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CONTRACT TO IDENTIFY WHETHER PERSISTENT AREAS OF HARBOUR PORPOISE AND BOTTLENOSE DOLPHIN ARE SUPPORTED BY AVAILABLE EVIDENCE

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EXECUTIVE SUMMARY

Dedicated shore watches for cetaceans have been conducted at a number of sites around the UK since 1965. Here, we analyse c. 120,000 effort records (amounting to >75,000 hours of watches) and c. 50,000 associated sightings of bottlenose dolphin and harbour porpoise from 678 sites around the coasts of Britain, in order to determine whether persistent areas of the two species are supported by available evidence.

All effort and sightings records were accumulated separately in Excel files. Effort records included location, date, time and weather information as well as recording observation and recording protocols. Sightings records indicated species, number of individuals, and behaviour, as well as date and time. A third file contained site characteristics for all observation sites (name, location, site elevation, and codes for field of view, observation and recording protocol, etc). For each site, fields were added for the ICES rectangle and appropriate management units (MU) for harbour porpoise and bottlenose dolphin.

The three main files were uploaded into an Access database and linked for additional exploration and screening, with further error checking applied. Summary analyses were completed in Access, queries created to extract data for each management unit of the two species, and the resulting data exported to Excel for analysis in R.

Analyses were carried out by MU and by species, using a simple GAM, and including all variables that vary. Most variables were fitted as smoothers, constraining curves to avoid overfitting. The variables - optics, effort type and area, were treated as categorical. To allow full expression of site differences, we fitted a 2-dimensional smoother, s(latitude, longitude), unconstrained, which allows the main effects of latitude and longitude and their interaction to

be captured. It is not feasible to include other interactions due to the large number of variables in the model and patchiness of the data in space and time. Model validation was based on checking residual plots and influential data points. Poisson models were checked for overdispersion; if this was significant (but not too extreme), quasi-Poisson was used. Full models with main effects were fitted for every MU.

Predictions were generated for each site, based on standardised observation and weather conditions and a fixed time and date, based on average values for that MU in order to achieve the best scaling. Additional predictions were run for one site for all years (since no interaction between temporal and spatial trends could be tested, all sites within a model showed similar predicted trends over time), and all months of one year.

Unadjusted sighting rates and count rates for the two species were first plotted by ICES rectangle (which enabled results from adjacent sites to be combined), and then by site, for different levels of effort. Count rates for each year were calculated, and detailed persistence tables constructed from 1965 to the present, for each site within a species management unit.

Those sites at which there were at least three years of effort, with a minimum of 100 minutes per year (i.e. 5 hours minimum of watch effort overall) were selected for plotting the GAM predictions. GAMs were run on the whole data set for each management unit separately.

The results indicate that land watch effort is reasonably well distributed around the UK, but certain areas (notably the west of Scotland, and to a lesser extent, Southeast England) had relatively poor coverage, and a few areas (e.g. Shetland) have had little effort in the last decade. Although dedicated effort started as long ago as 1965, the majority of effort has been in the last ten years. Similarly, effort has been concentrated on the summer months between May and September. For the most part, protocols used for land watches have been very comparable, despite large numbers of observers and local groups being involved over several decades. Around 100 sites had effort exceeding 50 hours.

The coastal distributions of the two species accord with our current knowledge: bottlenose dolphins are concentrated around west Wales and eastern Scotland, with very few along North Sea coasts south of Edinburgh and the coast of southern England east of Poole; harbour porpoises, on the other hand, are much more evenly distributed but nevertheless occur in a few areas at relatively high numbers. Strikingly, the distributions of the two species more or less displace one another, possibly due to the fact that bottlenose dolphins are known to attack porpoises where the two co-occur.

As to be expected, the Generalised Additive Models function best for management units where there are a lot of data. Thus the results from West Scotland, for example, are not very meaningful, whereas predictions are more robust in the Irish Sea, western Channel, east coast of Scotland, and eastern England.

The GAM predictions indicate that coastal bottlenose dolphins are concentrated in two main regions: 1) eastern Scotland from Brora to Carnoustie, with a relatively even distribution; and 2) the Welsh coast in

Cardigan Bay and to a lesser extent off north & east Anglesey. Elsewhere, the species occurs only occasionally, except possibly for the following locations: Falmouth Bay and around the Lizard Peninsula in Cornwall, and in Bideford Bay in North Devon. The species is also known to range around the Inner Hebrides in small numbers, with a small resident population off Barra; and the northern Irish Sea including the Isle of Man, the Cumbrian coast, and coasts of Counties Down and Antrim.

Harbour porpoises are more widely distributed, with relative hotspots (mostly associated with high tidal energy) in the following coastal areas:

North Sea MU: 1) southern and eastern Shetland; 2) the northern shores of the outer Moray Firth and around the Dornoch Firth), and to a lesser extent 3) along the northeast Grampian coast, and 4) along the coast of eastern England between Scarborough and Flamborough Head, in Yorkshire. Areas worth investigating further include the coast of north Caithness and around Scapa Flow, Orkney, and around the Wash and parts of East Anglia (Norfolk and Suffolk).

Celtic and Irish Sea MU: 1) the Lizard Peninsula, south Cornwall; 2) the south side of the outer Bristol Channel between Bideford, north Devon and Minehead, Somerset; 3) Swansea Bay and the Gower Peninsula; 4) west and north Pembrokeshire coast and islands; 5) northwest and north coasts of Anglesey; and 6) the coasts of Co. Down and south Antrim, Northern Ireland.

A final set of analyses used (a) the whole data set and (b) all data from 1994 onwards. For both data sets, models including a latitude x longitude smoother (as for the individual MUs) give similar results, highlighting the occurrence of bottlenose dolphins in two main areas: the east coast of Scotland and west Wales, with a smaller peak around the Southwest Peninsula of England (particularly since 1994), whereas harbour porpoise occurred all around the coast but with peaks identified notably in north Scotland and in eastern England along the north Yorkshire coast, and smaller peaks in southwest England, west and north Wales.

Re-running the 1994 onwards model with site number substituted for latitude and longitude (thus assuming the coast can be represented as a one-dimensional spatial access) produced a less nuanced picture, with some of the spatial structure in occurrence patterns flattened out. However, this approach facilitated inclusion of a site x year interaction.

Visualisation of predictions for 1994 and 2013 from this latter model indicates that while “preferred” areas were broadly similar in both years for both species, a model with a site x year interaction revealed a broadly consistent bottlenose dolphin spatial distribution pattern over the years, with consistent peak areas, although the size of the peak in local occurrence in southern Cardigan Bay, west Wales, is seen to have varied substantially. For harbour porpoise, on the other hand, there has been a decline in the importance of the east coast of Scotland (especially pronounced in the north) and an increase in importance on the east and south coasts of England.

1 BACKGROUND TO THE PROJECT

Under Article 4 of the EU Habitats Directive there is a requirement, where certain conditions are met, to protect bottlenose dolphins and harbour porpoises through the designation of Special Areas of Conservation (SACs) as part of the Natura 2000 network. The sites are graded A (15% to 100% of national population) to D (non-significant presence). The UK has a number of sites graded D for both species (26 for harbour porpoises and 7 for bottlenose dolphins). Three sites are graded C or above for bottlenose dolphins (Moray Firth [Scotland], Cardigan Bay [Wales] and the Llyn Peninsula and the Sarnau [Wales]), and one site graded C for harbour porpoise (Skerries & Causeway [Northern Ireland]).

The key criterion as set out in Annex III of the Habitats Directive – 'Criteria for selecting sites eligible for identification as Sites of Community Importance and designation as Special Areas of Conservation' - is: *(a) Size and density of the population of the species present on the site in relation to the populations present within national territory*. The explanatory notes to the Natura 2000 standard data form suggest the following progressive model to classify the size of the population in the site relative to the population in the national territory: A: >15% to 100% of national population B: >2% to 15% of national population C: >0% to 2% of national population. A fourth category (D) is used in all cases where a population of the species concerned is present on a site in a non-significant manner. No suggestion is made on how to classify the site in relation to density though, despite this being listed as one of the key criteria for identifying sites. Considering abundance without density means that sites could be designed with harbour porpoises as a qualifying species based entirely on the area covered by the site. For example, assuming that >0% means > or = to 0.1% of the national population, it then follows, with a North Sea porpoise population of *ca* 250,000 individuals (from SCANS II, 2008), that a site large enough to contain 0.1% (*ca* 250 individuals) will meet the size component of this criterion. Therefore sites in the North Sea larger than 450 km^2 could potentially be considered for inclusion of harbour porpoise as a qualifying feature if the density aspect is not taken into account (Pinn, 2008; Mendes et al, 2009).

The size and density criterion has been recognised as difficult to apply to the harbour porpoise in particular. To address this problem, the European Commission produced guidance in 2007. This included the results of a workshop held in December 2000. The workshop concluded that "*it is possible to identify areas representing crucial factors for the life cycle of this species. These areas would be identifiable on the basis of: i. the continuous or regular presence of the species (although subject to seasonal variations); ii. good population density (in relation to neighbouring areas); iii. high ratio of young to adults during certain periods of the year; iv. additionally, other biological elements are characteristic of these areas, such as very developed social and sexual life*." These guidelines represent the views of the Commission, but they are not legally binding and are secondary to the provisions of the Directive. Additionally, the Commission's guidance provides very little information on the practical application of these additional criteria, and as such, this has resulted

in the guidance being interpreted and applied differently by each Member State.

The UK will continue to search for SACs for harbour porpoises, and this contract is to complement additional analysis already being undertaken for the wider UK marine environment through the focus on data collected from shore based stations.

2 TERMS OF REFERENCE

This project comprises two parts. Part 1 assesses the availability of effort related shore-based sightings data and feasibility of collating this if there are multiple organisations involved. Part 2 focuses on the analysis of the data in order to determine whether there are clearly identifiable and persistent areas of relatively high harbour porpoise and bottlenose dolphin density in the coastal waters of the UK.

The term 'clearly identifiable' has been taken to mean that the area can be delineated from the surrounding (neighbouring) waters by, for example, an elevated abundance on a regular basis and over a reasonable period of time. The Interagency Marine Mammal Working Group (MMWG) has agreed that three years of data were the minimum requirement to demonstrate regularity of occurrence over a reasonable period of time (the three years should ideally not be concurrent). However, where monthly sightings data are available over the entire period of the year, this can be reduced to two years, preferably separated in time. Given the mobile nature of these species, particularly harbour porpoise, a reasonably high degree of confidence in the results is also required. The work requires:

1. Part 1: Identification and mapping of the location of shore-based sightings sites will be required. This includes a summary of the basic sightings methodology used at particular locations, the frequency of surveys and the length of time they have been running. There will also be the need to gain agreement from data holders for inclusion of their data for part 2.

2. Part 2: Assessment of the compatibility of different datasets, taking methodology and other relevant factors (e.g. sea state, realised area of search) into account. Land-based data generally fall into two methodological types: conventional timed watches and scan samples depending on the density of animals in an area and the issue of repeat sightings. Where animals occur in low densities, then timed watches are the most appropriate. As density increases, it becomes difficult to keep track of animals already recorded and, consequently, a scan sampling method that distinguishes repeat sightings, becomes more appropriate.

The work should also take into account the following considerations:

1. Locations where there has been insufficient temporal effort should also be identified and mapped. Any persistent areas of high density identified through the modelling that correspond to areas with insufficient temporal data will not be considered at this time. Such results should, however, be reported as they will be used to provide an indication of where surveys could potentially be focused in the future.

2. The analyses should be undertaken using the proposed management unit regions for harbour porpoise and bottlenose dolphin respectively. These have recently been agreed by the SNCBs and will be provided by the project officer. If the contractor feels further subdivision is required, this will need to be discussed and agreed with the SNCBs.

3. The sightings data will need to be standardised taking effort into account and a suitable statistic proposed (e.g. sightings per hour search). These proposed analyses should apply the most robust analytical tools to the available data resource, enabling the identification of persistent high-density areas in a proactive way. The analyses should also allow the importance and context of any predefined area to be assessed in a post hoc way if possible.

3 DATA SOURCES

3.1 Shore watches for cetaceans in the UK

During the 1970s, sea watching for cetaceans started from a number of land-based sites (Evans, 1976, 1980), as a by-product of the burgeoning interest at the time for observing and recording passage movements of seabirds (see, for example, Philips & Lea, 1966; Pettitt, 1972; Upton, 1976). At first, sightings reports were recorded on a casual basis but especially from the 1980s onwards, dedicated effort-related watches started in a number of locations, mainly headlands and at some bird observatories. Those that were sustained over a period of years allowed seasonal and longer-term trends to be obtained, for those specific locations (Evans *et al*., 1986; Evans, 1992).

Typically, a watch would involve a single observer situated on a cliff-top at an elevation of 15-50 metres. The observer would record the start and end time of the watch, and, in between, scan the sea largely with the naked eye but interspersed with binocular or telescope scans. Sea conditions and visibility would be noted at the start, and subsequently should they change. Whereas sea watching for birds tended to be conducted in rough sea conditions because that was when passage was often greatest, cetacean watches would generally only be started in conditions of sea state (SS) 3 or less (and where possible SS 0-1). They would also be typically conducted in good visibility (10km or more). Watch duration would vary but was usually one to two hours. Any cetacean seen would be recorded, identified to species (where possible), and group size and behaviour noted. If noticeably smaller individuals were observed, these would be recorded as calves or juveniles. However, generally, these have not been distinguished and so are not analysed further here. In a minority of cases, distances and angles to sightings have been recorded (but with unknown accuracy), and a few studies have used

theodolites to track movements of animals. However, since these form only a very small portion of the project database, those measurements have not been used here.

Data collected by observers from the Sea Watch Foundation (and its predecessor the UK Mammal Society Cetacean Group) since the late 1970s (Evans, 1976, 1980, 1992; Evans *et al*., 2003*)* and from the Irish Whale & Dolphin Group almost all since the early 2000s (Berrow, 2008; Berrow *et al*., 2010; Whooley & Berrow, 2012), have followed very similar protocols. These included data from the Manx Whale & Dolphin Watch (Isle of Man), Marine Awareness North Wales (mainly Anglesey), and Gower Marine Mammal Project (Gower Peninsula). A few other data sets have been collected with specific projects in mind. Ceredigion County Council have coordinated watches along the coast of southern Cardigan Bay since 1994, with observers targeting bottlenose dolphins as part of a study to monitor possible impacts of recreational boat activity (Pierpoint *et al*, 2009). Cardigan Bay Marine Wildlife Centre provided data from watches undertaken from New Quay but these were not used as they duplicated effort already processed in the SWF database.

Russell Wynn (National Oceanography Centre, Southampton University) has organised systematic watches targeting porpoises (and shearwaters) from Gwennap Head, Cornwall since July 2007 (mainly between July and October), some of the later data being collected using a theodolite to plot tracks. Data for bottlenose dolphins were not available for the earlier years (2007-10). During 2012 and 2013, watches were also conducted in St Ives Bay, Cornwall.

Whale & Dolphin Conservation (WDC) collected data for specific projects (at Bardsey Island, Melvaig near Gairloch, NW Scotland, and Tiumpan Head, Isle of Lewis) at periods between 2008 and 2012, as well as effort-related data from various sites in Scotland using volunteers, mainly since 2010 (WDC Shore Watch project). Also in Scotland, the Hebridean Whale & Dolphin Trust undertook systematic watches at Ardnamurchan Point (Highland Region) from June to September 2001-05.

The renewable energy company, EMEC, has contracted local shore-based observers in Orkney to conduct watches for marine mammals and birds at Fall of Warness since July 2005 (Duck *et al*., 2006; Lonergan *et al*., 2007), Billia Croo since March 2009 (Robbins, 2012), Scapa Flow (St Mary's) and Shapinsay Sound (Head of Holland and Head of Work) since January 2011. However, the emphasis has been on birds, and raw systematic effort data were only available for Billia Croo, although EMEC state that effort data for the other sites may be available towards the end of 2014. Two other energy companies have contracted local observers to collect data on marine mammal occurrence: MEYGEN along the north Caithness coast, and TEL across Ramsey Sound, Pembs since 2007. Unfortunately those data were not made available to us. Finally, watch data collected by SeaTrust South & West Wales at Strumble Head, Pembs, were also not made available for this project. Otherwise, we are not aware of any other major data sets missing.

3.2 Types of land-based data

Land-based data fall into two methodological types: conventional timed watches and scan samples. In the former case, start and end times of watches are recorded, together with environmental variables such as sea state. When a sighting is made, then as a minimum the time of first sighting is recorded, with species and group size. Repeat sightings of the same animals may be recorded, but if so, the status of such sightings as repeats is noted so that these can be excluded from analyses, if appropriate. This approach is adequate in low animal density situations, but it may become difficult to keep track of animals already recorded where densities are higher. Consequently, at a number of sites, a scan sampling method has been adopted for land-based watches in order to cope with situations in which there may be a flux of animals entering and leaving the observer's field of view.

In land-based watches using a scan sampling method, the field of view is scanned generally with optics for a fixed period of time, e.g. 10 or 20 minutes, and the number of animals of each species present during that period is recorded, together with environmental data such as sea state. This is then repeated in successive (usually contiguous) periods until the end of the watch. The EMEC renewables project at Billia Croo, Orkney employed a specific variant of scan sampling. Since they were surveying for both marine mammals and birds, they divided the area into sectors and using optics, routinely scanned different sectors for 5-minute periods, alternating sectors for searches of either birds or mammals.

Some sites involved scan sampling as well as in most cases recording individual sightings. These included SWF (in Shetland), WDC (in NW Wales and some sites in Scotland); MANW (in Anglesey); CCC (in southern Cardigan Bay, W Wales); Gower Marine Mammal Project (on the Gower Peninsula, S Wales); RWE nPower (at Rhyl Flats, NE Wales); Marijke de Boer (three Cornish sites); and Southampton University's NOC Cornish Project (Gwennap Head and St Ives Bay). In the last case, they usually involved 10-min scans (two sets of 4 min. with binoculars, 1 min. with naked eye; no more than one scan per hour). At a number of sites in Scotland, WDC undertook short (10-min) watches on a regular basis. At the other end of the scale, Spurn Bird Observatory personnel recorded animals over time periods up to 900 minutes. Otherwise, all other sites involved logging individual sightings from conventional timed watches.

4 DATA TREATMENT

Validation procedures were imposed on all SWF and IWDG data by the respective organisations before they were processed. It was assumed the same was undertaken for external data sets by the respective data collection bodies. Before incorporating data into the Project database, these were further checked for duplicates and other coding errors (incorrect observer codes, incorrect coordinates, unrealistic start or end times and durations, incomplete information, etc).

4.1 Data Collation and Fields

From the cleaned data, a number of fields were selected and extracted, supplemented by information on observation height and search area if not already recorded, derived from the internet (using Streetmap.com, Ordnance Survey, or Google Earth).

These were divided into three main categories:

General site information

- Recording Group
- Location (Site name, county, geographical area)
- Coordinates (Latitude & Longitude)
- Observation Height (in metres)
- Observation Area (i.e. area of search: 1 = uninterrupted 180^{o}+ view limited only by visibility; 2 = uninterrupted 90-180^{o} view limited in front only by visibility; 3 = 180^{o}+ view limited in front by land within 1 km (measured from maps); 4 = 90-180^{o} view limited by land 1-2 km distance on all sides)
- Optics: - 1 = mainly naked eye but supplemented by binoculars/telescope; 2 = use of binoculars/telescope for continuous scanning
- Observation method: 1 = regular scans; 2 = slow timed scans (duration variable between recording groups); 3 = slow scans but targeting particular sections of the sea (alternating with sections targeted for bird counts – used only in renewables studies that also involved birds – Alex Robbins in Blue Mull Sound, Shetland, and EMEC at Billia Croo, Orkney)
- Recording method: 1 = record of individual sightings (with group size count); 2 = counts of animals per watch period (typically 10- or 15-min duration)

Effort information

- Date of watch
- Start time (GMT)
- End time (GMT)
- No of observers
- Sea state

Sightings information

- Species
- Group size
- Best estimate of no. of adults
- Best estimate of no. of calves
- Time of sighting
- Sea state

Those form the Project Database. For all external data sets, the recording group or individual was asked to sign a Data Provider Agreement, which was then passed to JNCC.

4.3 Data Processing

All effort records (approx. 120,000) and sightings records (approx. 50,000) data were accumulated separately in Excel files. Effort records include location, date, time and weather information as well as recording whether observation was continuous, based on scans or undefined methodology (casual watches). Sightings records indicated species, number of individuals, information of calves, juveniles and behaviour, as well as date and time. A third file contained site characteristics for all c. 700 observation sites (name, location, site elevation also and codes for field of view, observation protocol, etc). For each site, fields were added for the ICES rectangle and management units for harbour porpoise (HP) and bottlenose dolphin (BND).

Data were checked for missing values, non-numeric values (e.g. “1-2” for Sea State) and inappropriate missing values codes (e.g. -1) and numbers formatted as text. Fully numerical copies of relevant fields were created (e.g. month, year, start time, duration, latitude, longitude, sea state). New site codes were created for locations not already assigned a code.

Site IDs were compared to latitude and longitude values to check correct allocation of site codes and a new numerical site code was created.

Effort data were filtered to exclude casual observations, zero durations (start time=end time), records from vessels, and records from the Republic of Ireland. Sightings data were filtered to exclude repeat sightings, and sightings records labelled as “casual”, as well as to exclude all species except HP and BND.

The three main files were uploaded into an Access database for additional exploration and screening. The three main tables were linked, with the effort table as the centre of the links (linked to sightings by effort code and to sites by site code). Duplicate effort records were detected and corrected where possible; associated sightings records were then also corrected. For the effort file, agreement between latitude, longitude, site name and site ID code was checked and some reassignments made. The sites file was checked for discrepancies in latitude and longitude by plotting all values. For the above reasons, about 5% of data was excluded. With more time, errors in those data could be found and corrected.

For HP and BND, secondary sightings files were created, grouping sightings records by effort code and containing information on the number of sightings records, number of groups and number of animals per effort code. Any sightings not corresponding to an effort code retained in the effort file were excluded from further analysis.

Summary analyses were completed in Access, queries created to extract data for each management unit (HP and BND), and the resulting data exported to Excel. Missing values were detected and replaced by “NA” and missing sightings totals (i.e. where there were no sightings) replaced by zeros. Files were then saved as tab delimited text, suitable for analysis in R.

4.4 Variable selection

Set up: each data point = 1 effort record (1 observation)

Possible response variables

- Groups seen – these data generally fit binomial (0,1) or Poisson distributions; although some some of the latter are overdispersed it is possible to use quasi-Poisson, therefore this is the first choice.
- Animals seen – most distributions are very overdispersed, too much so to be suitable for Poisson (or quasi-Poisson); 2-stage modelling would be possible (i.e., binomial followed by zero truncated Poisson). Zero inflated models would also be possible.
- Groups SPUE (GPUE) or Animals SPUE (APUE) – although the distributions look a bit like Poisson, these are not integer data; two stage or zero inflated models would be the only option.

