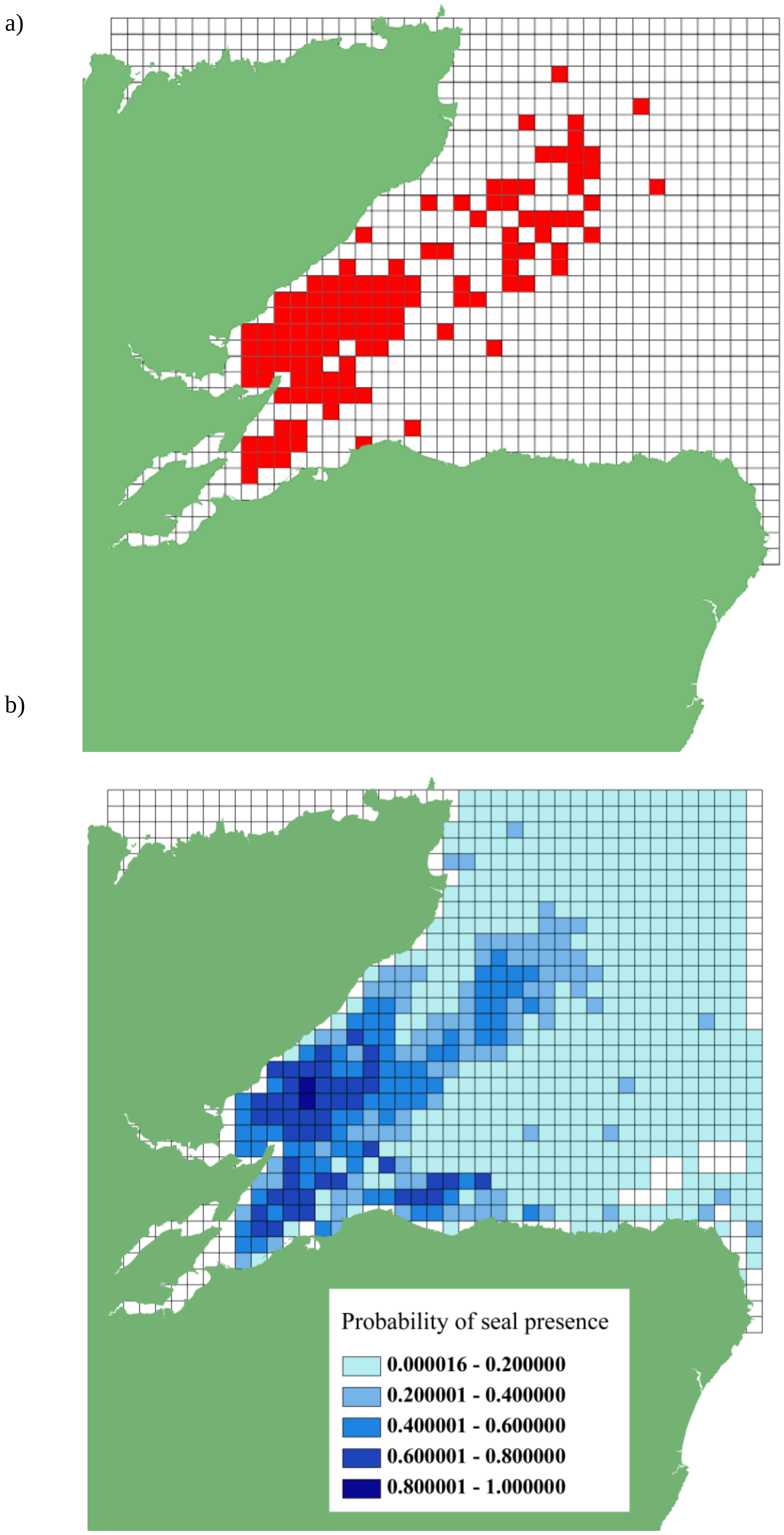

Figure 7: a) Seal presence from SSM daily positions during summer (April to July) in 4 x 4 km grid cells shown in red, b) GAM predicted probabilities of seal presence (white cells indicate no data).

3.4. 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 haulout (Table 4). 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 haulouts (compared to the distribution of control points). Foraging habitat preference was highest in the northeastern part of the Moray Firth and also in small areas of the southeastern part (Figure 8).