Explanatory variables:

- Site characteristics: elevation, area of view
- Weather: sea state (visibility and wind have too many missing values and in any case wind is strongly collinear with sea state)
- Observation: optics, effort type (continuous or scan), duration
- Location: site latitude, longitude
- Time: start hour of observation, month, year

4.5 Analysis strategy

Analyses were carried out by MU and by species.

We used a simple GAM, including all variables that vary (e.g. excluding effort type and optics if they were constant). Most variables were fitted as smoothers, constraining curves using k=4 to avoid overfitting. The variables optics, effort type and area are categorical.

To allow full expression of site differences, we fitted a 2-dimensional smoother, s(latitude, longitude), unconstrained, which allows the main effects of latitude and longitude and their interaction to be captured. It is not feasible to include other interactions due to the large number of variables in the model and patchiness of the data in space and time.

Model validation was based on checking residual plots and influential data points (hat values). Poisson models were checked for overdispersion; if this was significant (but not too extreme), quasi-Poisson was used.

No forwards or backwards selection was used, for the pragmatic reason that it is harder to standardise the approach if selection is used, and this stance is

also justified by strong philosophical objections to forwards and backwards selection that are increasingly prevalent in the ecological literature. Therefore, full models with main effects were fitted for every MU.

Predictions were generated for each site based on standardised observation and weather conditions and a fixed time and date, based on average values for that MU in order to achieve the best scaling. Additional predictions were run for one site for all years (since no interaction between temporal and spatial trends could be tested, all sites within a model showed similar predicted trends over time), and all months of one year.

5 RESULTS

5.1 Site Summaries

Appendix 1 summarises basic information from the 678 sites at which some dedicated systematic watching for cetaceans have been conducted, and for which data were available to the project. The geographical locations of these are plotted as four maps in Appendix 2, each showing sites for which there are different levels of effort: Fig. A1 - sites with up to 3h of effort; A2 – sites with between 3 and 10h of effort; A3 – sites with between 10 and 50h of effort; and A4 – sites with more than 50h of effort. Some sites had watches conducted from more than one location within close proximity (<2 km). These were generally satellite locations near a site with much more effort but they have been kept separate for the GAM analyses which took account of any differences in site elevation, field of view, observing or recording protocol. Figure 1 overleaf shows the overall distribution of sites by ICES rectangle. This caters for sites in close proximity to one another, and gives the best representation of geographic coverage. Note that the symbols are located in the centre of each rectangle so some may appear a little offshore or inland. However, all effort is land-based (coastal) with observations of waters within 1-3km of the coast.

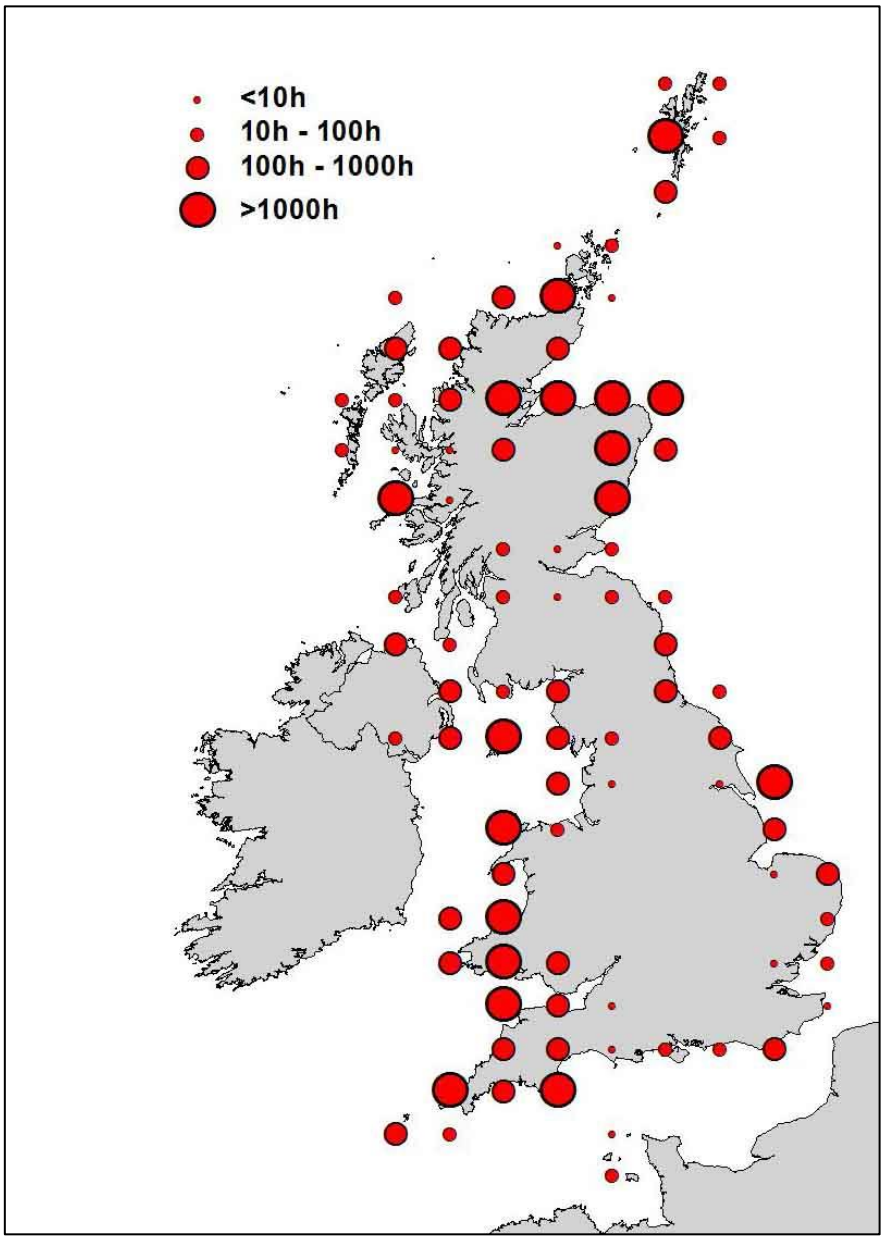

Figure 1. Map of land watch effort by ICES rectangle

The two tables that form Appendix 1 summarise the following information for each site: in Table A1, site name, region, location (coordinates), site elevation, observation area (field of view), use of optics, observation method, recording method, and to which management unit that site was assigned for bottlenose dolphin and harbour porpoise; and in Table A2, site name, region, total amount of effort, number of years in which watches were conducted, span of years and, again, the management unit to which that site was assigned, for bottlenose dolphin and harbour porpoise. Each site was numbered in ascendant order from the Northern Isles south down the east coast of Britain and then in a clockwise manner around southern and western Britain, ending up with the Channel Islands and Northern Ireland. Thus, sites in the same area have numbers close to each other. If a site was within 1-2 km, it was given the same number before a decimal point, e.g. 1.1, 1.2, 1.3.

As can be seen from Figure 1, effort has been greatest around northeast Scotland, Southwest England and West Wales, and has been least in West Scotland (including the Hebrides), the Firth of Forth, over most of Eastern England, and particularly between Suffolk and Dorset.

5.2 Exploratory Analyses

As part of the exploratory analysis of the full dataset, the distribution of effort records (totalling c, 120,000) was examined in relation to sea state, time of day, season and year.

Figure 2 shows that the great majority of effort records were in sea states 1 or 2 with very few in sea states above 3. Any effects of sea state upon sighting rates were examined during the GAM analysis for each species management unit.

Watches were conducted at anytime during the day, but with most effort between 09:00h and 15:00h (Figure 3).

There was a strong seasonal bias in effort, with the great majority of watches conducted in summer between May and September (Figure 4).

The first dedicated effort-related watching from land sites took place in 1965. Effort remained low and confined to a few sites throughout the 1970s and 1980s, increasing to a small peak in the 1990s (though still restricted to a few locations) but with the great majority of effort from 2000 onwards (Figure 5). However, some areas (e.g. Shetland, and some sites in southern and SW England) had most watch effort in the 1990s whereas others (e.g. Northern Ireland, North Wales) had effort largely confined to the most recent period from 2000 onwards. A few areas (e.g. Moray Firth, Grampian Region, Cardigan Bay) have had watch effort spanning two or three decades. Temporal details of effort can be found site by site in Appendix 3.

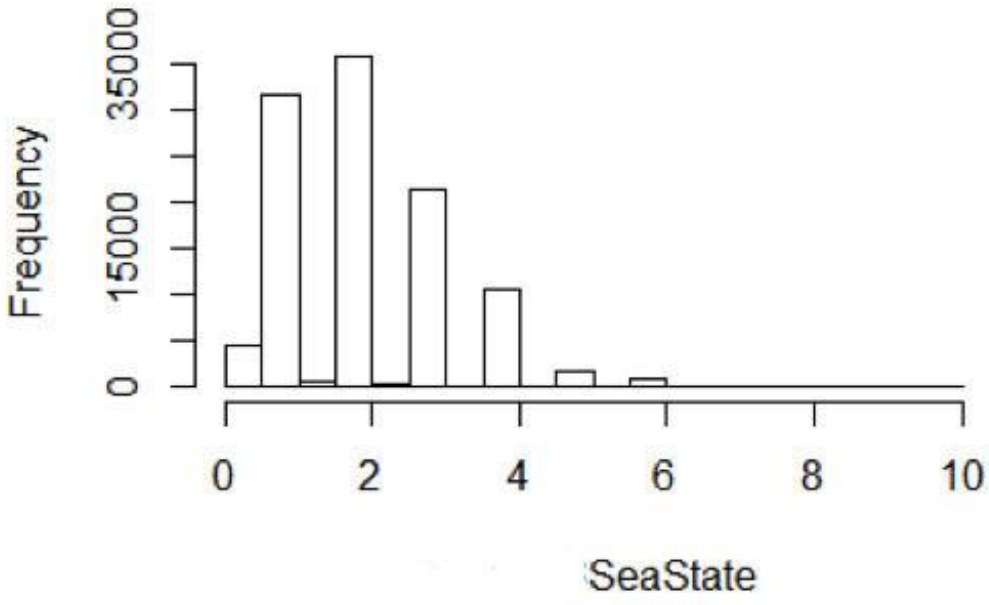

Figure 2. Distribution of effort records by sea state

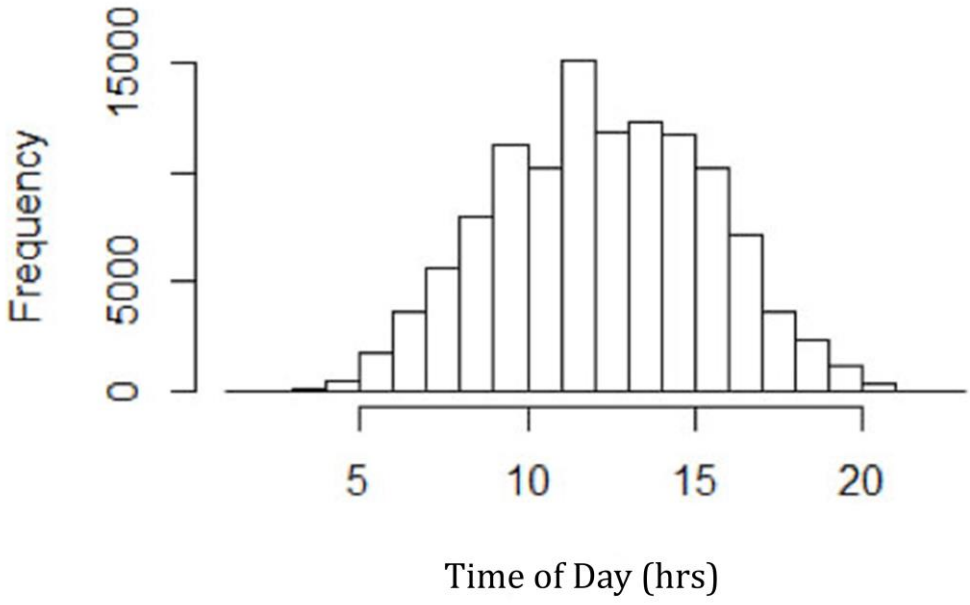

Figure 3. Distribution of effort records by time of day

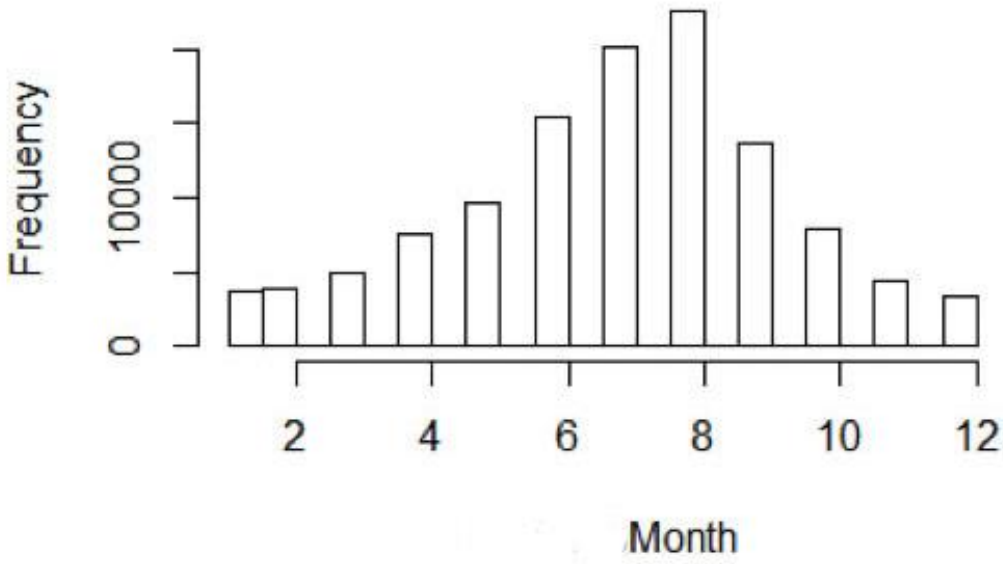

Figure 4. Distribution of effort records by month

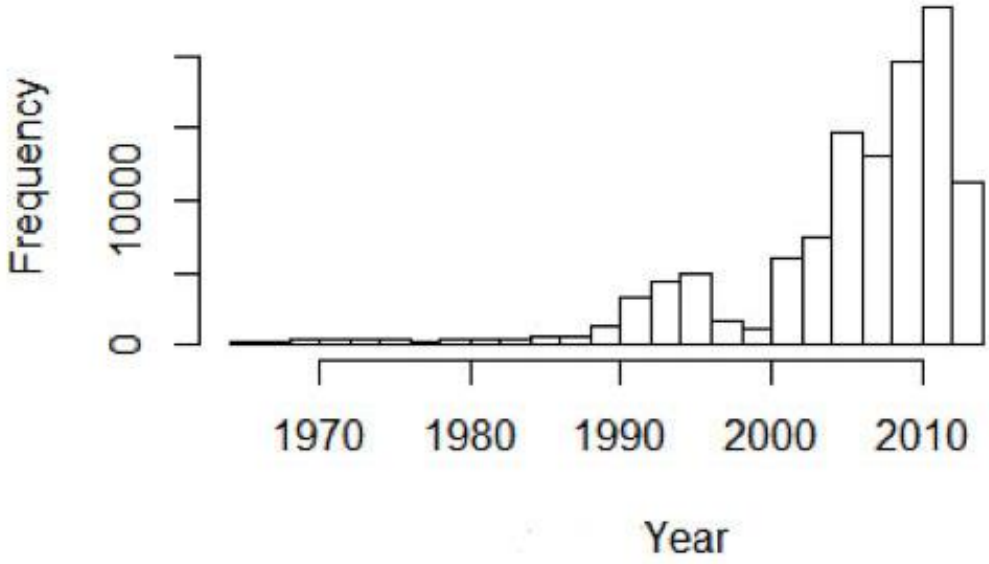

Figure 5. Distribution of effort records by year

5.3 Bottlenose Dolphin

A plot of raw sighting rates (number of sightings per hour effort) by ICES rectangle highlights the two main coastal regions where bottlenose dolphins occur: the Moray Firth and Cardigan Bay (Figure 6). The Moray Firth shows up particularly strongly probably because of three premier watch points (Cromarty, Chanonry Point and Kessock) that have received a lot of effort. It should be noted, however, that the species occurs in small numbers over a wide area of the British Isles although scarce in eastern Britain south of the Firth of Forth and in west Scotland (except in the southern Outer Hebrides).

Figure 7 shows sighting rates at particular sites partitioned by different levels of effort. All four maps show similar patterns, with sightings concentrated in the Moray Firth and Cardigan Bay, but the greater detail shows clearly the importance of the outer Moray Firth as far north as the Dornoch Firth and the east Grampian coast south towards the Firth of Forth in eastern Scotland; and the North Wales coast and Isle of Anglesey, in Wales (see Table 1). Nine sites in southwest England have moderately high sighting rates: Blackstone Point, south Devon; Pendennis (but based on only 3h effort), Bass Point and Predannack Head on the Lizard Peninsula in south Cornwall; Land's End, west Cornwall; St Ives Bay, north Cornwall; and Welcombe Mouth (but based on just 1h effort), around Croyde Bay, and Combe Martin in north Devon. The resident bottlenose dolphin population that inhabits waters around Jersey, Channel Islands, is revealed by the relatively small amount of effort there.

Raw count rates (number of animals per hour effort) by ICES rectangle highlight the same main coastal regions: 1) the Moray Firth and east Grampian coast, and 2) Cardigan Bay and North Wales including Anglesey (Figure 8). Other areas with moderately high count rates include Jersey and the Lizard Peninsula. It is worth noting that bottlenose dolphin group sizes are often higher away from core areas. In Wales, for example, mean group size for the species in Cardigan Bay is 4.2 whereas off Anglesey in North Wales (to which region the Cardigan Bay population largely moves in winter), mean group size is 18.0 (Pesante *et al*., 2008; Feingold and Evans, 2013).

Figure 9 shows count rates at sites partitioned by varying levels of effort. Again, the four maps show similar patterns, count rates consistently being highest in the Moray Firth and East Grampian region and along the coasts of Cardigan Bay and around North Wales (see also Table 1). Relatively high count rates occur also along the Angus coast, and at most of the same sites referred to above in north Devon and Cornwall. Elsewhere, high count rates occur at Port Erin, Isle of Man, the Isle of Mull, and Kildonan, South Uist in west Scotland, as well as Grouville Bay, Jersey in the Channel Isles.

Using the six management units for bottlenose dolphin recommended by JNCC (see Figure 10), sites were allocated to one of the following: 184 in East Coast Scotland (ECS), 154 in North Sea (NS), 163 in Channel and Southwest England (CSW), 128 in Irish Sea (IS), 48 in West Coast Scotland (WCS), and one (from Northern Ireland) in Offshore (OS).

Table 1. List of sites with relatively high sighting/count rates for bottlenose dolphin (lower threshold: 0.2 sighting/hour or 1.0 animal/hour)

Site name	Region	Effort (hrs)	SPUE	CPUE
Avoch	Highland	3.0	0.3	1.0
Golspie, Iain Macdonald's house	Highland	10.8	0.5	1.0
Embo	Highland	2.0	0.5	1.0
Tarbat Ness	Highland	32.3	0.3	3.5
Balintore Harbour	Highland	101.3	0.2	0.9
Nigg (near Cromarty)	Highland	6.8	0.3	2.4
Cromarty	Highland	15.9	0.6	4.3
South Sutor, Cromarty	Highland	53.1	0.6	3.1
Castlecraig	Highland	48.0	1.1	5.2
Rosemarkie	Highland	10.5	0.6	3.8
Fort George	Highland	265.9	0.6	2.6
Fortrose	Highland	0.3	4.0	16.0
Chanonry Point	Highland	1454.3	0.9	4.0
Kessock bridge (north)	Highland	4.0	0.3	5.0
Kessock Bridge Inverness	Highland	12.5	0.2	1.8
Kessock bridge (south)	Highland	2.0	0.5	1.5
North Kessock	Highland	205.1	2.7	7.5
South Kessock	Highland	128.2	0.9	2.3
Ardersier	Moray	2.8	1.1	7.3
Nairn Harbour	Moray	48.9	0.7	2.0
Burghead	Moray	331.0	0.2	1.6
Cummingston	Moray	9.3	0.3	1.0
Covesea	Moray	29.9	0.2	1.8
Covesea Lighthouse	Moray	2.0	0.5	0.7
Lossiemouth Harbour	Moray	13.4	0.3	2.4
Lossiemouth Pier	Moray	159.7	0.3	1.2
Lossiemouth	Moray	32.2	0.2	2.9
Spey Bay	Moray	2498.1	0.7	1.5
Buckie	Moray	74.6	0.2	1.1
Craig Head west of Findochty	Moray	6.3	0.2	3.7
Findochty/Findochty Church	Moray	820.7	0.4	3.0
West of Portnockie Harbour	Moray	104.9	0.3	5.5
North of Portknockie Harbour	Moray	233.1	0.5	12.0
Green Castle Rock, Portknockie	Moray	1.0	1.0	3.5
Portknockie	Moray	51.1	0.3	4.4
Bow Fiddle, Portnockie	Moray	7.5	0.4	0.3
Cullen	Moray	167.3	0.3	1.4
Between Cullen & Sandend Bay	Moray	2.0	1.5	24.0
Findlater Castle	Aberdeenshire	0.6	1.7	6.9
Banff Harbour	Aberdeenshire	13.2	0.3	1.1
Banff	Aberdeenshire	10.5	0.6	8.4
Troup Head	Aberdeenshire	9.0	0.2	1.2
Macduff Marine Aquarium	Aberdeenshire	38.7	0.3	1.3
Boyndie Bay east of Whitehills	Aberdeenshire	0.5	0.4	3.1
Macduff, Gellymill	Aberdeenshire	297.3	0.4	3.1
Donmouth	Aberdeenshire	80.8	0.7	5.7
Aberdeen Beach	Aberdeenshire	68.3	0.4	4.0
Aberdeen Harbour	Aberdeenshire	230.0	1.2	11.4

Aberdeen Torry Battery	Aberdeenshire	423.4	1.3	11.5
Girdleness	Aberdeenshire	246.7	0.3	3.3
Nigg Bay	Aberdeenshire	18.0	0.9	4.7
Doonies Farm	Aberdeenshire	8.0	0.4	2.5
Souter Head, Cove	Aberdeenshire	97.7	0.1	1.3
Stonehaven	Aberdeenshire	661.7	0.2	1.7
Inverbervie south of Stonehaven	Aberdeenshire	0.8	1.3	6.7
St Cyrus	Aberdeenshire	46.6	0.5	3.8
Montrose	Angus	6.3	0.3	4.4
Scurdie Ness	Angus	2.0	1.0	3.0
Lud Castle, Auchmithie	Angus	27.0	0.2	1.0
Arbroath	Angus	27.5	0.2	1.5
Three Storey Hoose, Arbroath	Angus	517.0	0.2	1.1
Blackstone Point	South Devon	11.0	0.2	0.5
Pendennis, S of Falmouth	Cornwall (S)	3.0	0.3	4.0
Bass Point (nr Lizard Point)	Cornwall (S)	16.5	0.4	1.5
Predannack Head, Lizard	Cornwall (S)	5.5	0.4	2.0
Lands End	Cornwall (W)	62.5	0.4	3.8
St. Ives Bay	Cornwall (N)	573.0	0.2	0.9
Welcombe Mouth	North Devon	1.0	1.0	1.0
Saunton Beach, nr Croyde Bay	North Devon	12.5	0.2	1.2
Lester Point, Combe Martin	North Devon	4.0	0.3	0.3
Dinas Head	Pembs (N)	17.5	0.2	1.3
Clumyr Ynys headland	Ceredigion	13.2	0.2	1.3
Cardigan Island	Ceredigion	6.0	0.3	1.0
Aberporth A	Ceredigion	77.4	0.4	1.0
Aberporth B	Ceredigion	673.6	0.2	0.6
Pen Peles	Ceredigion	1.5	0.7	2.7
Mwnt	Ceredigion	1569.1	0.4	1.7
Llangrannog	Ceredigion	17.7	1.0	2.7
Ynys Lochtyn	Ceredigion	360.3	0.3	1.0
Caerwenfor	Ceredigion	60.6	0.5	1.1
New Quay Harbour	Ceredigion	21.0	0.4	0.8
New Quay, Birds Rock	Ceredigion	1.5	0.7	5.3
Target Rock, New Quay	Ceredigion	1.3	0.8	3.2
Fish Factory, New Quay	Ceredigion	0.5	2.0	14.0
New Quay Headland	Ceredigion	2097.8	0.2	0.7
Aberystwyth Harbour	Ceredigion	8.8	1.1	10.6
Friog Cliffs	Gwynedd	8.3	0.2	0.2
Criccieth	Gwynedd	21.0	0.2	0.8
Mynydd Mawr, Bardsey Island	Gwynedd	5.7	0.7	1.6
Porth Dinllaen	Gwynedd	25.0	0.1	1.0
Dinas Dinlle	Gwynedd	2.0	2.5	12.5
Nant Bychan	Anglesey	3.5	1.7	17.6
Whitebeach, Penmon	Anglesey	1.3	0.8	5.6
Great Orme Country Park	Conwy	19.3	0.2	2.7
Arches, Port Erin	Isle of Man	50.3	0.1	3.6
Bloody Bay, Isle of Mull	Inner Hebrides	6.4	0.2	1.7
Tobermory LH, Isle of Mull	Inner Hebrides	3.0	0.3	1.0
Scourie Bay	Sutherland	6.0	0.2	3.0
Garrynamonie, South Uist	Western Isles	6.1	0.2	0.5

Kildonan, South Uist	Western Isles	2.5	0.4	2.4
Grouville Bay, Jersey	Channel Isles	4.0	0.5	3.0

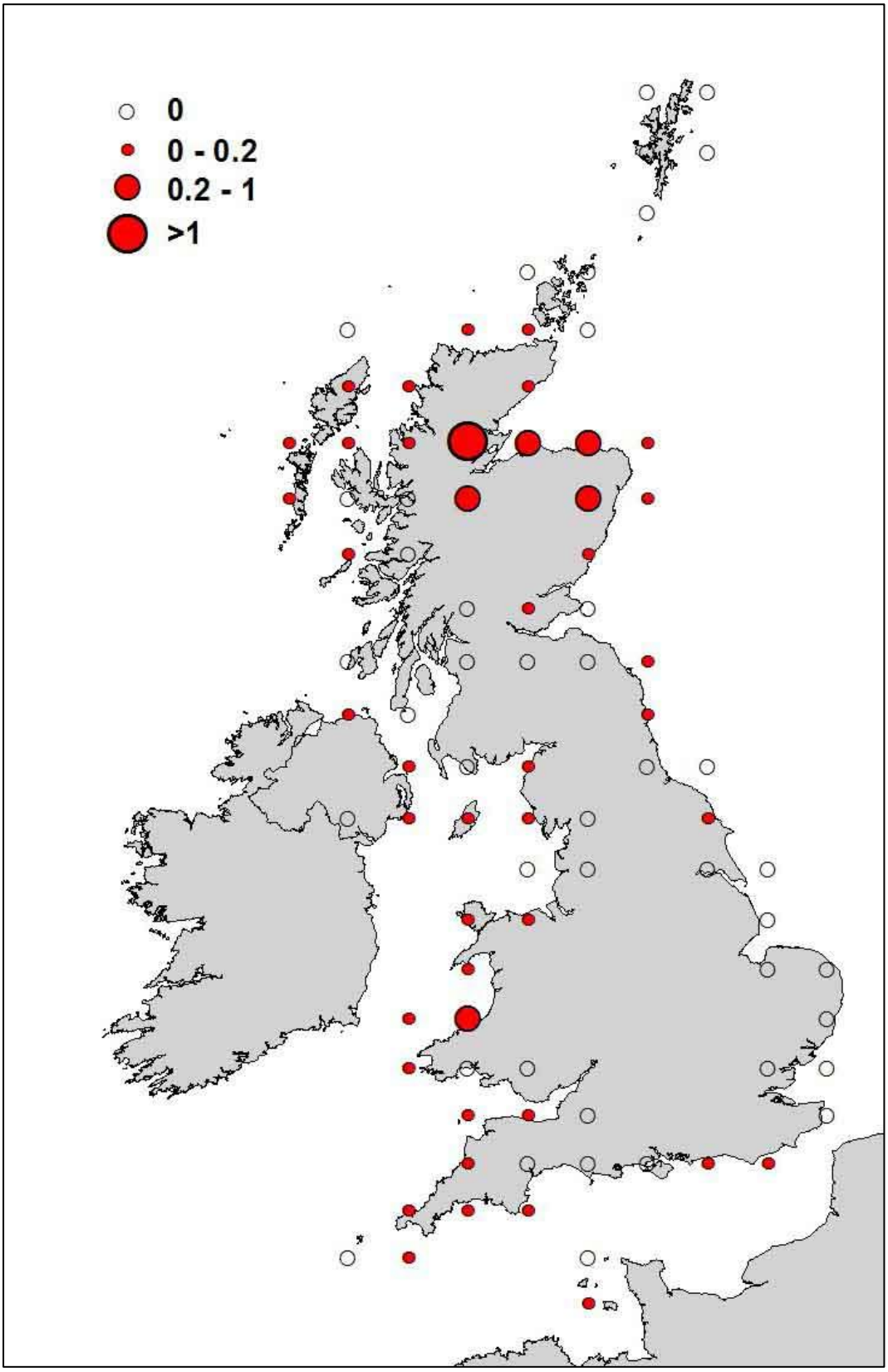

Figure 6. Map of Bottlenose Dolphin Sighting Rates by ICES rectangle

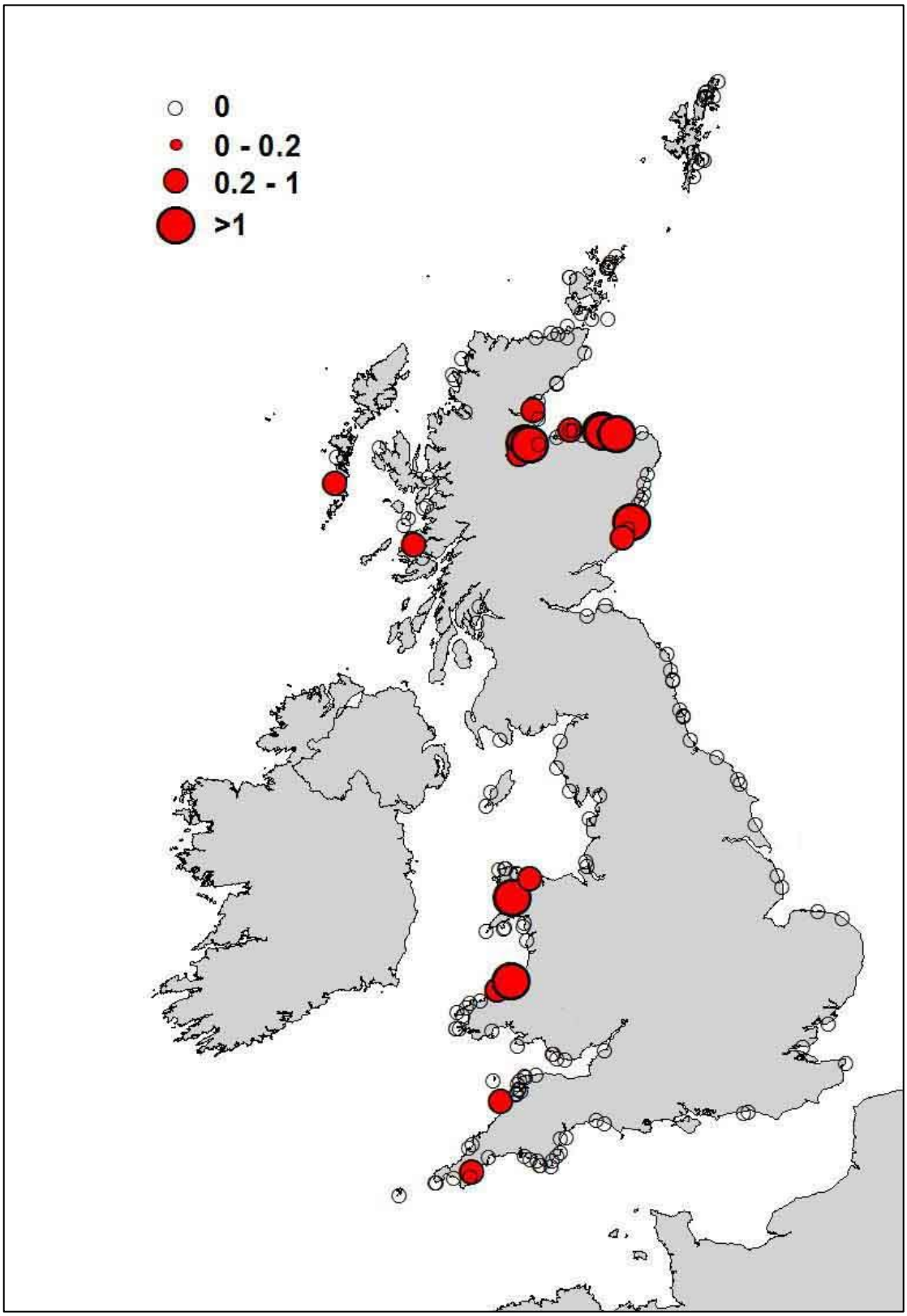

Figure 7a. Map of Bottlenose Dolphin Sighting Rates by site
(for watches with <3 h effort)

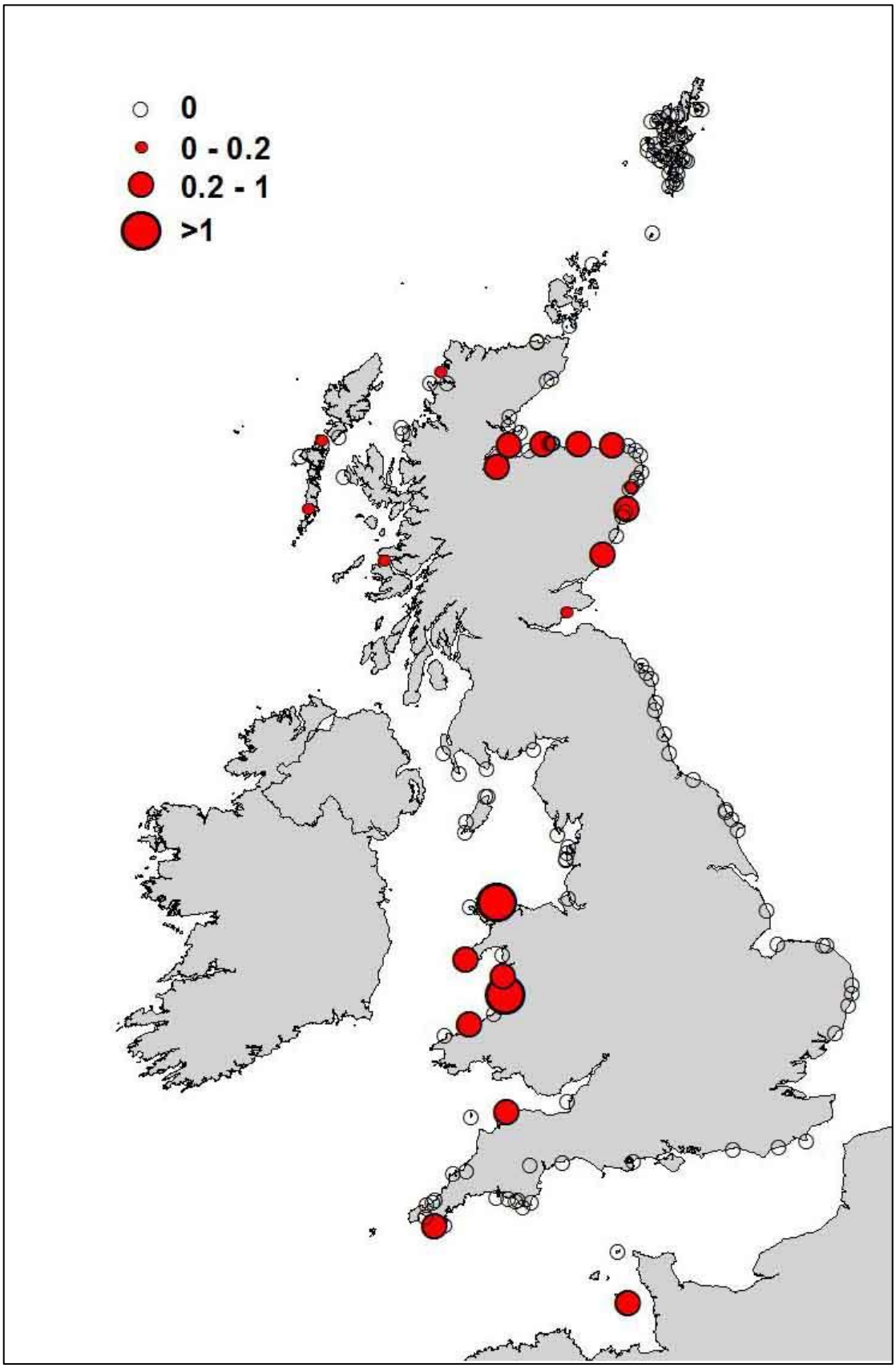

Figure 7b. Map of Bottlenose Dolphin Sighting Rates by site
(for watches with 3-10 h effort)

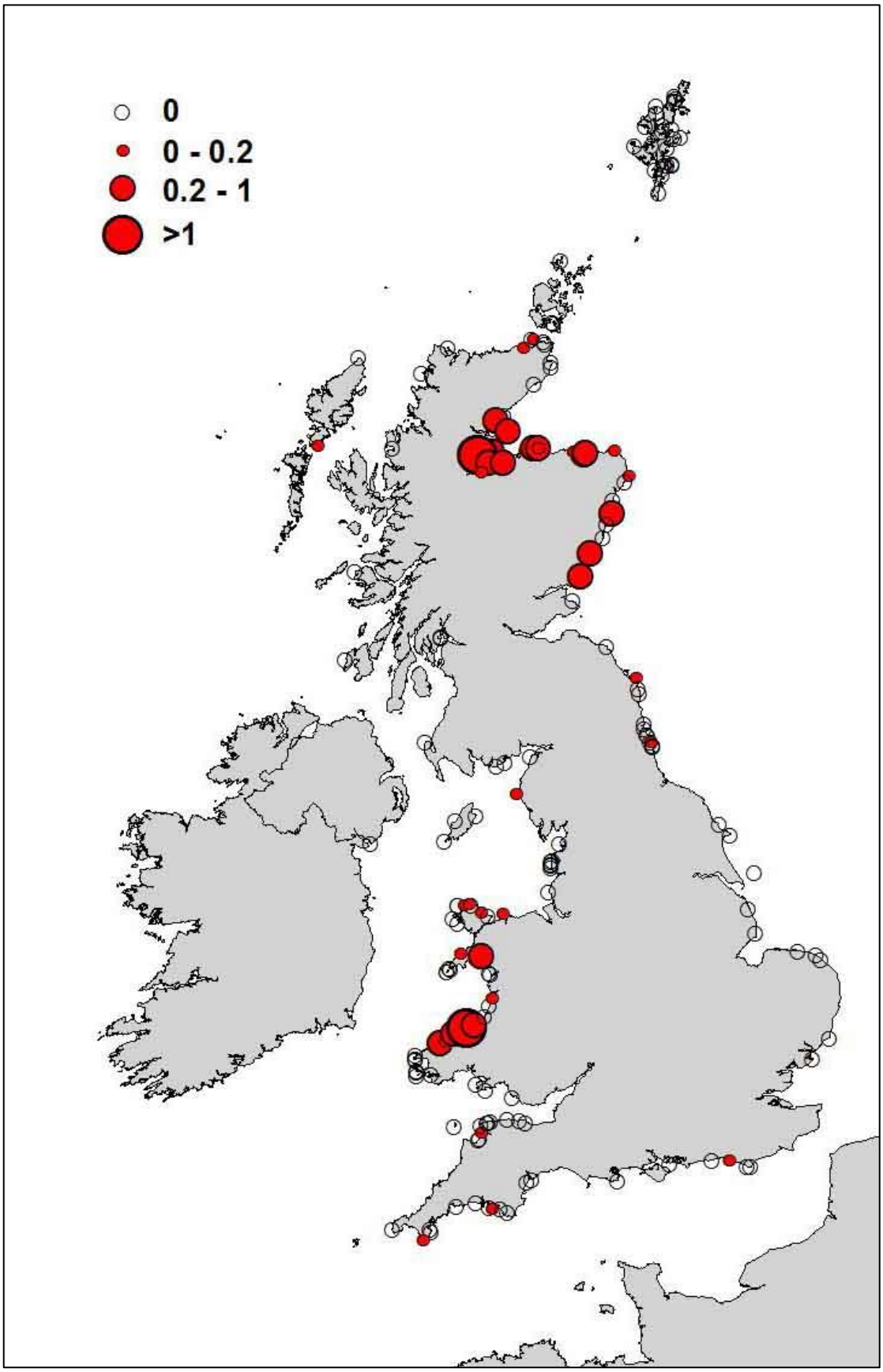

Figure 7c. Map of Bottlenose Dolphin Sighting Rates by site
(for watches with 10-50 h effort)

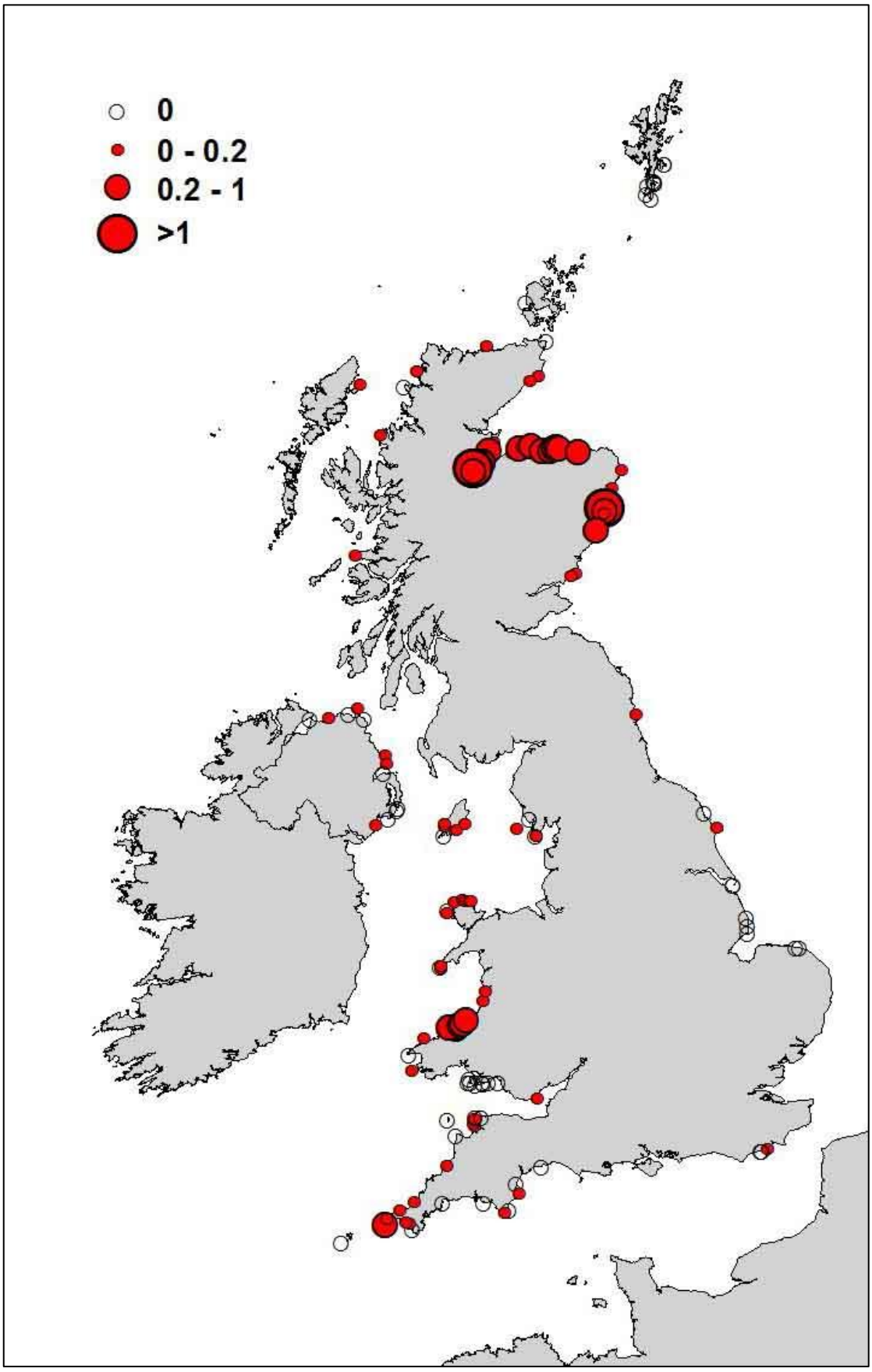

Figure 7d. Map of Bottlenose Dolphin Sighting Rates by site
(for watches with >50 h effort)