Table 4: 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 haulout 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 haulout	*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*

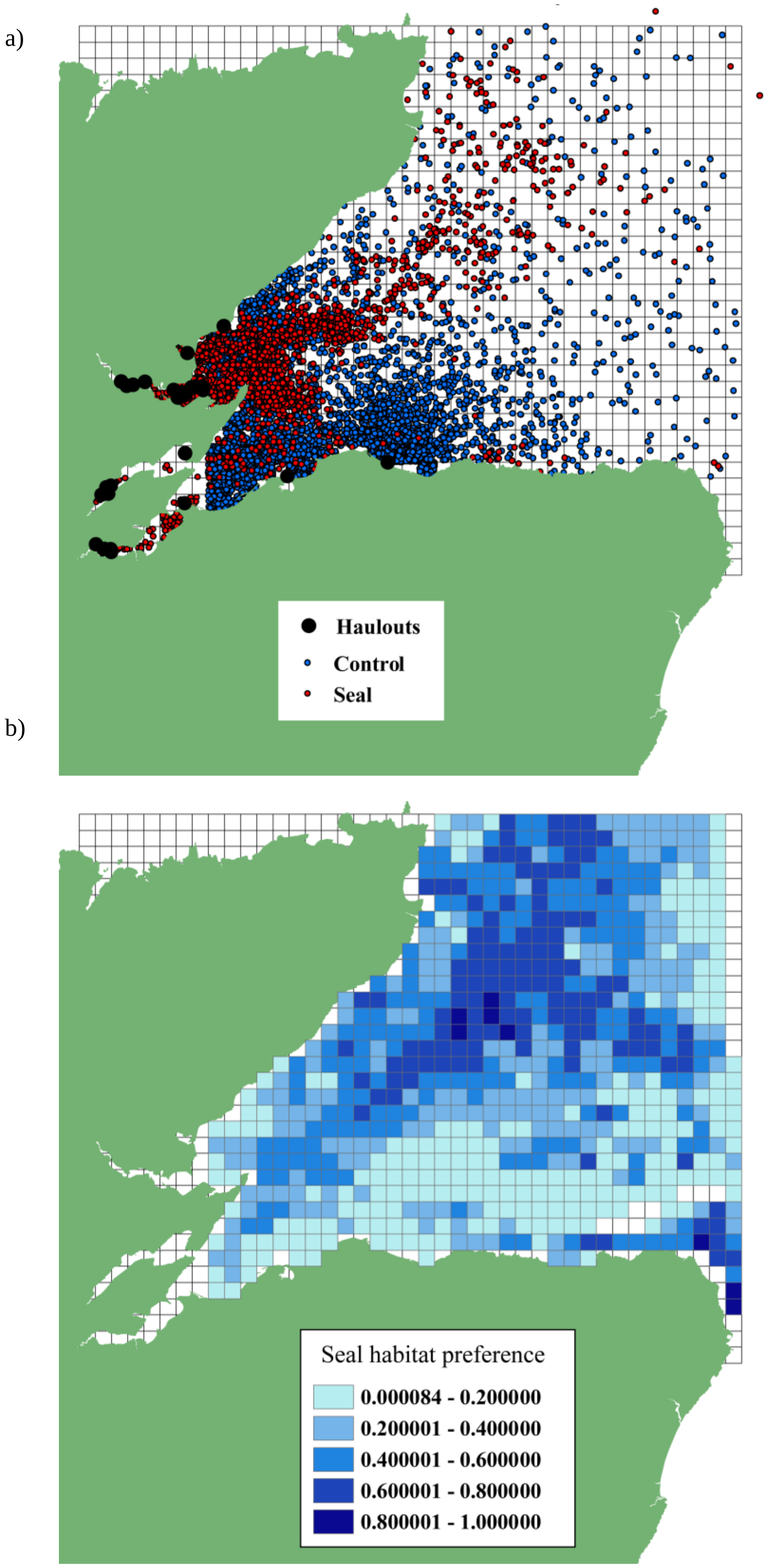

Figure 8: a) Map of seal SSM daily positions and control points, b) GEE predicted values of seal habitat preference (white cells indicate no data). The BOWL (green) and MORL (blue) sites are overlaid.

3.5 Summer 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 haulout (Table 5). 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 haulouts (compared to the distribution of control points), although not as great (Figure 9).

Table 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 haulout 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 haulout	*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