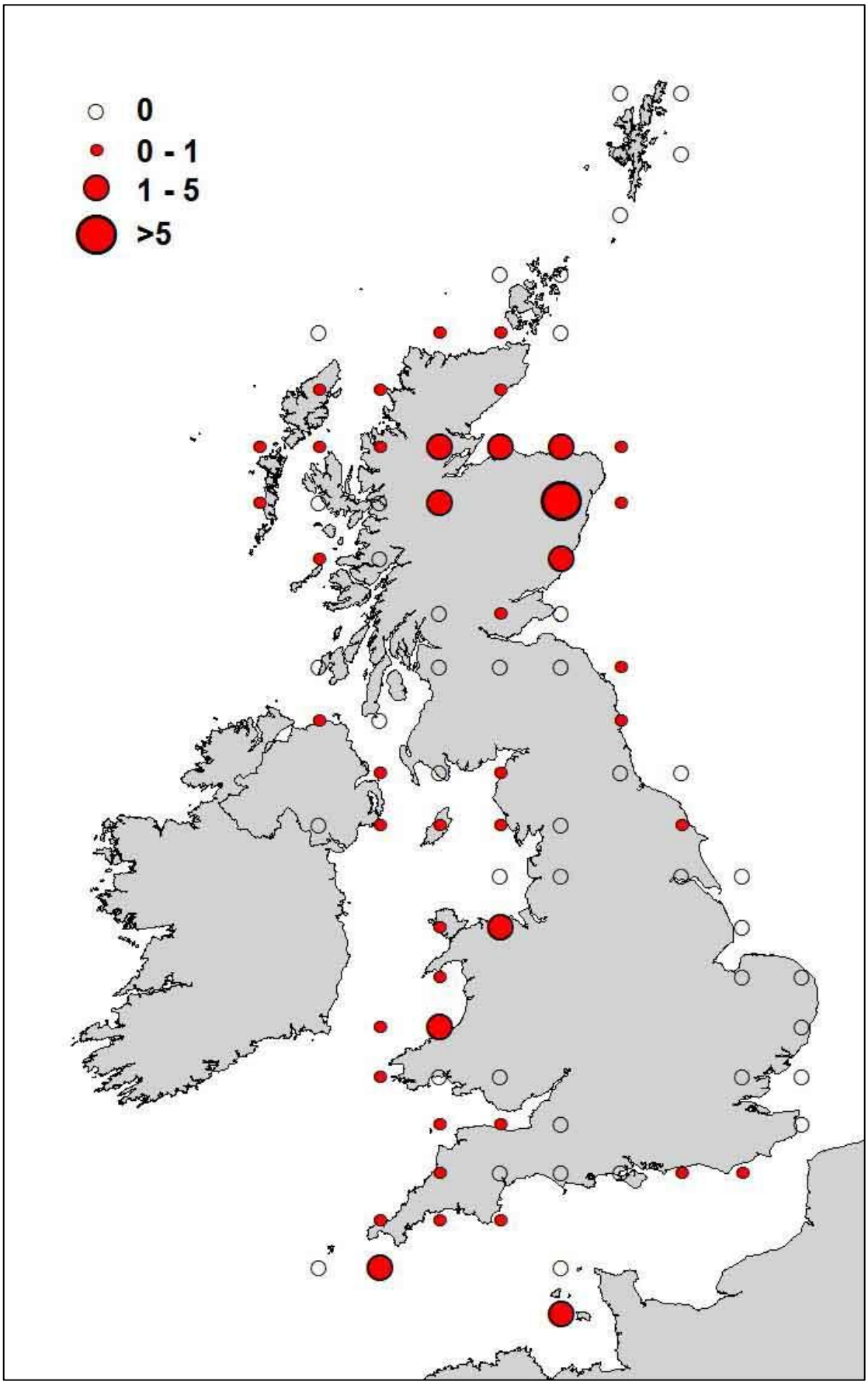

Figure 8. Map of Bottlenose Dolphin Count Rates by ICES rectangle

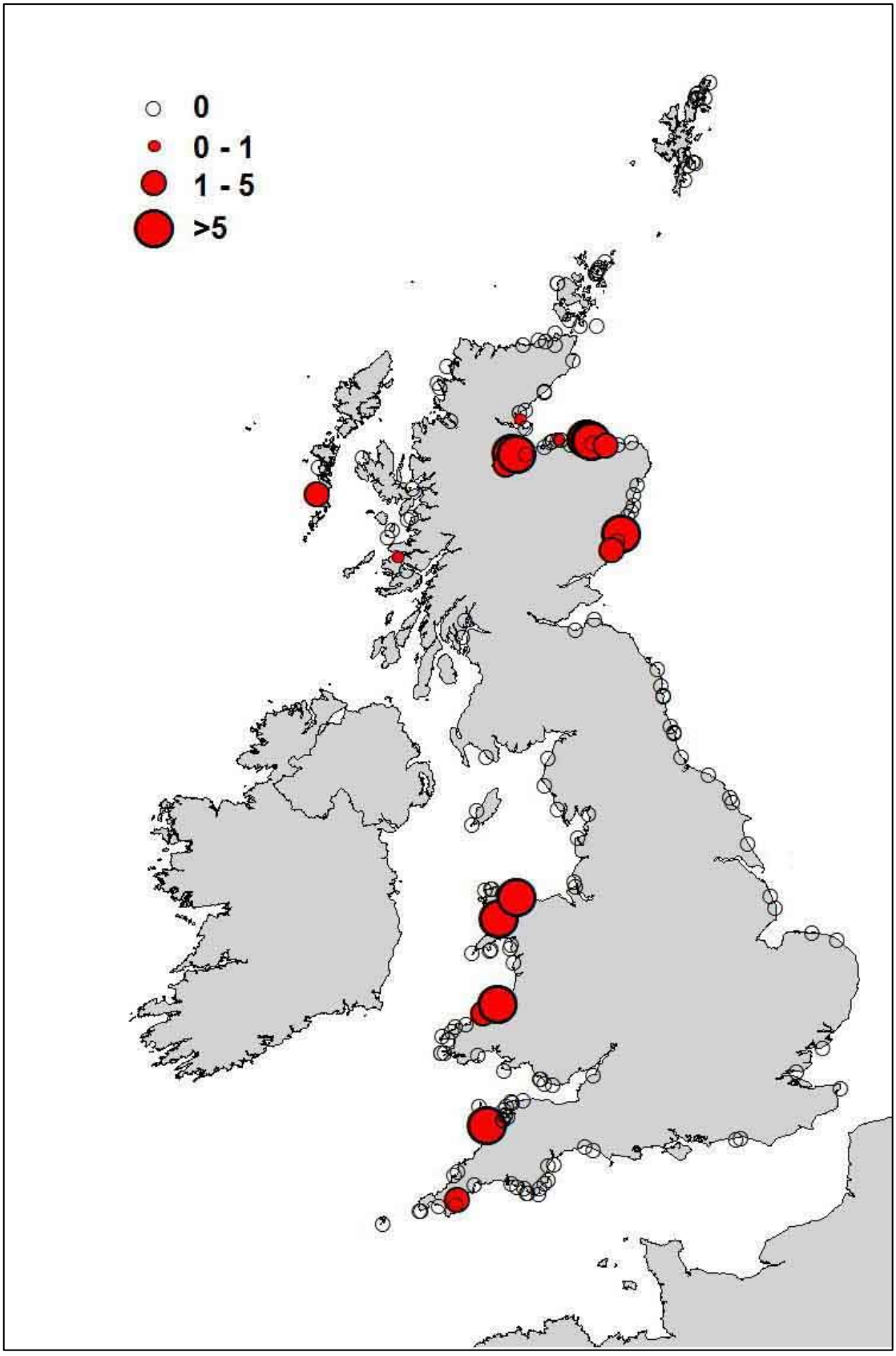

Figure 8a. Map of Bottlenose Dolphin Count Rates by site
(for watches with <3 h effort)

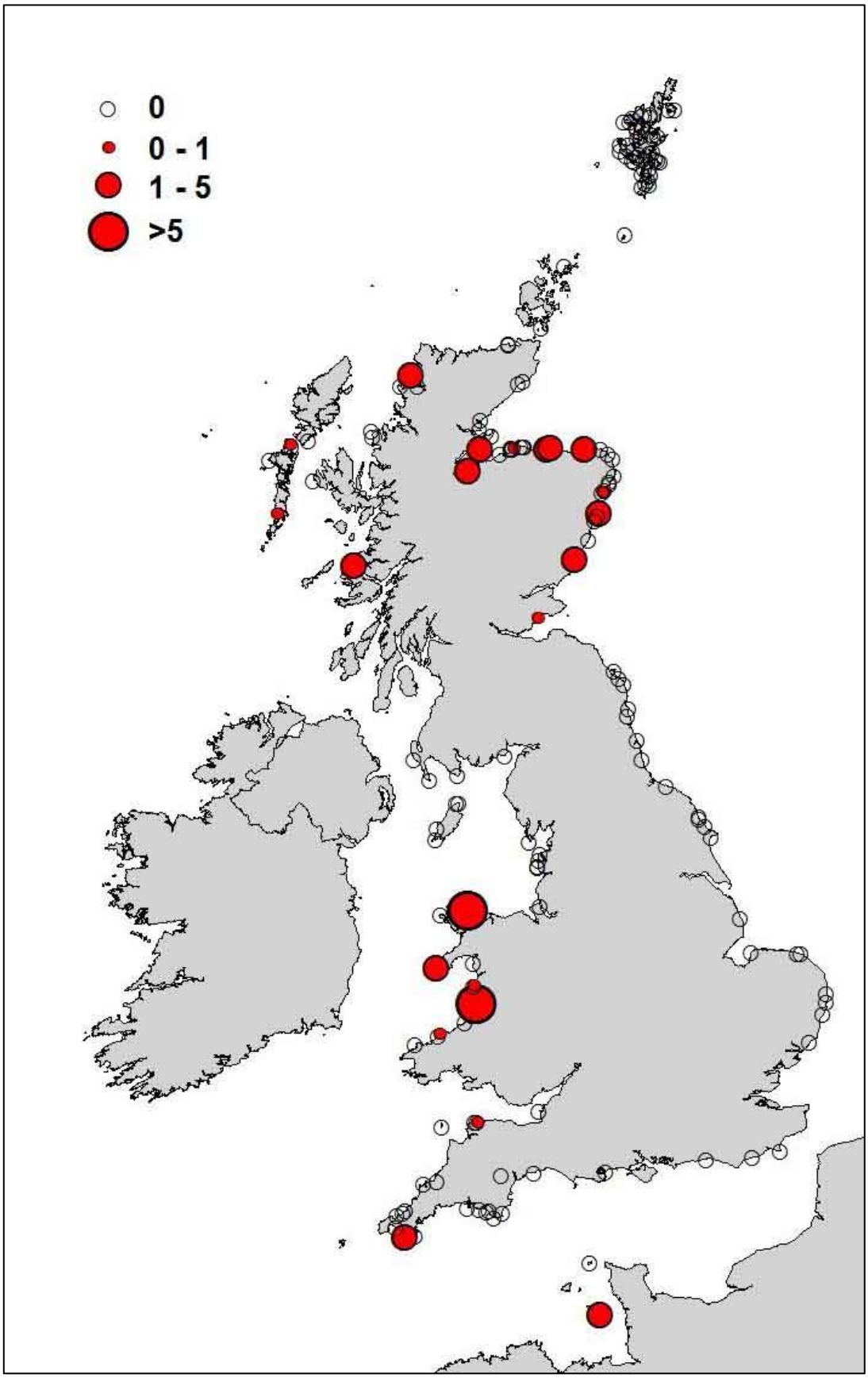

Figure 8b. Map of Bottlenose Dolphin Count Rates by site
(for watches with 3-10 h effort)

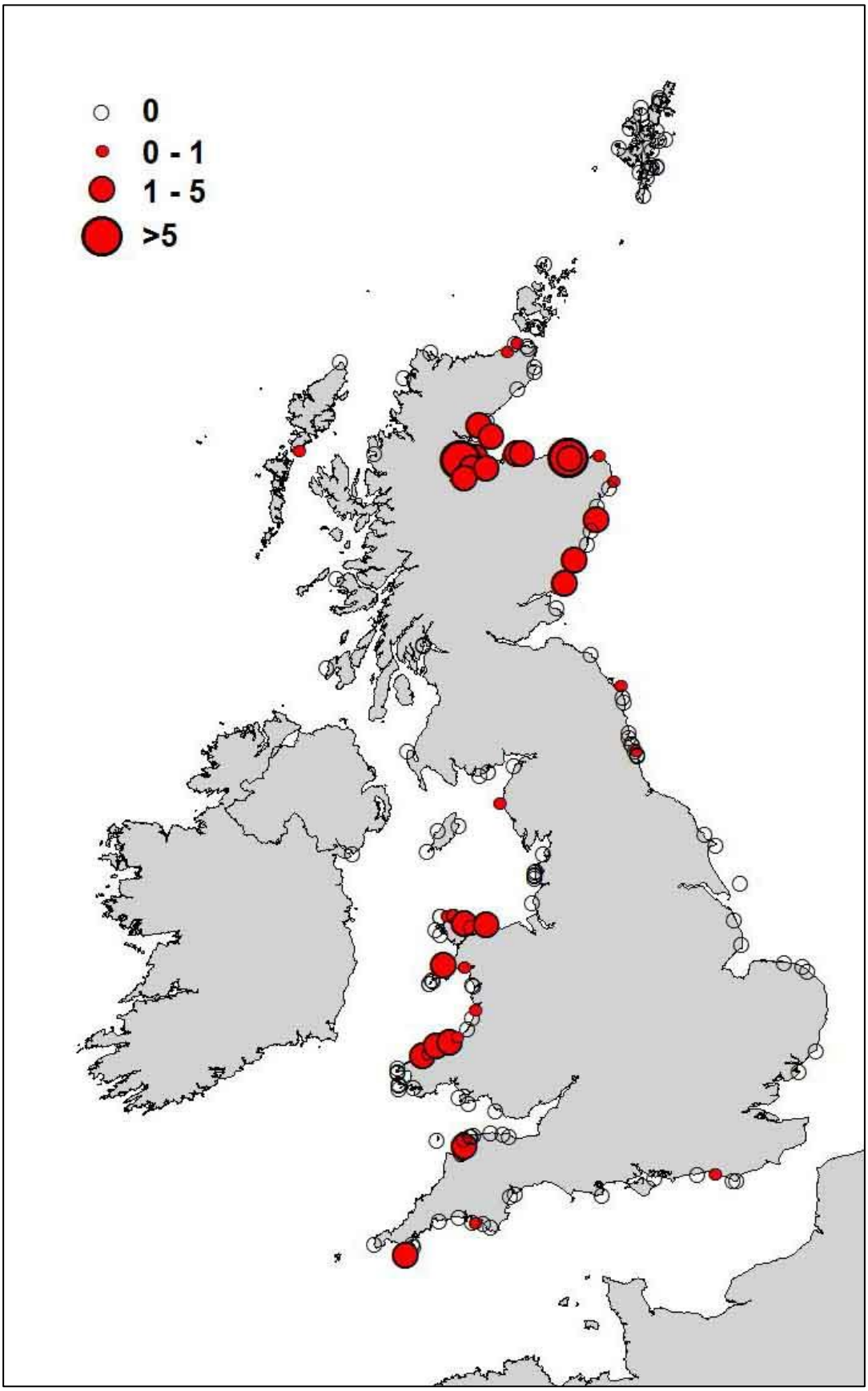

Figure 8c. Map of Bottlenose Dolphin Count Rates by site
(for watches with 10-50 h effort)

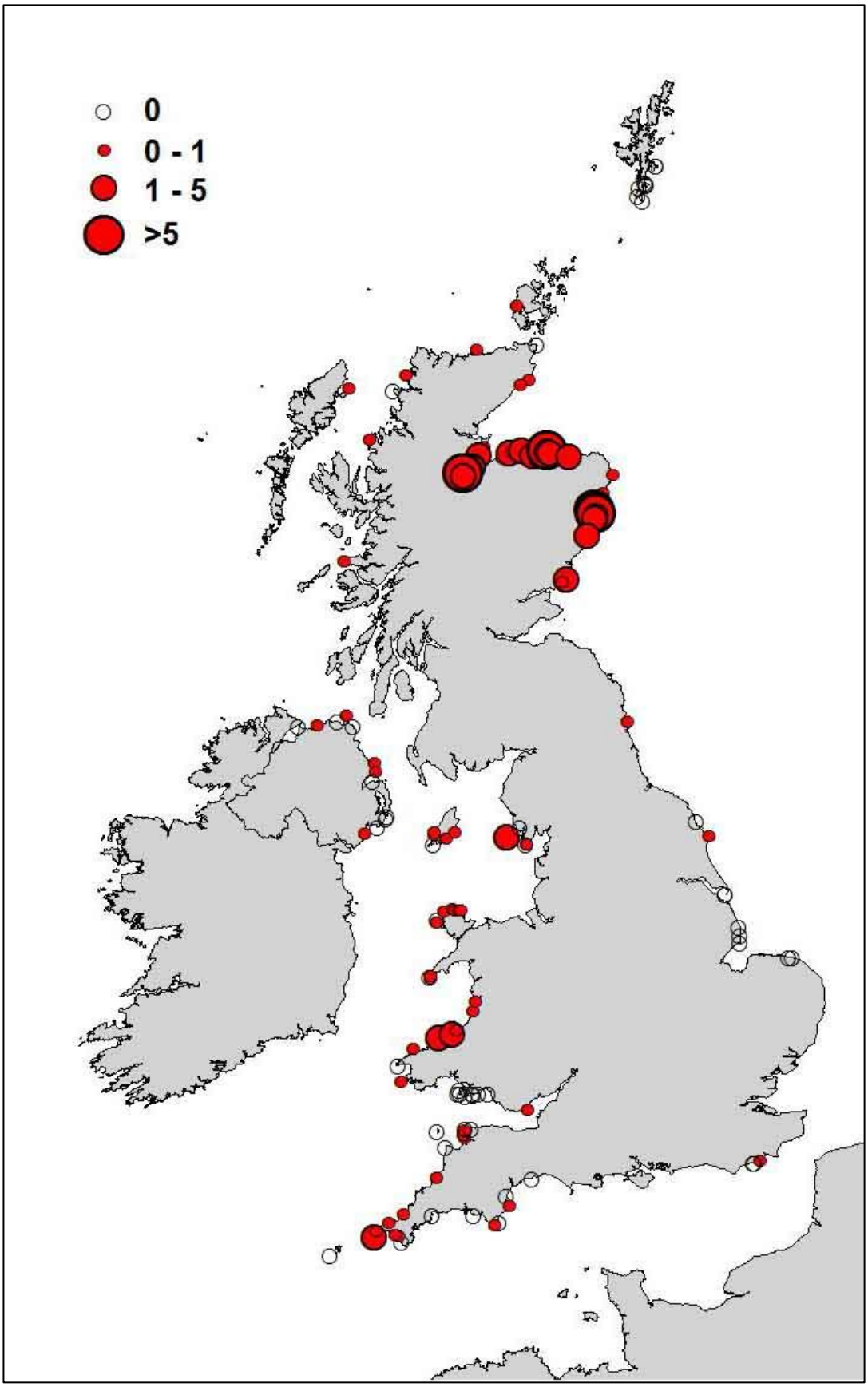

Figure 8d. Map of Bottlenose Dolphin Count Rates by site
(for watches with >50 h effort)

Count rates for each year were calculated for each of the 678 sites. Appendix 3 provides full details of effort and count rates by year from 1965 to the present, for each site within that management unit. Any entry in blue indicates effort in that year without any sightings of that species. Entries in yellow indicate positive sightings and provide the count rates for that year. Count rates are expressed as numbers of animals per minute of observation. At the end of the matrix is the sum of years for which there was watch effort from 1965 onwards, and then since 2000.

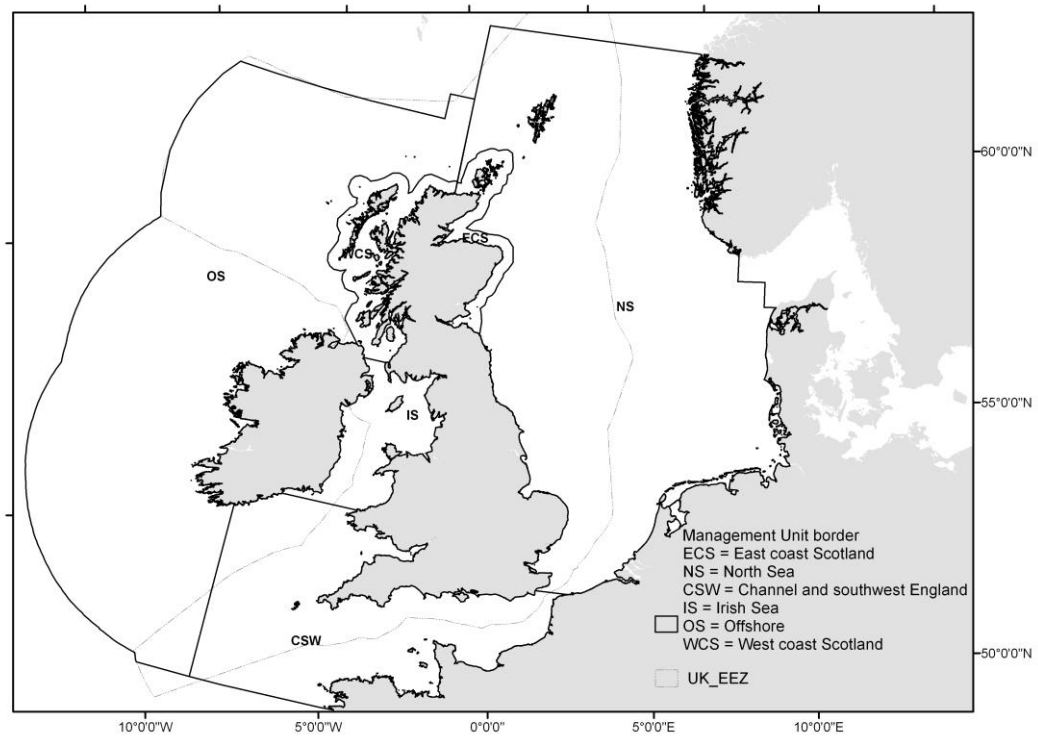

Figure 9. Map showing Management Units used for Bottlenose Dolphin

Generalised Additive Models were performed on each bottlenose dolphin management unit (except for the single site from Northern Ireland belonging to the OS management unit). The findings are presented in detail in Appendix 4.

Using Appendix 3, those sites at which there were at least three years of effort, with a minimum of 100 mins per year (i.e. 5 hrs minimum of watch effort overall) were selected for plotting the GAM predictions. GAMs were run on the whole data set for each management unit separately and the results presented here are scaled differently for the different management units, to best display variation within a particular MU. Thus comparisons between sites (see Figures 10a-e) should only be made within an MU.

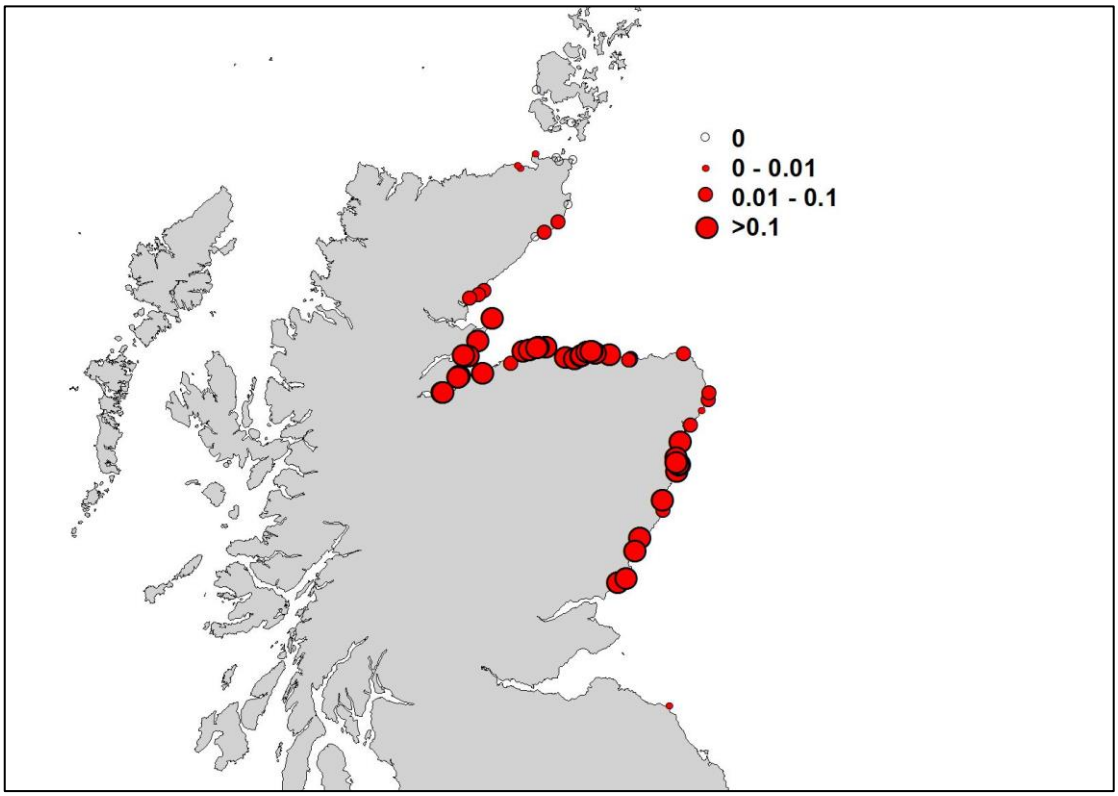

Figure 10a. Map of GAM predicted groups per standardised observation for Bottlenose Dolphin East Coast Scotland Management Unit

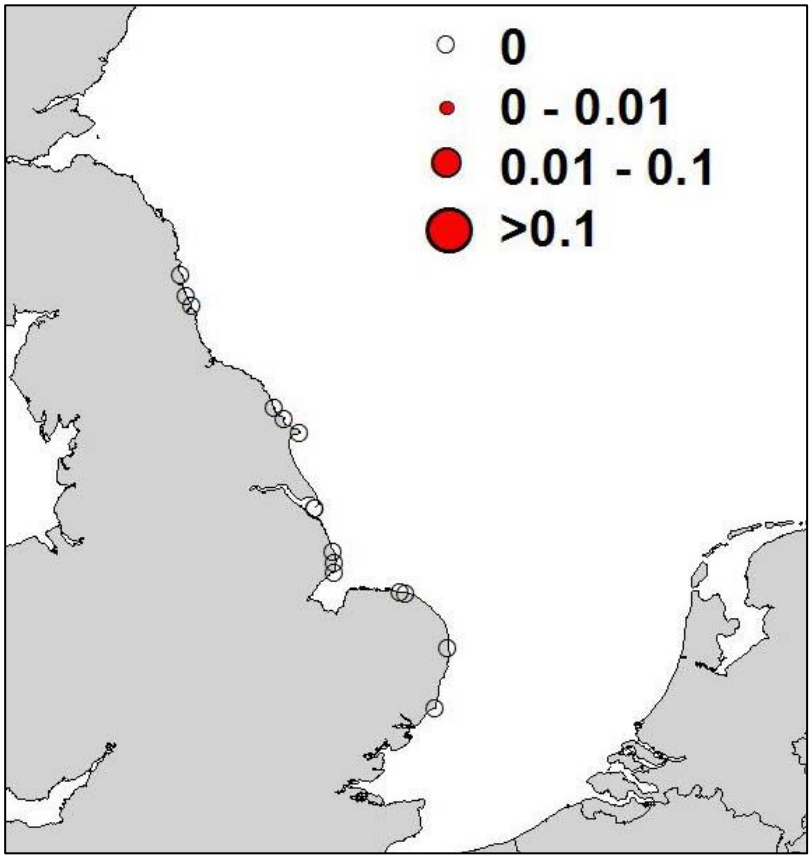

Figure 10b. Map of GAM predicted groups per standardised observation for Bottlenose Dolphin North Sea Management Unit

Figure 10c. Map of GAM predicted groups per standardised observation for Bottlenose Dolphin Channel & SW England Management Unit

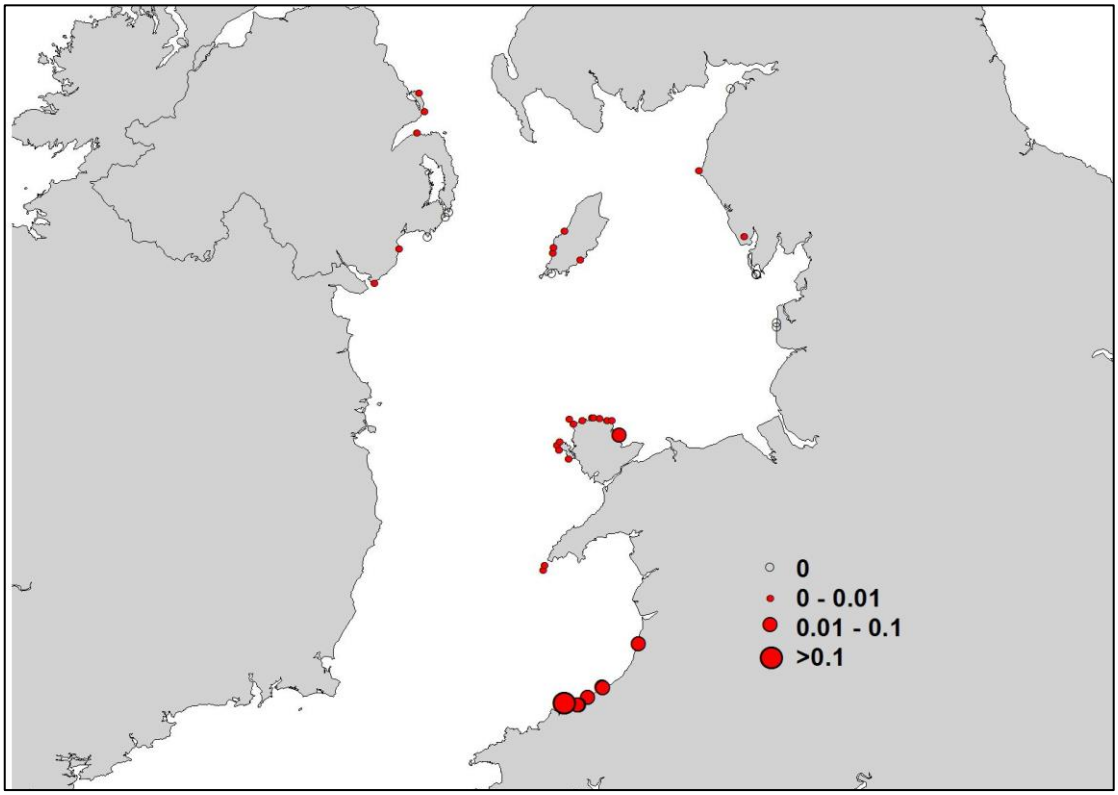

Figure 10d. Map of GAM predicted groups per standardised observation for Bottlenose Dolphin Irish Sea Management Unit

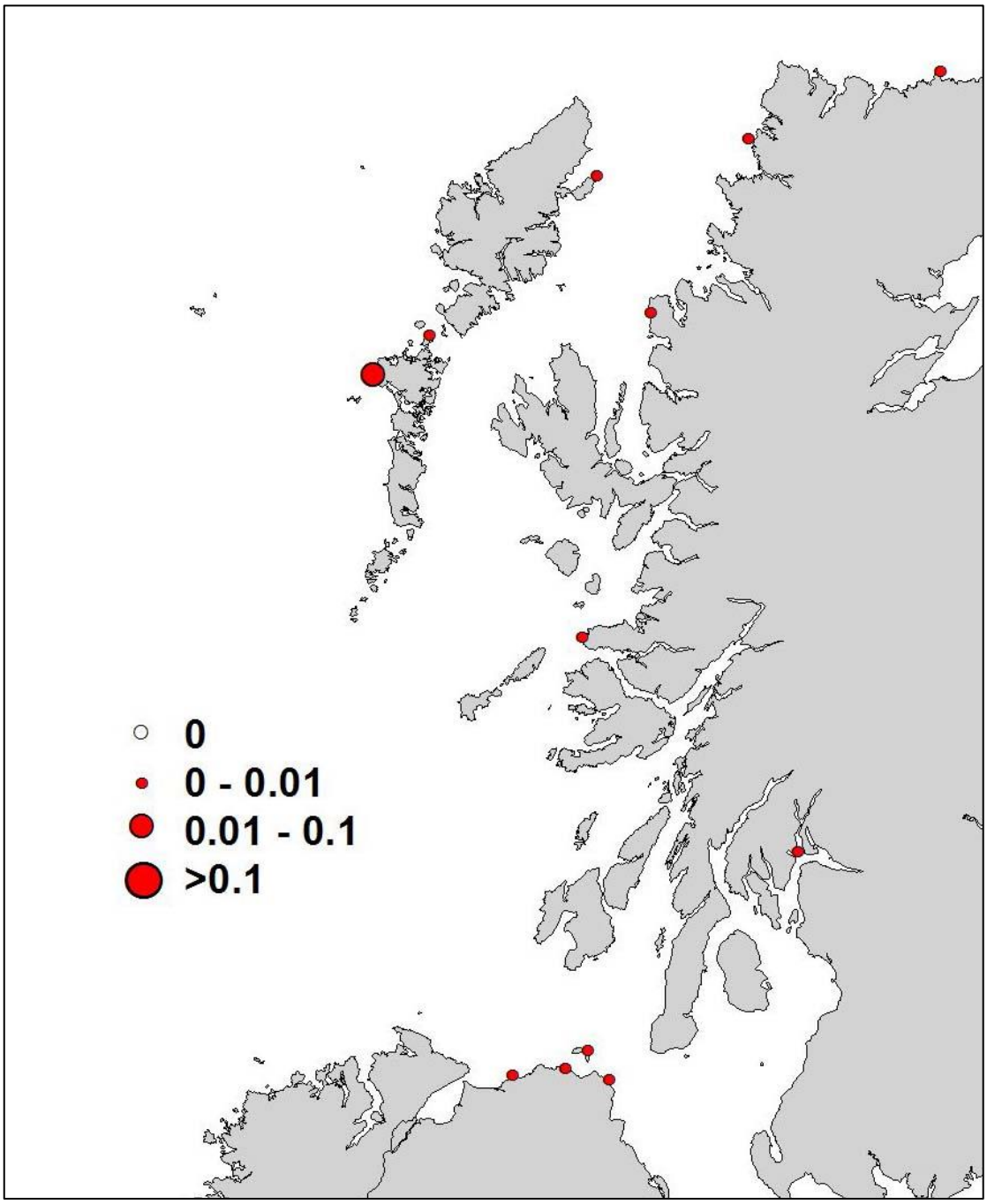

Figure 10e. Map of GAM predicted groups per standardised observation for Bottlenose Dolphin West Coast Scotland Management Unit

Figure 10a highlights the relatively even distribution of East Coast Scottish bottlenose dolphins between Brora (north of the Dornoch Firth) and Carnoustie along the Angus coast. There are a few outlying sites to the north, with observations on the northeast Caithness coast. Further south, there has been limited land watch effort in Fife, which is probably why the well-known presence of the species in St Andrews Bay is not revealed here.

There is a conspicuous general absence of the species within the North Sea management unit (Figure 10b). Although bottlenose dolphins occur occasionally in this region (see, for example, Figure 8), this accords with our general knowledge of the species (Reid *et al*., 2003; Evans *et al*, 2003).

The Channel and Southwest England management unit has sightings concentrated around the South-west Peninsula (Figure 10c). Highest predictions occur in Falmouth Bay and around the Lizard Peninsula in Cornwall, and in Bideford Bay in North Devon.

The importance of southern Cardigan Bay, West Wales, to bottlenose dolphins is reflected in the prediction map for the Irish Sea management unit (Figure 10d), although the presence of the species in northern Cardigan Bay and around the Llyn Peninsula is likely to be under-estimated due to limited land watch effort there. The north and east coasts of Anglesey, particularly Red Wharf Bay, is also highlighted. Elsewhere, the species occurs around the Isle of Man, and at sites along the Cumbrian coast to the east, and in Counties Down and Antrim in Northern Ireland to the west.

The West Coast of Scotland management unit has very limited long-term coverage, and the only area with a relatively high prediction is on the west coast of North Uist (Figure 10e). Elsewhere, the species is recorded at sites along the County Antrim coast, Northern Ireland, and at scattered locations along the west mainland coast of Scotland. These results accord with our knowledge from offshore surveys, with low numbers of the species ranging around the Hebrides. The small resident population that inhabits the Sound of Barra is not identified here due to lack of land watch effort in that area.

A final set of analyses used (a) the whole data set and (b) all data from 1994 onwards (see Appendix 4. Figures A4.1-4.3). For both data sets, models including a latitude x longitude smoother (as for the individual MUs) give similar results, highlighting the occurrence of bottlenose dolphins in two main areas: the east coast of Scotland and west Wales, as well as the Southwest Peninsula of England.

A model with a site x year interaction revealed a broadly consistent spatial distribution pattern over the years, with consistent peak areas, although the size of the peak in local occurrence in southern Cardigan Bay, west Wales, is seen to have varied substantially.

5.4 Harbour Porpoise

A plot of raw sighting rates (number of sightings per hour effort) by ICES rectangle shows the widespread distribution of harbour porpoise around the British Isles (Figure 11). Highest rates occur in Shetland. However, those were derived from dedicated land watch effort in the 1990s and there has

been very little such effort since then. Opportunistic sightings and offshore effort indicate that the species has become much less common in the region in the last decade, probably due to the collapse of sandeel stocks there. Other areas where relatively high sighting rates occur include north-west Scotland, east Grampian region, North Yorkshire and East Riding, west Pembrokeshire, the western end of the Llyn Peninsula, and around Anglesey (Figure 11).

Figure 12 shows sighting rates at particular sites partitioned by different levels of effort. Reassuringly, the four maps reveal similar patterns for those locations where there has been variable effort. Table 2 details those sites with relatively high sighting rates. The east side of Shetland, particularly around the islands of Whalsay, Noss, Mousa, and both sides of the southern mainland peninsula have the highest sighting rates (1.2-6.5 sightings/h). Two sites in Orkney also have high sighting rates: Herston Head (1.1 sightings/h) and The Wing (3.0 sightings/h) in South Ronaldsay. In north Caithness, moderately high sighting rates (0.6-2.0 sightings/h) were observed at Scrabster Lighthouse, Thurso, and Gills Bay. In east Caithness, high sighting rates (1.8-5.6 sightings/h) occurred at Shelligoe Clifftop near Lybster, and then around the Dornoch Firth at sites from Brora to Dornoch on the north side, and at Tarbat Ness (0.5 sighting/h) and Rockfield (3.1 sighting/h) on the south side. Sighting rates were then relatively low (<1.0 sighting/h) in the inner Moray Firth, southern shores of the outer Moray Firth and Aberdeenshire, with moderate rates (0.6-1.5 sightings/h) only at Whinnyfold, Collieston, Newburgh, Balmedie, Cove, and Downie Point, Stonehaven.

Further south, sighting rates remain low (<0.5 sightings/h) until King Edward's Bay in Tynemouth and Marsden Lea in South Shields (both c. 0.5 sightings/h), and at Souter Lighthouse, Tyne & Wear (1.0 sighting/h). Sighting rates then increase along the North Yorkshire coast, ranging from 1.1-4.9 sightings/h at Scarborough and Filey Bay, and 0.6-0.9 sightings/h at Bempton (80h effort), and Flamborough Head (>40h effort) in East Riding.

Sighting rates are low (<0.5 sightings/h) at all sites from Humberside and the Wash south to the Thames Estuary (although low elevation at most watch points may contribute to this) until Dungeness Bird Observatory (1.1 sighting/h). Along the southeast coast of England (Sussex, Hants, and Dorset), sighting rates remain low (<0.5 sightings/h) until Start Point and Bolt Head (0.5-0.6 sightings/h) in south Devon. Most of Cornwall has low sighting rates (<0.5 sightings/h) until the north Cornish coast at Trenance near Newquay and Stepper Point near Padstow (sighting rates 0.9-1.1/h), but these are both based on low effort (<3h). Lundy Island has intermediate sighting rates (0.4-0.5/h) based on moderate effort (c. 20h effort). Several sites in north Devon have similar sighting rates: Hartland Point, Greencliff, Westward Ho!, Baggy Point, Grunta Beach, Morte Point, and Bull Point (all ranging between 0.4-01.3 sighting/h). Further into the Bristol Channel, sighting rates at Ilfracombe, Foreland Point, High Veer Point, Hurlstone Point, and Minehead ranged from 0.4-1.1/h.

Along the South Wales coast, moderate sighting rates (0.4-1.6/h) occur at several locations around the Gower Peninsula and in Swansea Bay: Port Talbot, Mumbles, Pwll Du (>50h effort), Port Eynon Point, Paviland, Limekiln Point, Worm's Head, and Burry Holm.

In west Pembrokeshire, sighting rates at Skokholm and Skomer Islands ranged from 0.4-0.8 sightings/h, increasing in Ramsey Sound to 1.3 sightings/h. At Strumble Head, the sighting rate was 0.4/h and at Dinas Head up to 1.9/h, although the former figure is based upon >500h of effort whereas the latter is based on <3h effort. Sighting rates are then low (<0.3/h) along the coast of Cardigan Bay until the west end of the Llyn Peninsula, where they increase a little at Trwyn y Wylfa (0.4/h but based on <3h effort) and then significantly at Bardsey Island (1.2-5.4/h).

In North Wales, sighting rates were low until northwest Anglesey where sighting rates of 0.6-1.2/h occur at South Stack and North Stack respectively. Eastwards along the north coast, sighting rates ranged from 0.5-1.2/h at Carmel Head (>80h effort), Llanbadrig (>35h effort), Middle Mouse (>100h effort), Bull Bay (>100h effort), and Point Lynas (>2,000h effort). The east side of Anglesey and northeast mainland coast of Wales have low sighting rates (<0.5/h) although based on relatively limited coverage.

Sighting rates at sites in the Isle of Man are relatively high, mainly between 0.4-0.8/h but with rates of 2.1-659/h at Elby Point (Niarbyl), Ballaghenie, and Point of Ayre (although effort at these three sites is <5h).

Sites in Lancashire and Cumbria have low sighting rates (<0.5/h) until one reaches St Bees Head (where it is 0.6/h with >40h effort). In Southwest Scotland, sighting rates of 0.5-1.0/h occur at Corsewall Point (>40h effort), Galloway, Strone near Dunoon (>30h effort), and Blairmore (c. 20h effort).

Further north in west Scotland, there are very few sites with much land watching. Relatively high sighting rates (0.5-2.7/h) occur at several sites on the Isle of Mull (but generally based upon less than 5h effort per site), the Isle of Muck (but only 2h effort), and Mallaig (only 1.5h effort), as well as Culkein (8h effort), Kylesku (3h effort) and Stoer Head (79h effort). On the north Sutherland coast, a moderate sighting rate (0.6/h) occurs at Strathy Point (c. 150h effort).

In the Outer Hebrides, sighting rates were 0.9/h at Berneray, North Uist (c. 8h effort), 1.1/h at Rodel, Harris (c. 20h effort), and 0.5/h at Tiumpan Head, Isle of Lewis (c. 200h effort).

In Northern Ireland, moderate sighting rates occur at Black Head (0.4/h with >200h effort), 0.6/h at Portmuck, Island Magee, 0.4/h at Ramore Head, and 0.4/h at Magilligan Point. All these sites had >50h of effort. Sighting rates in the Channel Islands are zero (although effort is limited – totalling c. 17h at three sites), and incidental sightings are also rare around these islands.

Raw count rates (number of animals per hour effort) by ICES rectangle highlight two areas in particular: 1) the southern part of Shetland, and 2) west Pembrokeshire (Figure 13). As noted earlier, the relative importance of the species in the first of these areas has almost certainly diminished over the last decade. On the other hand, porpoises off the west coast of Scotland and around the Hebrides are clearly under-represented by land watches, as indicated from vessel surveys and opportunistic sightings (Reid *et al.*, 2003; Evans *et al*., 2003; Marubini *et al*., 2009; Booth, 2010; Embling *et al*., 2010).

Figure 14 shows count rates at sites partitioned by varying levels of effort, and Table 2 gives details of those sites with relatively high values. Several of the

locations with high sighting rates also had high count rates, although there were others that did not. Consistently high count rates (>3.0 animals/h) were observed in east and south Shetland, notably at Fethaland, Tresta on Fetlar, Skaw on Whalsay, Bressay Broch, Noss Sound and the Isle of Noss, Mousa Sound, Noness, St Ninian's Isle, Boddam, Quendale Bay, and Sumburgh Head. Most of these were based on >25h of effort.

Although several sites in Orkney had a regular porpoise presence, only The Wing in North Ronaldsay had a high sighting rate (11.0/h) but that was based on just 1h of effort. All other Orkney sites had count rates of 2.0/h or less.

In north Caithness, count rates of c. 3-4 animals/h occurred at Scrabster Lighthouse (>9h effort) and St John's Point, Gills Bay (>10h effort), and on the northeast coast, Shelligoe Clifftop (c. 5h effort), Brora (>25h effort), Strathsteven (>15h effort), and Golspie (>10h effort) all had count rates of 3-5 amimals/h. On the south side of the Dornoch Firtth, count rates at Dornoch (c. 3h effort), Tarbat Ness (>30h effort), and Rockfield (5h effort) all exceeded 3 animals/h. The inner Moray Firth had consistently low count rates (<1 animal/h) as did the southern shores of the outer Moray Firth including north Aberdeenshire (<2 animals/h), with the exception of Covesea with 3.4 animals/h (c. 30h effort). On the east Aberdeenshire coast, high count rates (3.2-7.8 animals/h) occurred at Collieston (>100h effort), Newburgh (>10h effort), Balmedie (>45h effort), Cove (c. 100h effort), and Downie Point, Stonehaven (c. 3h effort). Count rates were then low (1 animal/h or less) until Souter, Sunderland (3.7 animals/h, but based on only 3h effort), Scarborough (4.2 animals/h with >500h effort) and Filey Bay (4.6 animals/h; c. 4h effort) in north Yorkshire. Although slightly elevated at Bempton and Flamborough (c. 1.5 animals/h at both, with >40h effort), count rates remained low (generally c. 0.2 animal/h) at all sites in eastern England south to the Thames Estuary (except Blakeney Point with 1.7 animals/h, but with just 3h effort), and westwards along the south coast only increasing somewhat from Start Point (1.4 animal/h) in south Devon. The only site on the south coast with a high count rate (3.7 animals/h) was Warren Point, south Devon (c. 15h effort), count rates at sites in south Cornwall being all <2 animals/h.

In north Cornwall, Stepper Point near Padstow had an extremely high count rate (73.8 animals/h), but based upon just 3h effort and presumably the result of unusual conditions. Along the north Devon coast, Hartland Point (>75h effort), Baggy Point (>350h effort), and Morte Point (c. 400h effort) all had high count rates (3-5 animals/h). Count rates at Lundy Island were between 1-2.5 animals/h (c. 90h effort overall).