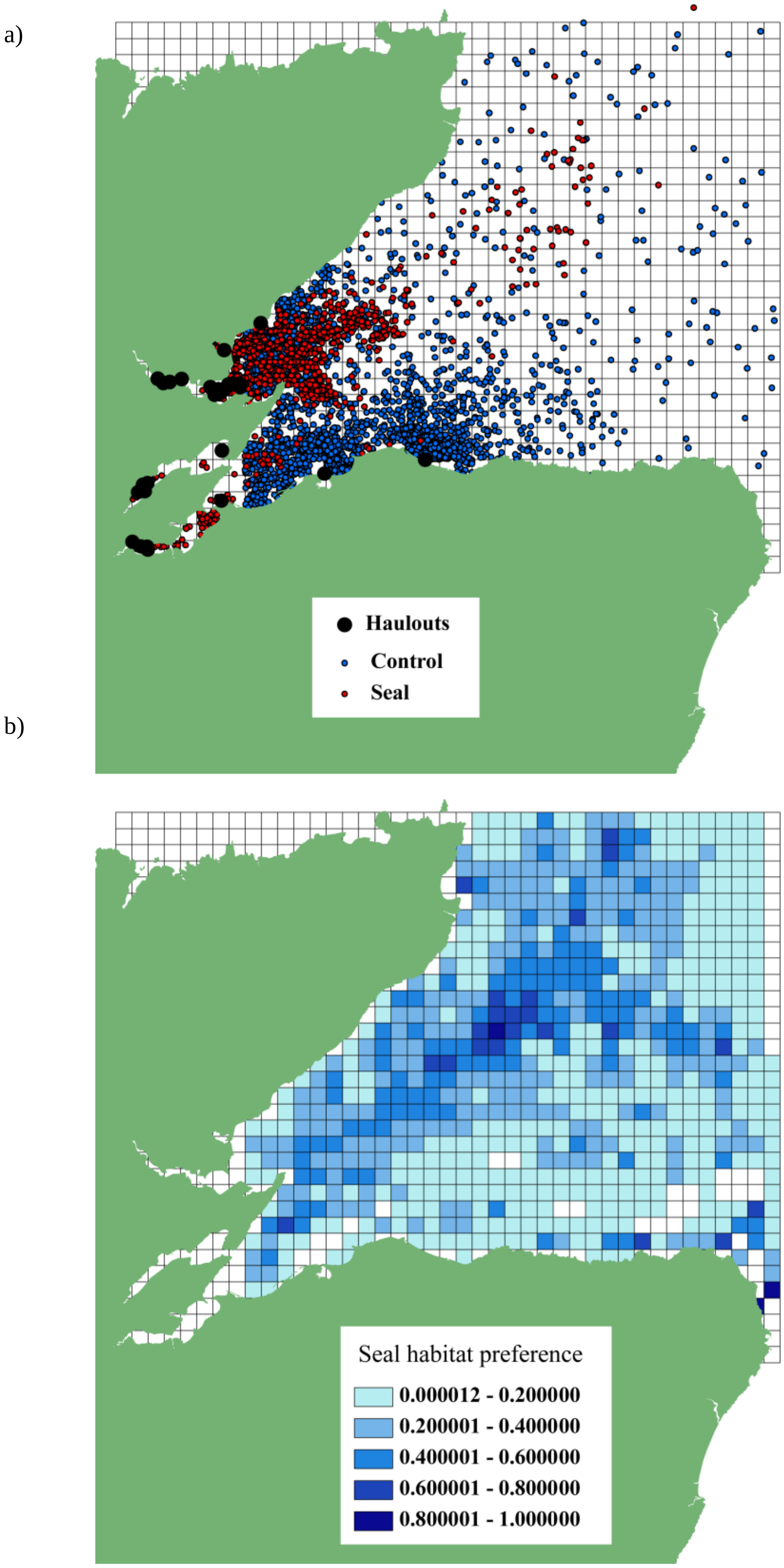

Figure 9: a) Map of seal SSM summer (April to July) daily positions and control points, b) GEE predicted values of seal habitat preference (white cells indicate no data).

3.6 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. 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; Cordes et al. 2011; Cordes Unpublished Data)