Further east into the Bristol Channel, count rates were consistently around 1-2 animals/h, except at High Veer Point where 4.5 animal/h (but based on just 2h effort).

Sites along the south coast of Wales had count rates of 1-2 animals/h, except Paviland on the Gower Peninsula with 3.2 animals/h (but based on only 2.5h effort). The islands of Skomer and Skokholm had count rates of 1-2 animals/h (effort >30h for both islands).

Table 2. List of sites with relatively high sighting/count rates for harbour porpoise (lower threshold: 1.0 sighting/hour or 3.0 animals/hour)

Site name	Region	Effort hrs	SPUE	CPUE
Muness, Unst	Shetland	1.1	1.8	2.8
Fethaland	Shetland	15.0	1.8	5.0
Tresta, Fetlar	Shetland	6.0	1.2	3.0
Skaw, Whalsay	Shetland	26.0	3.0	9.6
Lunning Sound from Lunning	Shetland	9.3	1.7	2.9
Bressay Broch	Shetland	13.7	2.0	8.3
Mansies Berg, Noss	Shetland	3.8	3.9	9.7
Cols Ness, Noss	Shetland	2.2	1.4	5.1
Noss Sound from Noss	Shetland	357.3	1.8	4.4
Turr Ness, Noss	Shetland	29.8	6.5	15.9
Mousa North Site	Shetland	467.9	4.5	8.8
Mousa Sound (Central site)	Shetland	484.5	4.2	7.6
Mousa South Site	Shetland	83.3	3.1	5.2
Sandwick	Shetland	6.7	1.4	2.6
Noness	Shetland	5.0	1.8	3.8
St. Ninians Isle	Shetland	54.1	2.8	6.7
Boddam (OutVoe)	Shetland	40.2	1.4	3.2
Quendale Bay	Shetland	101.2	1.6	3.7
Sumburgh Head	Shetland	183.0	0.4	4.3
Herston Head, South Ronaldsay	Orkney	10.4	1.1	2.1
The Wing, South Ronaldsay	Orkney	1.0	3.0	11.0
Scrabster Lighthouse	Caithness (N)	9.8	1.2	4.1
Thurso caravan park	Caithness (N)	2.0	2.0	4.0
St. John's Point, Gill's Bay	Caithness (N)	13.5	0.6	3.0
Shelligoe Clifftop	Caithness (E)	7.3	1.9	5.0
Brora	Caithness (E)	28.6	3.0	0.7
Strathsteven	Highland	17.0	1.9	4.9
Dunrobin Point	Highland	0.7	3.0	4.5
Golspie, Iain Macdonald's house	Highland	10.8	2.1	5.6
Golspie go cart track	Highland	4.0	1.8	3.0
Embo	Highland	2.0	3.0	7.0
Dornoch	Highland	3.8	5.6	24.8
Tarbat Ness	Highland	32.3	0.5	3.4
Rockfield	Highland	5.4	3.1	15.2
Covesea	Moray	29.9	0.4	3.4
Whinnyfold	Aberdeenshire	7.9	1.1	1.9
Collieston	Aberdeenshire	108.8	0.8	5.0
Newburgh	Aberdeenshire	5.3	1.1	7.6
Balmedie Beach	Aberdeenshire	45.5	0.6	3.8
Souter Head, Cove	Aberdeenshire	97.7	0.8	3.2
Downie Point, Stonehaven	Aberdeenshire	2.8	1.5	6.2
Souter Lighthouse, Sunderland	Tyne & Wear	3.0	1.0	3.7
East Pier, Scarborough	North Yorkshire	1.8	4.9	9.3
Holbeck Bay, Scarborough	North Yorkshire	6.3	1.6	2.4
Marine Drive, Scarborough	North Yorkshire	704.1	1.8	4.2
Filey Bay	North Yorkshire	3.7	2.7	4.6
Dungeness Bird Observatory	Kent	3.5	1.1	1.7

Warren Point S of Thurlestone	South Devon	14.3	0.4	3.2
Trenance, nr. Newquay	Cornwall	1.8	1.1	1.1
Stepper Point nr Padstow	Cornwall	3.3	0.9	73.8
Hartland Point	North Devon	75.9	0.6	3.1
Greencliff	North Devon	1.5	1.3	4.7
Baggy Point	North Devon	352.2	0.5	3.0
Tunnels Beach, Ilfracombe	North Devon	2.0	1.0	1.0
High Veer Point nr Martinhoe	North Devon	2.0	1.0	4.5
Hurlstone Point	North Devon	14.8	1.2	2.0
Paviland	Swansea	2.5	1.6	3.2
S. Ramsey Sound	Pembs (N)	389.8	1.3	5.3
Ramsey Bitches	Pembs (N)	31.5	1.0	3.1
Penbrush, Strumble Head	Pembs (N)	8.3	0.2	5.6
Strumble Head	Pembs (N)	638.5	0.4	5.9
Needle Rock, Dinas Head	Pembs (N)	2.7	1.9	5.6
Pen-y-Cil, Bardsey Island	Gwynedd	35.7	1.2	2.1
St Mary's Well, Bardsey Island	Gwynedd	39.1	5.4	10.0
North Stack	Anglesey	64.7	1.2	3.8
Llanbadrig	Anglesey	36.7	1.2	3.7
Point Lynas	Anglesey	2111.7	0.6	4.6
Elby Point, Niarbyl	Isle of Man	5.3	2.1	5.7
Ballaghennie	Isle of Man	3.0	5.9	10.9
Point of Ayre	Isle of Man	4.8	3.8	6.7
Blairmore	Argyll	20.3	1.0	2.2
Tobermory Lighthouse, Isle of Mull	Inner Hebrides	3.0	1.7	3.7
Salen Cemetery car park, Isle of Mull	Inner Hebrides	1.5	2.7	3.3
Stoer Head Lighthouse	Highland	79.4	1.4	4.0
Rodel, Harris	Western Isles	20.8	1.1	3.2
Portmuck, Island Magee	Co. Down	192.0	0.6	3.4

On the north Pembrokeshire coast, sites had high count rates (3-6 animals/h), notably at Ramsey Sound (>350h effort), Strumble Head >500h effort), and Needle Rock, by Dinas Head (but with <3h effort). The coast surrounding Cardigan Bay had low count rates of porpoises (<0.5 animal/h) until the western end of the Llyn Peninsula where Bardsey Island (particularly overlooking Bardsey Sound) (>150h effort) has a very high count rate (10 animals/h).

In North Wales, count rates are high (3-5 animals/h) around Anglesey at North Stack (>50h effort), Llanbadrig (>35h effort), and Point Lynas (>2,000h effort), and 1-3 animals/h at north coast sites in between. The east side of Anglesey and northeast mainland coast of Wales have low count rates (<1 animal/h).

Further north, sites in the Isle of Man generally had count rates around 1 animal/h, being high (5.7-10.9 animals/h only at Elby Point, Ballaghennie, and Point of Ayre (but all three sites with <5h effort).

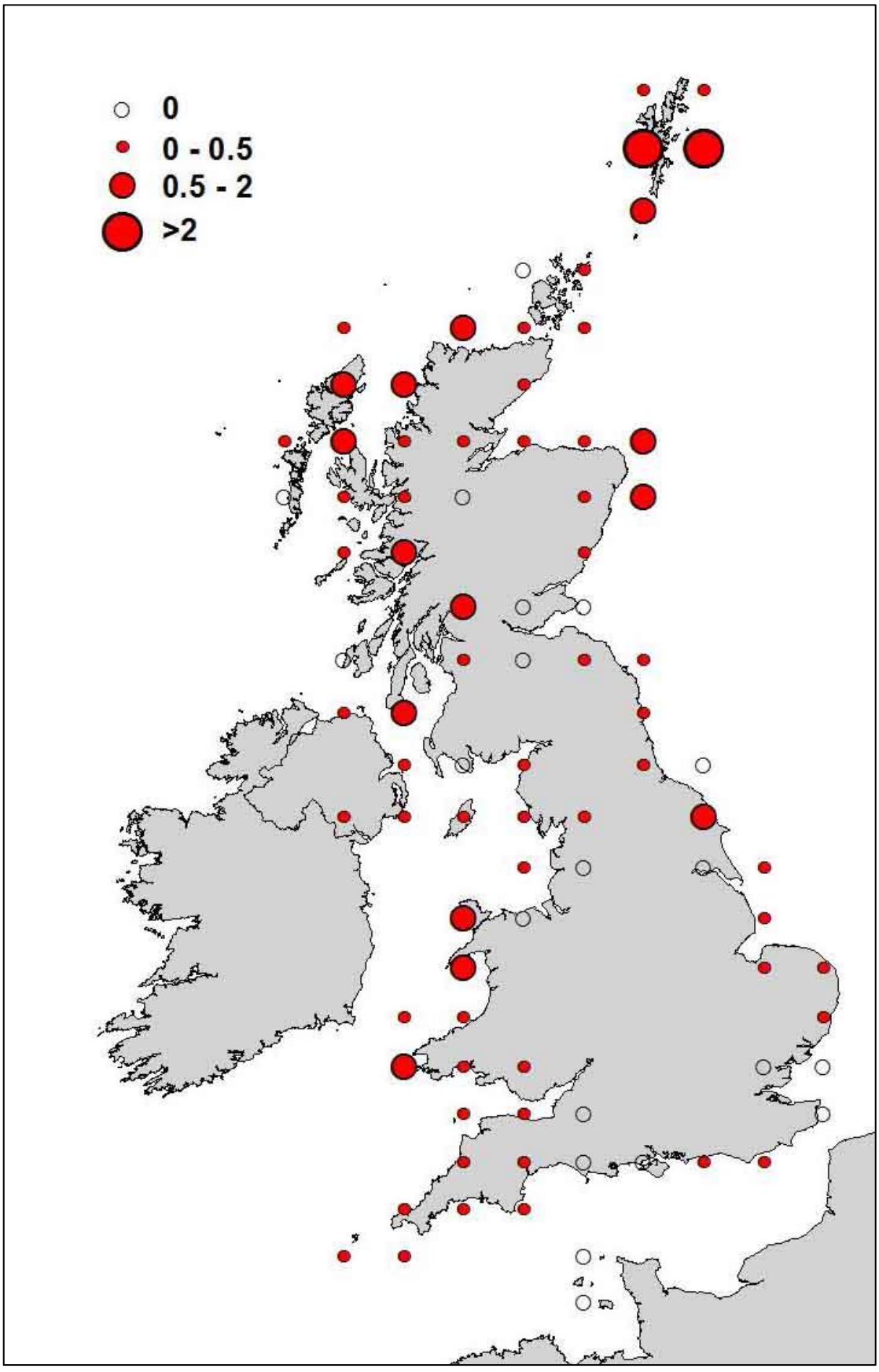

Figure 11. Map of Harbour Porpoise Sighting Rates by ICES rectangle

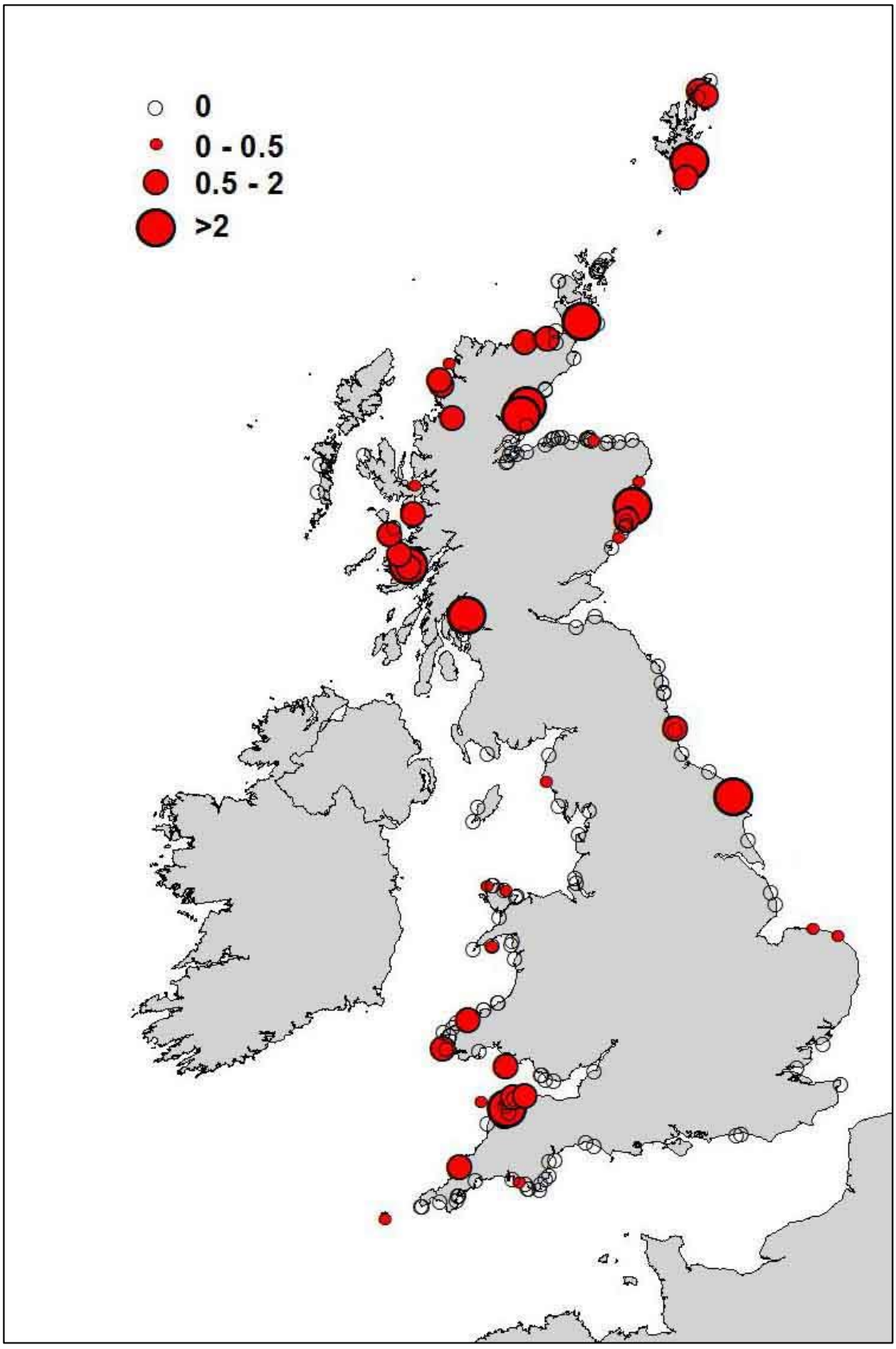

Figure 12a. Map of Harbour Porpoise Sighting Rates by site
(for watches with <3 h effort)

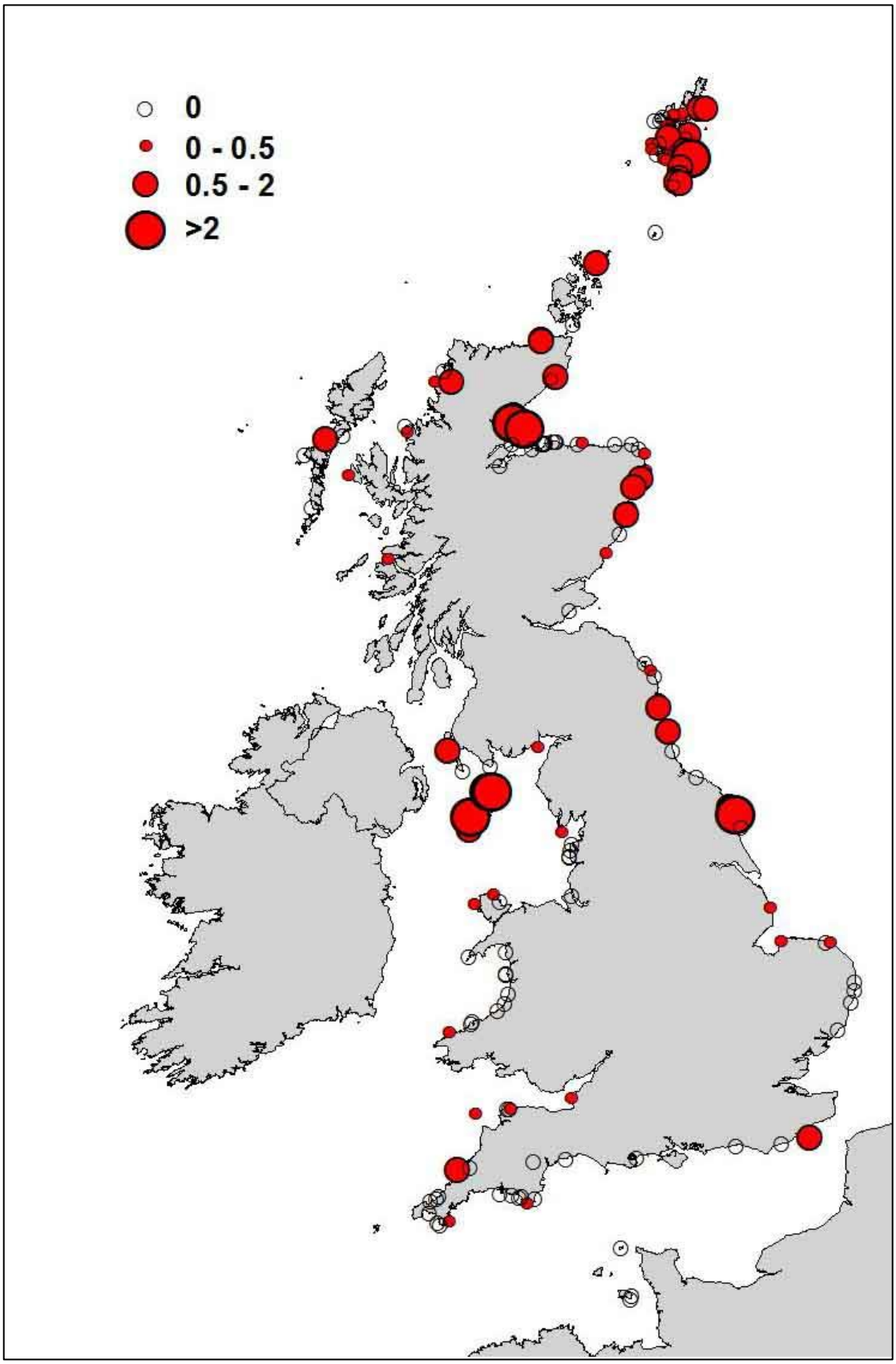

Figure 12b. Map of Harbour Porpoise Sighting Rates by site
(for watches with 3-10 h effort)

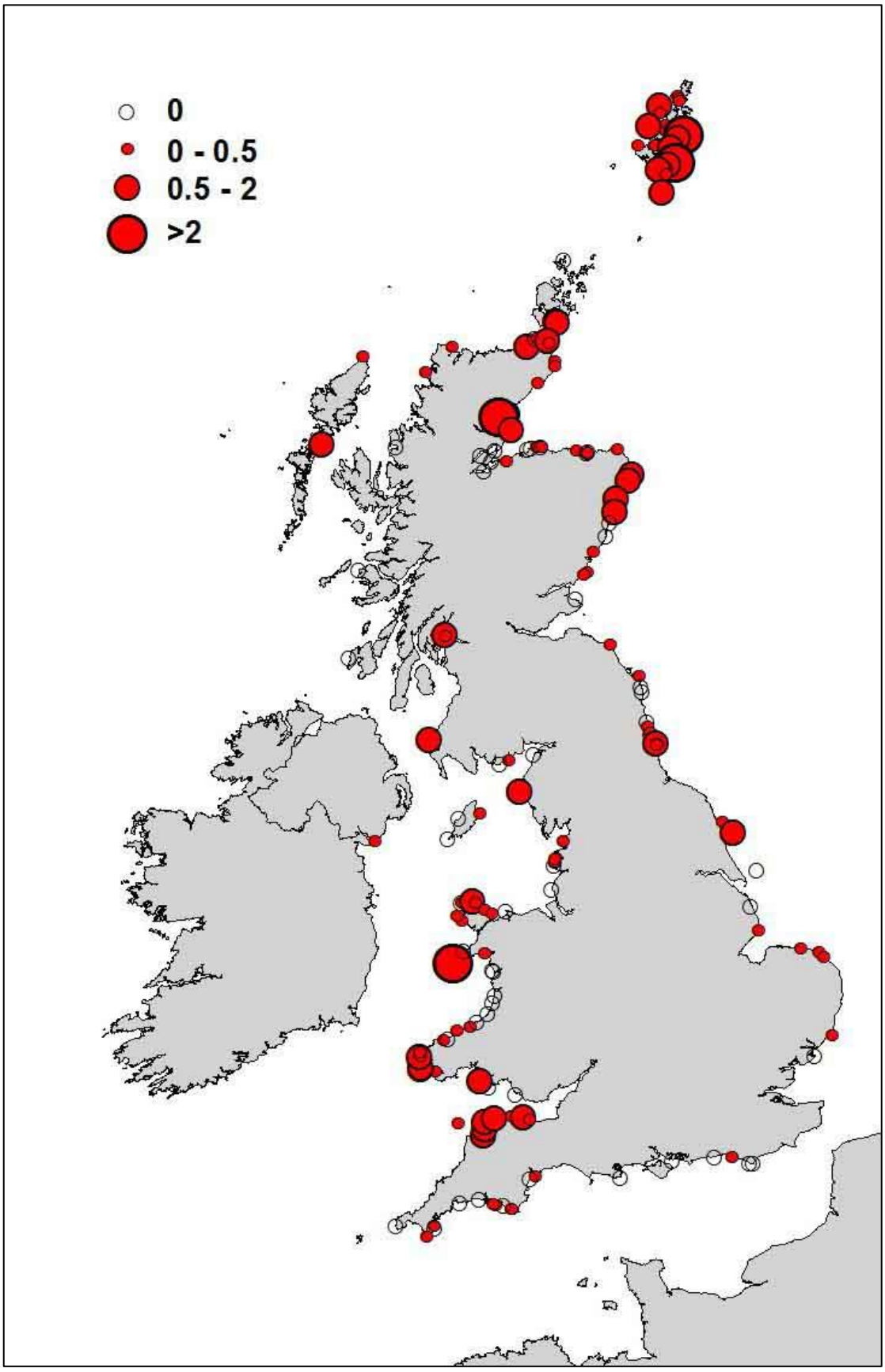

Figure 12c. Map of Harbour Porpoise Sighting Rates by site
(for watches with 10-50 h effort)

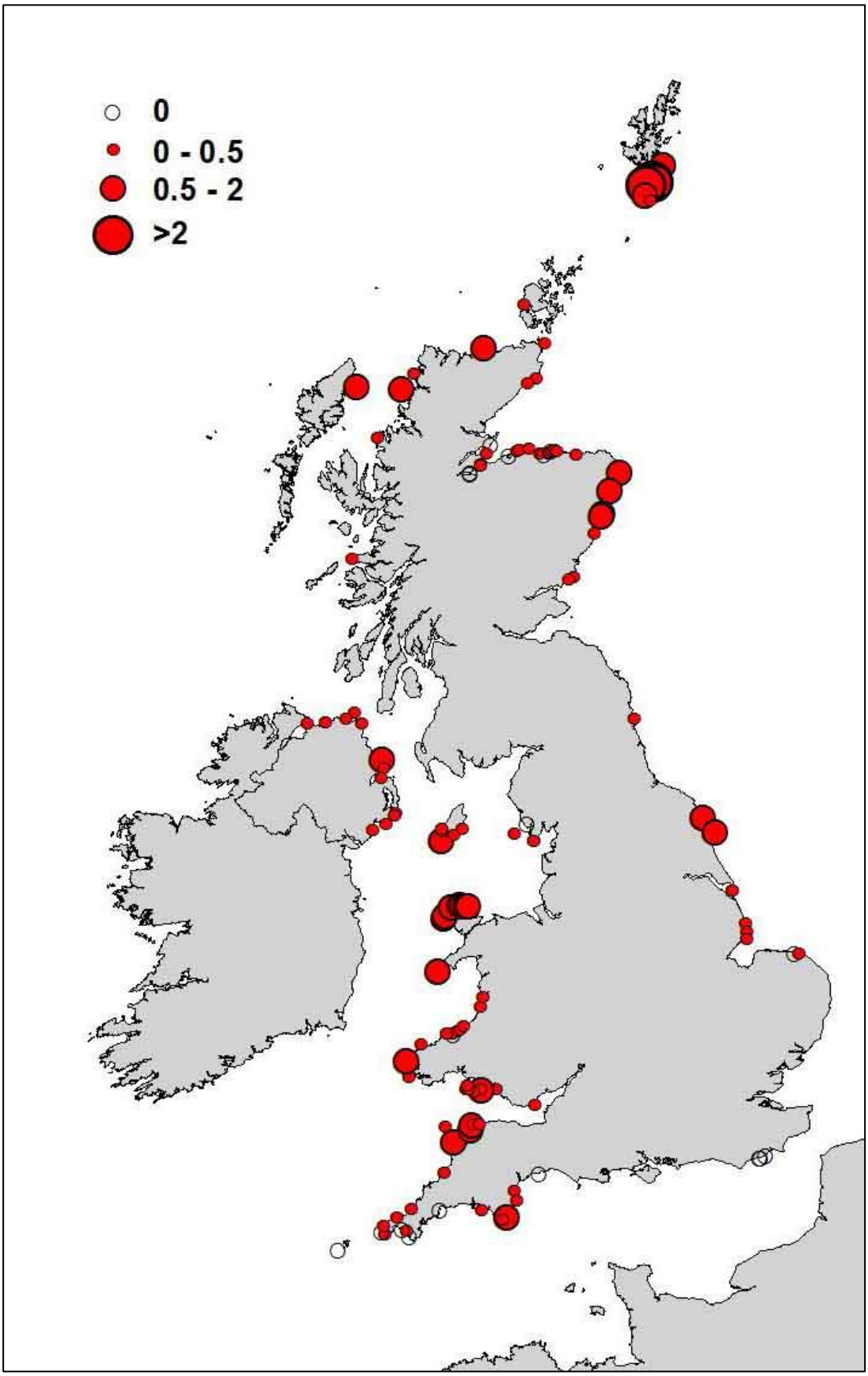

Figure 12d. Map of Harbour Porpoise Sighting Rates by site
(for watches with >50 h effort)

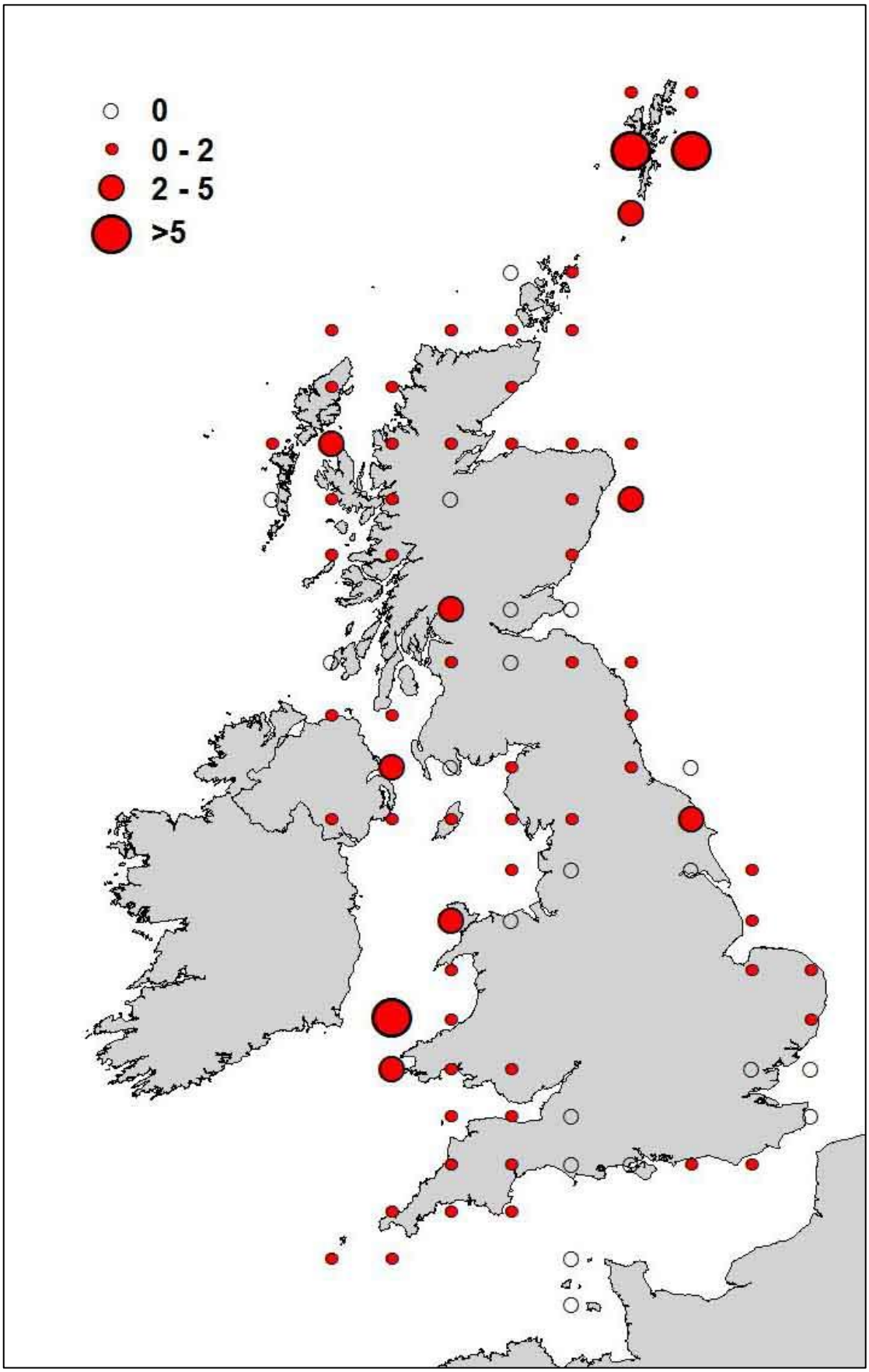

Figure 13. Map of Harbour Porpoise Count Rates by ICES rectangle

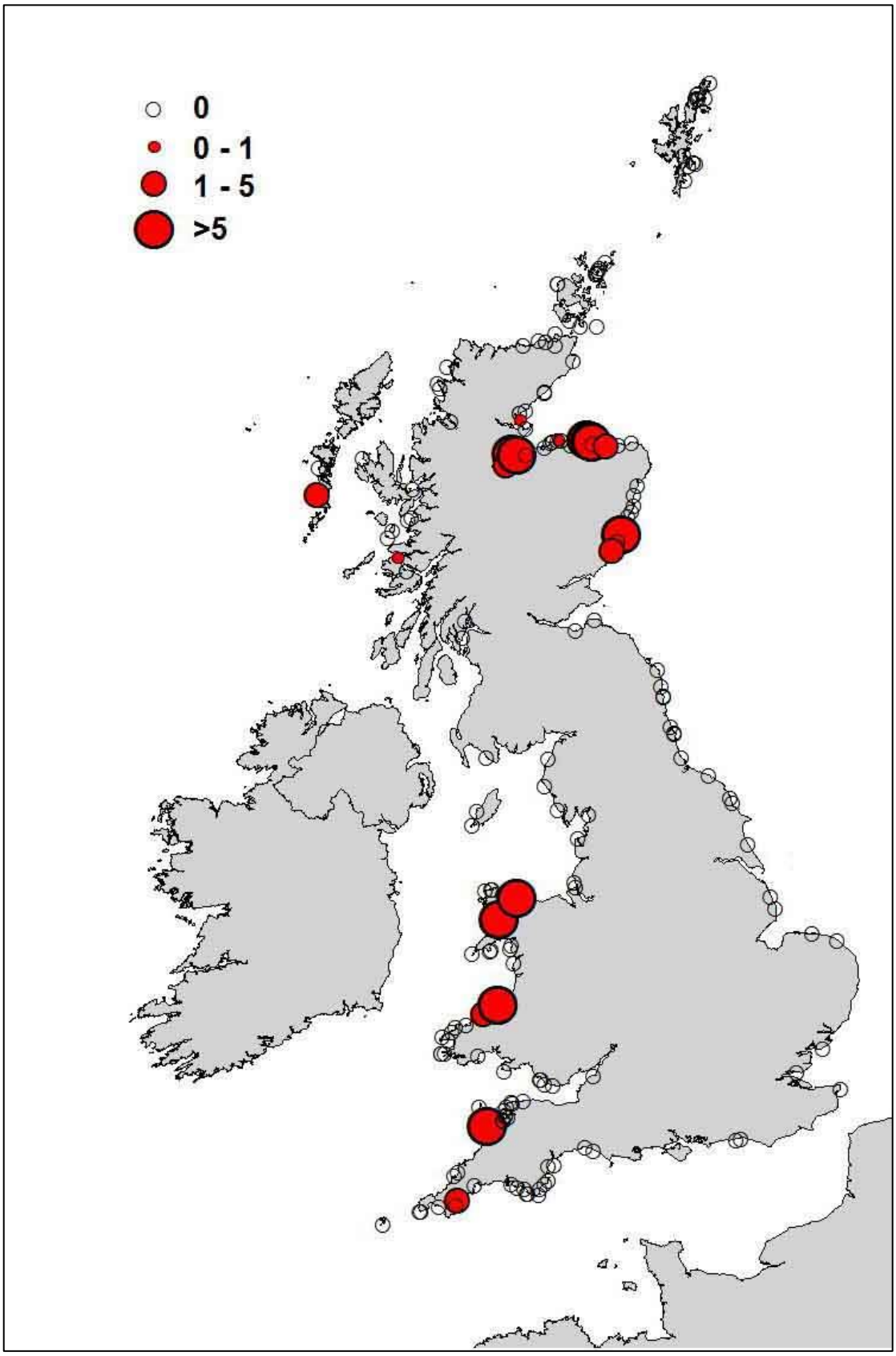

Figure 14a. Map of Harbour Porpoise Count Rates by site
(for watches with <3 h effort)

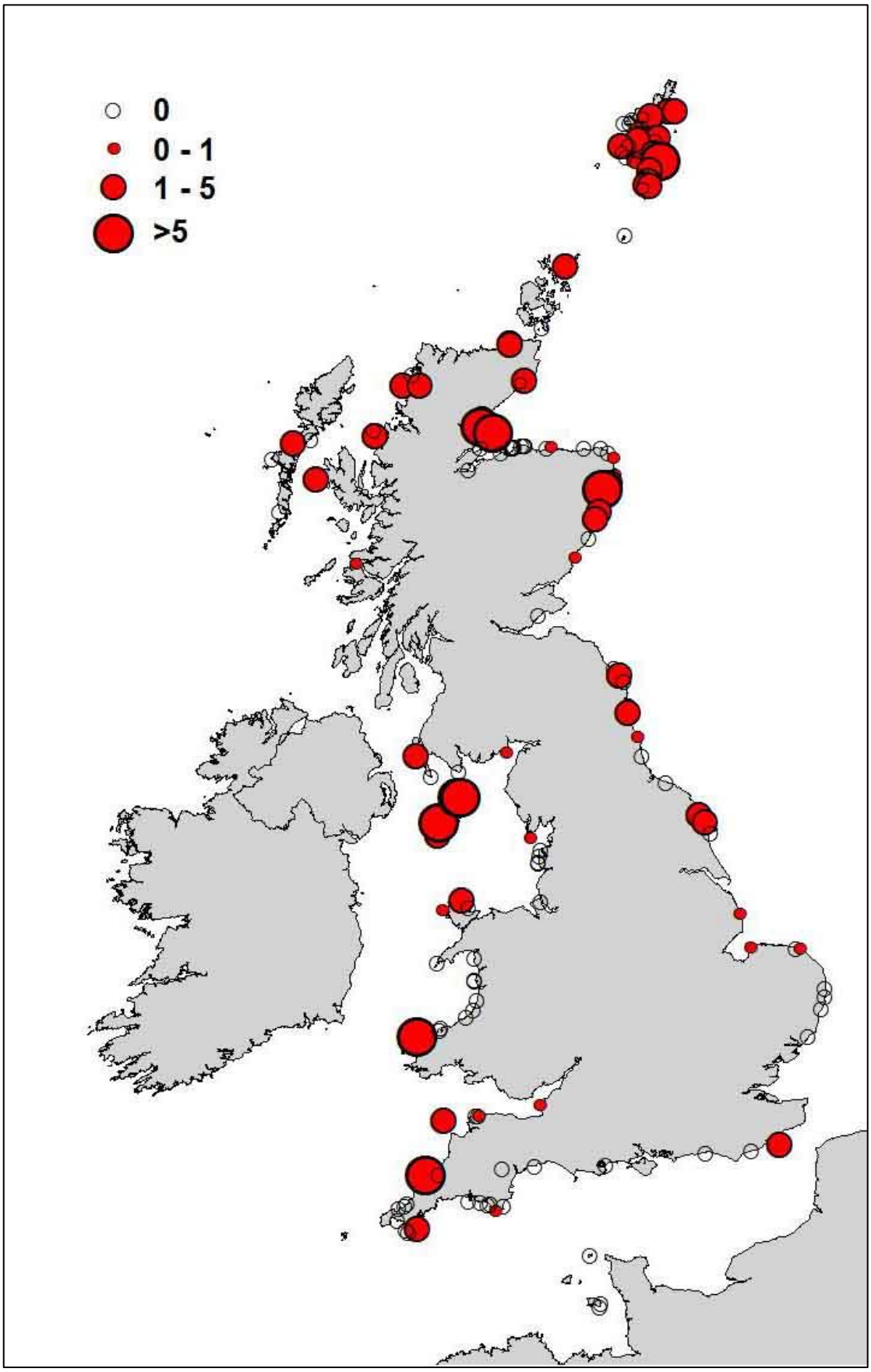

Figure 14b. Map of Harbour Porpoise Count Rates by site
(for watches with 3-10 h effort)

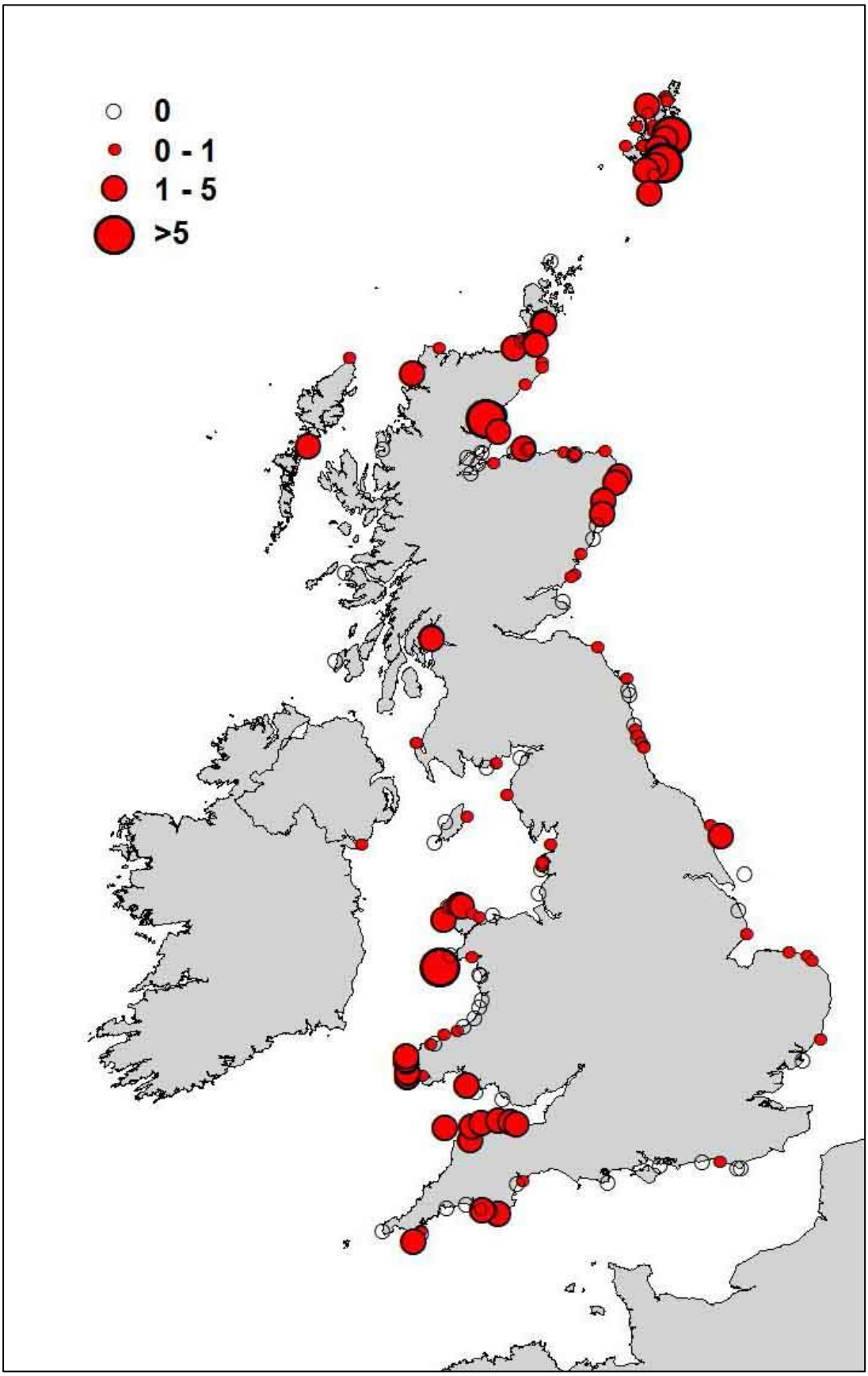

Figure 14c. Map of Harbour Porpoise Count Rates by site
(for watches with 10-50 h effort)

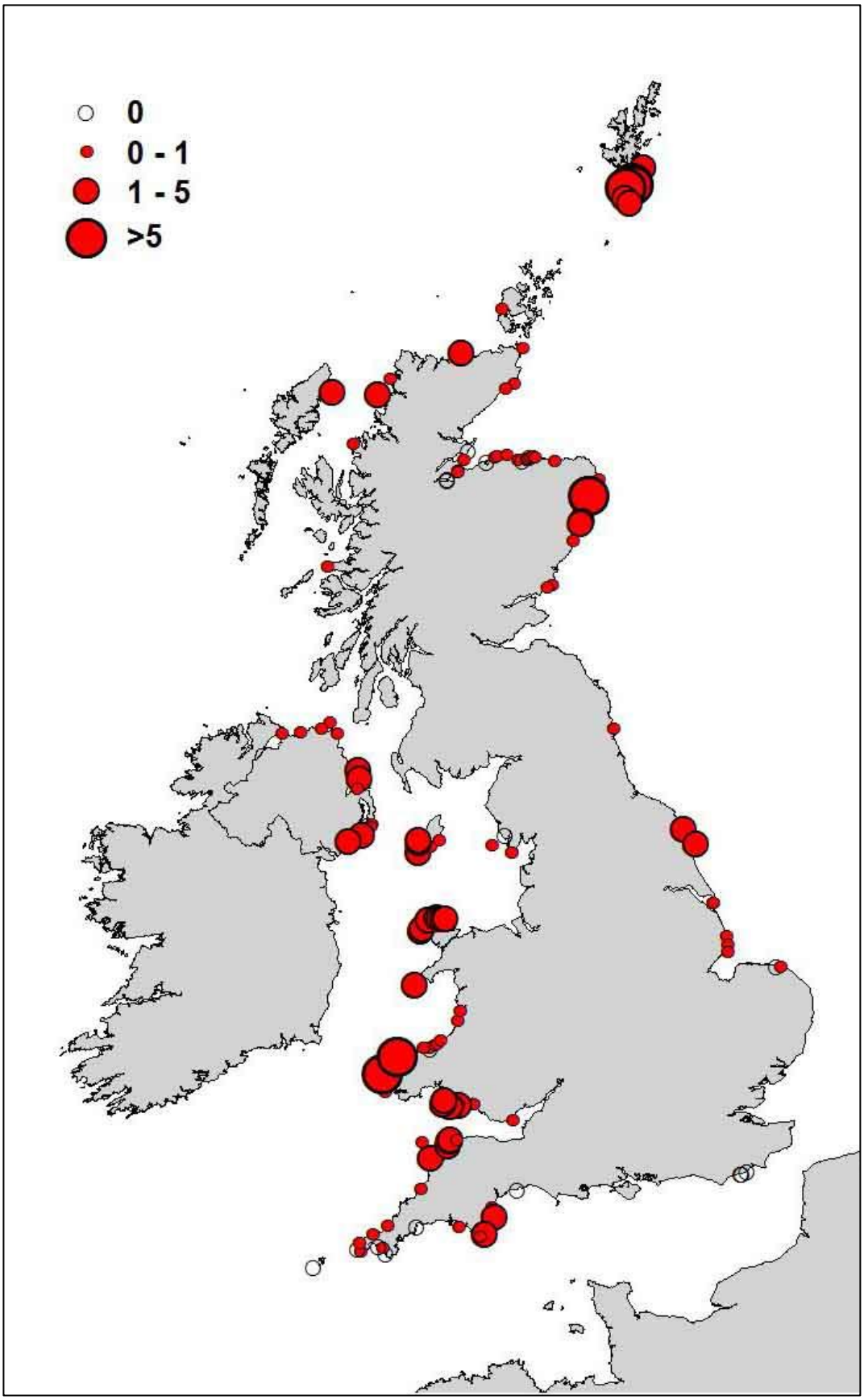

Figure 14d. Map of Harbour Porpoise Count Rates by site
(for watches with >50 h effort)

Count rates remain low (<1 animal/h) in Lancashire, Cumbria and Southwest Scotland until Strone and Dunoon where count rates increased to between 1-2.5 animals/h, and to between 3-4 animals/h on the Isle of Mull. Of the few sites in West Scotland where watches have occurred, high count rates of 3-4 animals/h are found at Stoer Head (c. 80h effort) and in the Outer Hebrides, at Rodel, Harris (>20 h effort), the rest all averages between 1-2 animals/h. Only moderate count rates (1.5 animals/h) have been recorded at the intensively watched Tiumpan Head, Isle of Lewis.