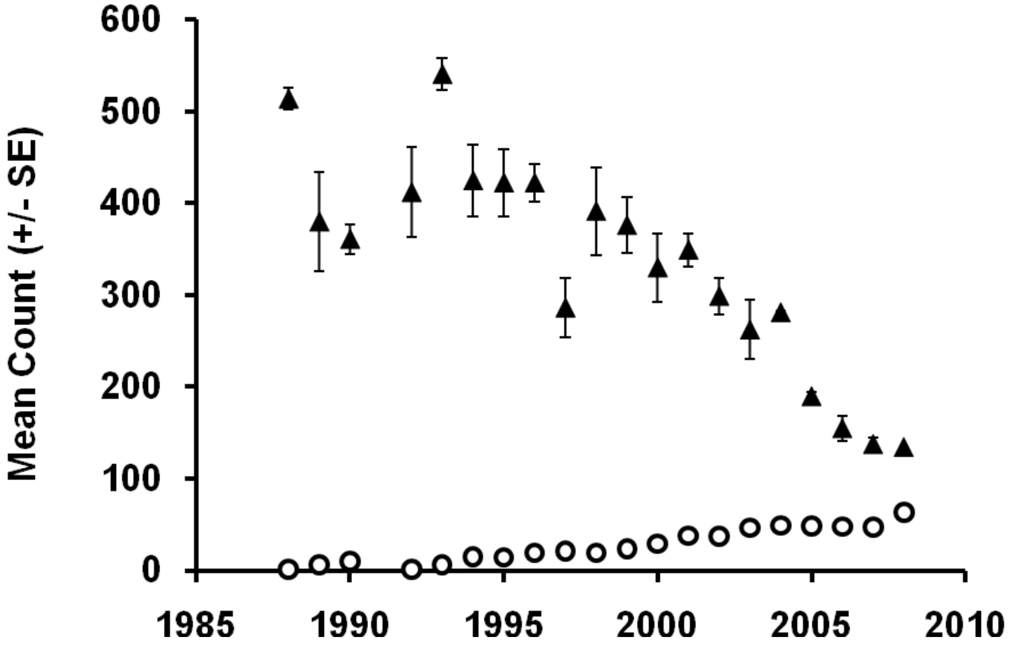

Figure 10. Trends in the mean pupping season count of harbour seals (not including pups) at haul-out sites within the Dornoch Firth (closed triangles) and Loch Fleet (open circles). (Taken from Cordes et al. 2011 – to be updated))

3.7 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 11). These data suggest that there is variability in the importance of different parts of the BOWL and MORL sites, but that some grid squares in this region might be expected to hold up to 8 seals, representing a density approaching 0.5 individuals per km^2.

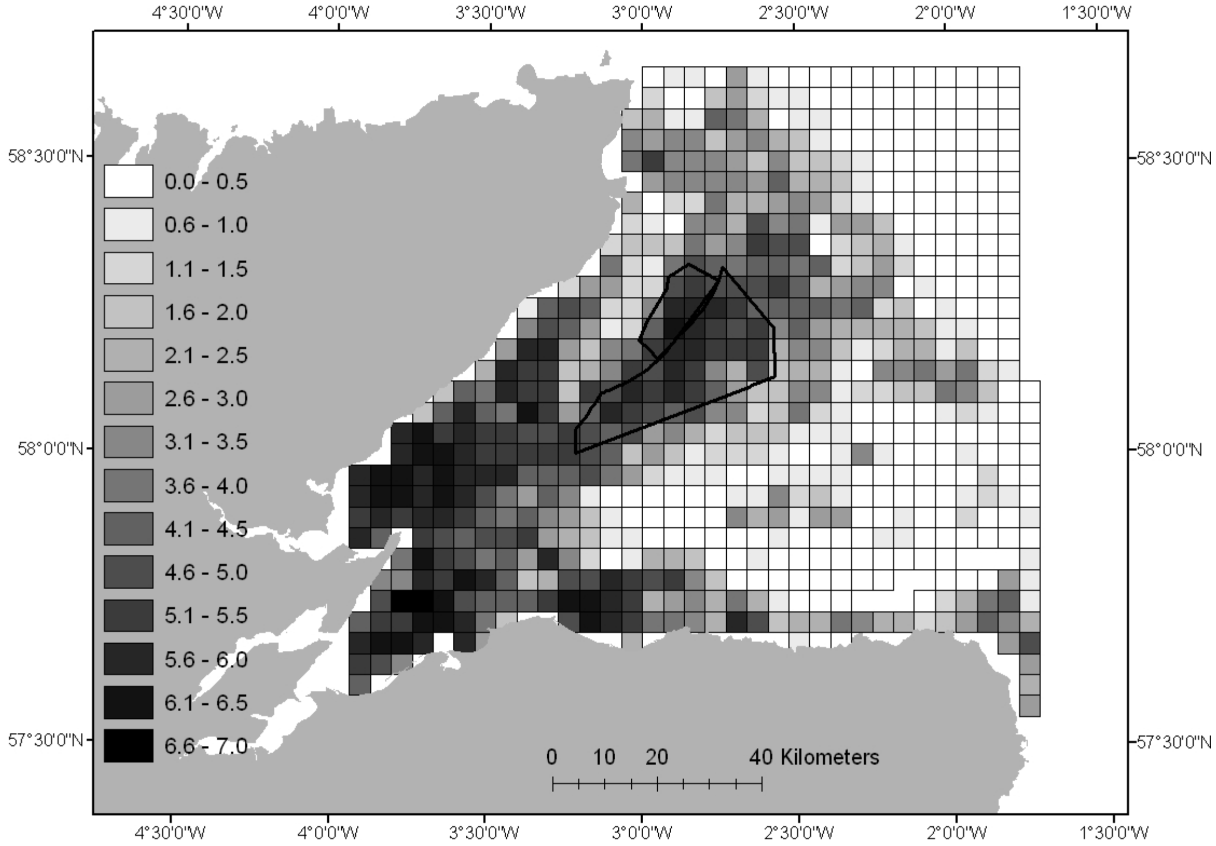

Figure 11. Predicted numbers of harbour seals from Moray Firth haul-out sites in different 4 x 4 km grid cells across the Moray Firth.

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