In Northern Ireland, count rates are <2 animals/h at all sites except Black Head (2.1 animals/h with >200h effort), and Portmuck, Island Magee (3.4 animals/h with c. 200h effort) in Co. Antrim. No porpoises were recorded during limited watching in the Channel Isles.

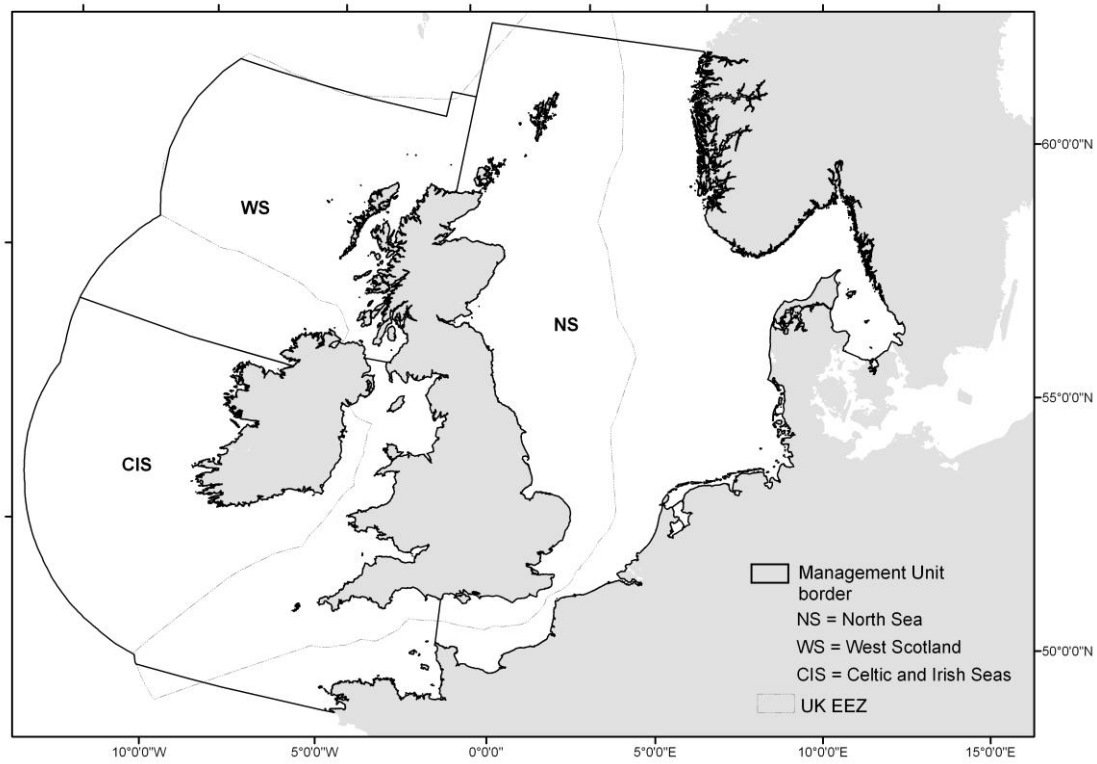

Figure 15. Map showing Management Units used for Harbour Porpoise

Using the three management units for harbour porpoise recommended by JNCC (see Figure 15), sites were allocated to one of the following: 352 in North Sea (NS), 278 in Celtic and Irish Sea (CIS), and 48 in West Scotland.

As with bottlenose dolphin, count rates per year were calculated for each of the 678 sites. Appendix 3 provides full details of effort and count rates by year from 1965 to the present, for each site within that management unit. Any entry in blue indicates effort in that year without any sightings of that species. Entries in yellow indicate positive sightings and provide the count rates for that year. Count rates are expressed as numbers of animals per minute of observation. At the end of the matrix is the sum of years for which there was watch effort from 1965 onwards, and then since 2000.

Generalised Additive Models were performed on each of the three harbour porpoise management units. The findings are presented in detail in Appendix 4.

Using Appendix 3, those sites at which there were at least three years of effort, with a minimum of 100 minutes per year (i.e. 5 hrs minimum of watch effort overall) were selected for plotting the GAM predictions. GAMs were run on the whole data set for each management unit separately, and the results presented here are scaled differently for the different management units, to best display variation within a particular MU. Thus comparisons between sites (see Figures 16a-e) should only be made within an MU.

Within the North Sea management unit, highest predictions occur in southern and eastern Shetland, the northern shores of the outer Moray Firth and around the Dornoch Firth), to a lesser extent along the north-east Grampian coast, and along the coast of eastern England between Scarborough and Flamborough Head, in Yorkshire (Figure 16a).

Moderately strong predictions occur along the coast of north Caithness and around Scapa Flow, Orkney, and, interestingly, around the Wash and parts of East Anglia (Norfolk and Suffolk).

Porpoises within the Celtic and Irish Sea management unit are more evenly distributed but with six main focal areas: 1) the Lizard Peninsula, south Cornwall; 2) the south side of the outer Bristol Channel between Bideford, north Devon and Minehead, Somerset; 3) Swansea Bay and the Gower Peninsula; 4) west and north Pembrokeshire coast and islands; 5) northwest and north coasts of Anglesey; and 6) the coasts of Co. Down and south Antrim, Northern Ireland (Figure 16b). Babbacombe Bay and the western sector of Start Bay (south Devon) may also be a hotspot based upon high predictions, but those sites have relatively low effort.

Predictions for the West Scotland management unit are weak due to the paucity of land watch data, with only the coast in the vicinity of Magilligan Point, Co. Derry, showing up strongly (Figure 16c).

A final set of analyses used (a) the whole data set and (b) all data from 1994 onwards (see Appendix 4, Figures A4.4-A4.6). For both data sets, models including a latitude x longitude smoother (as for the individual MUs) give similar results, highlighting the occurrence of harbour porpoise all around the coast but also identifying peaks, notably those in north Scotland and in eastern England along the north Yorkshire coast.

Re-running the 1994 onwards model with site number substituted for latitude and longitude (thus assuming the coast can be represented as a one-dimensional spatial access) produced a less nuanced picture, with some of the spatial structure in occurrence patterns flattened out. However, this approach facilitated inclusion of a site x year interaction. Visualisation of predictions for 1994 and 2013 from this latter model indicates that while “preferred” areas were broadly similar in both years, there has been a decline in the importance of the east coast of Scotland (especially pronounced in the north) and an increase in importance on the east and south coasts of England (see Figure A4.6).

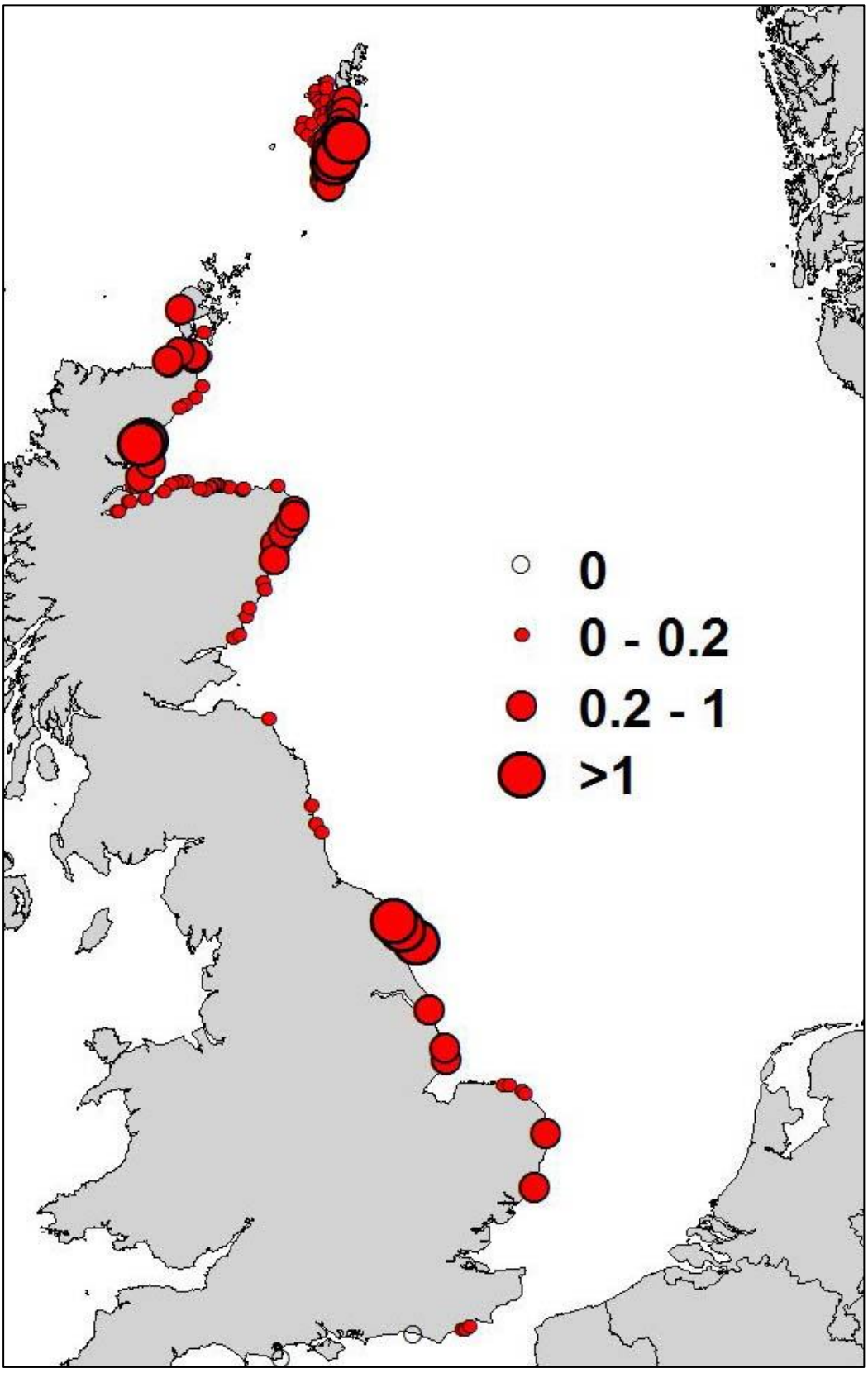

Figure 16a. Map of GAM predicted groups per standardised observation for Harbour Porpoise North Sea Management Unit

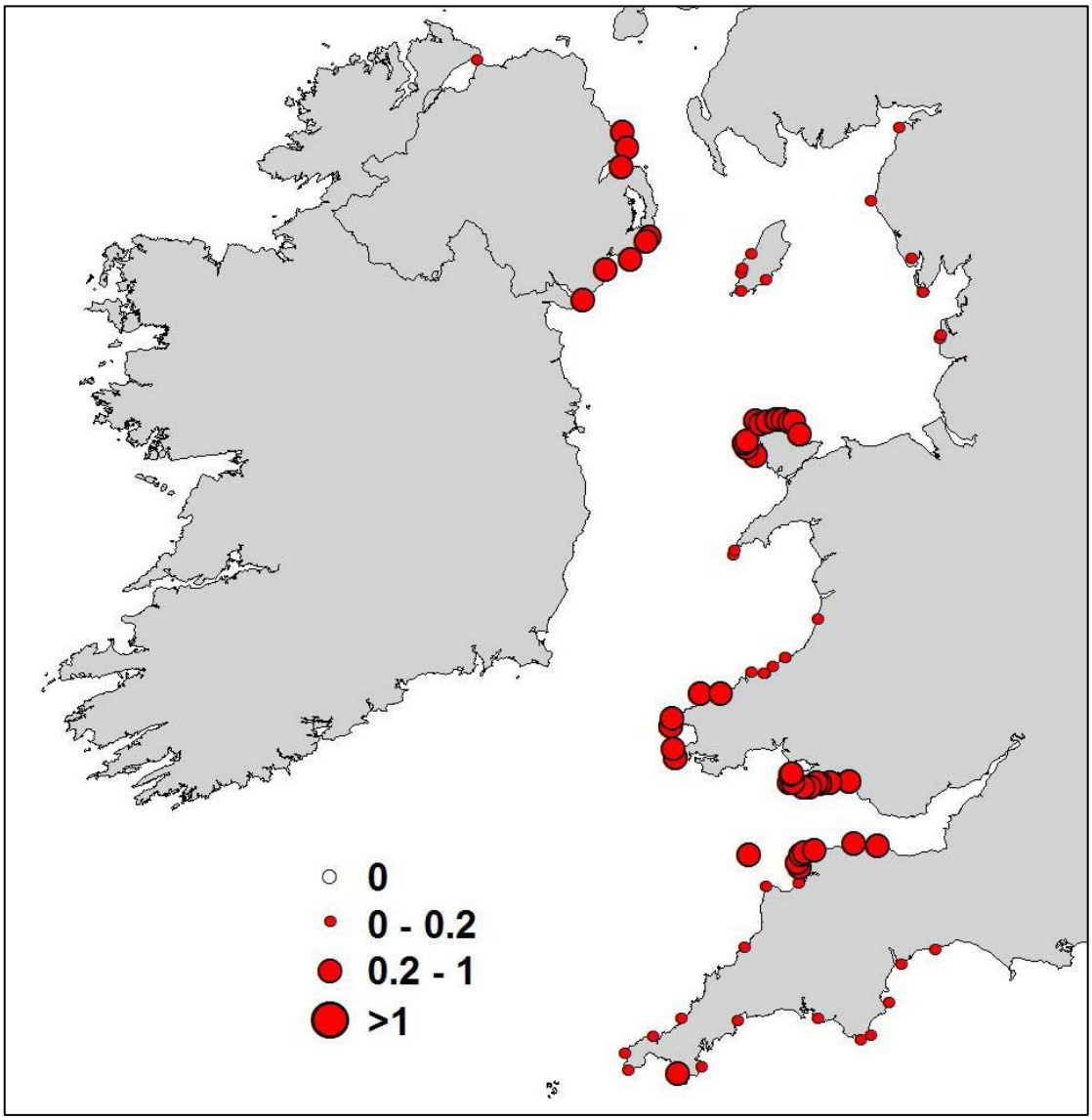

Figure 16b. Map of GAM predicted groups per standardised observation for Harbour Porpoise Celtic & Irish Sea Management Unit

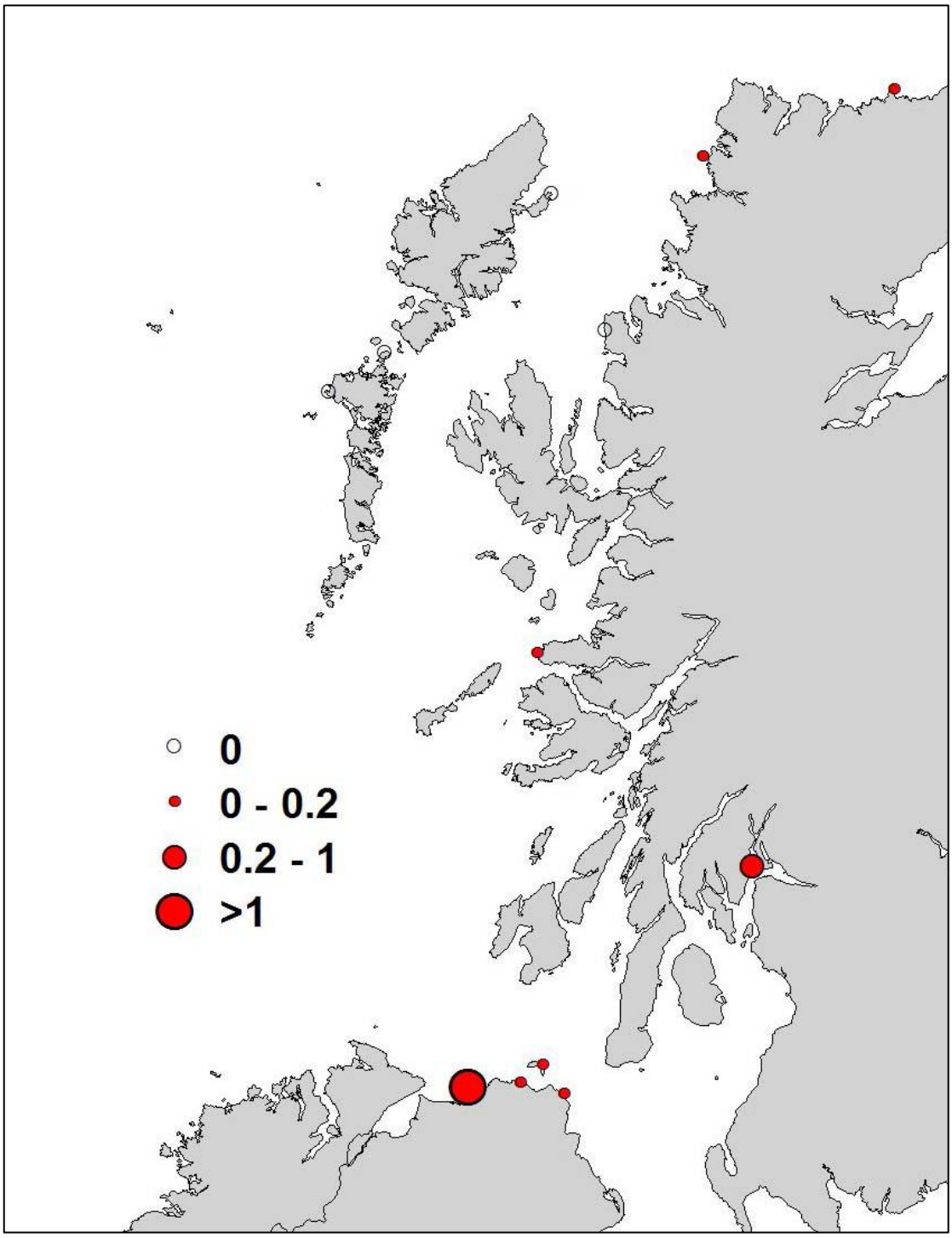

Figure 16c. Map of GAM predicted groups per standardised observation for Harbour Porpoise West Coast Scotland Management Unit

6 DISCUSSION & CONCLUSONS

Land watch effort is reasonably well distributed around the UK. However, there are certain areas where coverage is poor. Notable amongst these are the west mainland coast of Scotland, the Hebrides, and to a lesser extent, Southeast England, whilst some areas (e.g. Shetland) have had very little effort in the last decade. Although dedicated effort started as long ago as 1965, the majority has been in the last ten years. Similarly, effort has been concentrated very much on the summer months between May and September. For the most part, protocols used for land watches have been very comparable, despite large numbers of observers and local groups being involved over several decades. Compared with offshore vessel surveys, land watch effort is significantly greater (with effort exceeding 50 hours at around 100 sites), and may extend over several years. On the other hand, the fact that observations are at a static location means that it is impossible to derive absolute densities or abundance from observations. However, the results presented here do indicate areas of relative high numbers of sightings and animals, and should complement offshore survey effort.

The coastal distributions of the two species under consideration as revealed from the land watches accord with our current knowledge: bottlenose dolphins are concentrated around west Wales and eastern Scotland, with very few along North Sea coasts south of Edinburgh and the coast of southern England east of Poole; harbour porpoises, on the other hand, are much more evenly distributed but nevertheless occur in a few areas at relatively high numbers. Strikingly, the distributions of the two species more or less displace one another. This is further demonstrated by the results of the GAM model comparing harbour porpoise and bottlenose dolphin distributions by site, which emphasises the negative relationship between the occurrences of the two species. Wherever bottlenose dolphins occur regularly (south side of the Moray Firth around the Grampian coast south to the Firth of Forth, coastal Cardigan Bay, and east coast of Anglesey), porpoise are relatively uncommon. This may well be due to the fact that bottlenose dolphins are known to attack porpoises where the two co-occur.

As one might expect, the Generalised Additive Models function best for management units where there are a lot of data. Thus the results from West Scotland, for example, are not very meaningful, whereas predictions are more robust in the Irish Sea, western Channel, east coast of Scotland, and eastern England.

To conclude, land watches indicate that coastal bottlenose dolphins are concentrated in two main regions: 1) eastern Scotland from Brora to Carnoustie, with a relatively even distribution; and 2) the Welsh coast in Cardigan Bay and to a lesser extent off north & east Anglesey. Elsewhere, the species occurs only occasionally, except possibly for the following locations: Falmouth Bay and around the Lizard Peninsula in Cornwall, and in Bideford Bay in North Devon. The species is also known to range around the Inner Hebrides in small numbers, with a small resident population off Barra; and the northern Irish Sea including the Isle of Man, the Cumbrian coast, and coasts of Counties Down and Antrim.

Harbour porpoises are more widely distributed, with relative hotspots (mostly associated with high tidal energy) in the following coastal areas:

North Sea MU: 1) southern and eastern Shetland; 2) the northern shores of the outer Moray Firth and around the Dornoch Firth), and to a lesser extent 3) along the northeast Grampian coast, and 4) along the coast of eastern England between Scarborough and Flamborough Head, in Yorkshire. Areas worth investigating further include the coast of north Caithness and around Scapa Flow, Orkney, and around the Wash and parts of East Anglia (Norfolk and Suffolk).

Celtic and Irish Sea MU: 1) the Lizard Peninsula, south Cornwall; 2) the south side of the outer Bristol Channel between Bideford, north Devon and Minehead, Somerset; 3) Swansea Bay and the Gower Peninsula; 4) west and north Pembrokeshire coast and islands; 5) northwest and north coasts of Anglesey; and 6) the coasts of Co. Down and south Antrim, Northern Ireland. It is possible that Babbacombe Bay and the western sector of Start Bay (south Devon) may also be a hotspot. This area has relatively high predictions but these are based upon sites with low effort.

These analyses have followed the management units prescribed by JNCC. It is perhaps worth noting, however, that for bottlenose dolphin, photo-identified individuals from the Moray Firth have been observed inside the current North Sea management unit (as far south as Whitby in Yorkshire), whereas on the other hand, with the Channel and Irish Sea management unit, no bottlenose dolphin photo-identified from the Channel Isles and adjacent coast of Normandy (where a resident population, numbering around 400 animals, lives) has ever been photographed along the coast of southern England (and the converse). There is also evidence to suggest that the harbour porpoise population in Shetland is more closely related to that in southern Scandinavia (and both appear to be experiencing similar demographic changes).

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APPENDICES

1 Site Summaries: Table A1 - headings: site number, site name, region, latitude, longitude, elevation, number of observers, observation area (field of view), optics (whether optics used continuously), observation method (scan sampling or not), and recording method; Table A2 - headings: site name, region, number of minutes of effort, months covered, years covered, bottlenose dolphin management unit, harbour porpoise management unit)

2 Geographical Distribution of land watch effort: a) up to 3 hours; b) 3-10 hours; c) 10-50 hours; d) more than 50 hours of effort

3 Tables of Persistence by species and by management unit: headings: management unit, site number, year, count of years with effort, count of years with effort since 2000

4 Detailed Results of the GAM Analyses by species, and by management unit.