

ATLAS

*of CETACEAN
distribution in north-west
European waters*

compiled and edited by

James B. Reid, Peter G.H. Evans and Simon P. Northridge



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2003



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INTRODUCTION



Cetaceans sustain a depth of fascination that is almost without parallel in nature. Along with primates, they are among the most intelligent of all mammals; but while this might account for the allure of primates, the natural environment of cetaceans also adds to the interest of this order of animals. Encounters with cetaceans are difficult to contrive because they inhabit a world that is largely unseen. Despite increased attention in recent years, the oceans remain places of mystery; the ecological processes that underlie observable patterns in marine communities are largely unknown and seem almost arcane.

Compared with many terrestrial mammals, little is known of cetacean natural history. Indeed, knowledge of some species comes from only a handful of dead specimens, and new species are still being either recognised or discovered relatively frequently. Again, this is not surprising for animals that usually only briefly break the surface of the sea.

That cetaceans are difficult to observe, however, should not disguise the fact that populations of some species are very large. This is true not only in seas traditionally thought of as high in cetacean abundance but also of the Atlantic and associated seas around Europe. For example, in north-west European and adjacent waters there may be more than 100,000 minke whales present at certain times of the year (Schweder *et al.* 1997). The seas of north-west Europe also host a rich variety of cetacean species. More than 20 species may be seen here regularly throughout the year, about half as many again as occur regularly in the south-west Atlantic at similar latitudes (White *et al.* 2002). This represents a diversity of form and function that demands effective conservation.

The proper conservation of cetaceans depends on knowledge of many aspects of their population ecology. Ideally, information on population size, structure and seasonal distribution, as well as data on mortality, breeding productivity, and emigration and immigration rates should be available. For the reasons outlined above such information for most cetaceans is largely non-existent.

However, cetacean populations in some parts of the world are rather better known than in others. In north-west European waters, for example, there are many data available that may aid in the conservation of populations here. In particular, the increasing number of at-sea surveys adds to knowledge of the distribution, and in some cases the abundance, of our animals. Perhaps the best example here is the SCANS survey, which investigated the distribution and estimated the population size of harbour porpoises in the North Sea and adjacent waters in July 1994 (Hammond *et al.* 1995, 2002). Such large-scale surveys aid in placing subsequent mortality events, chronic or otherwise, in the proper population and geographical contexts. For example, the estimated magnitude of fishery bycatches of porpoises in the North Sea has allowed an assessment of the sustainability of current bycatch levels to be made (Vinther 1999; Hammond *et al.* 2002). Identification of patterns of cetacean distribution and abundance is an important early goal of research that aims to underpin conservation measures, as well as being one that can be relatively easily achieved. In conjunction with other information, knowledge of cetacean dispersion also aids in the investigation of the ecological determinants of dispersion, of the biological and physical processes that might generate dispersion patterns, and consequently of the habitat requirements of the various species. If time series data are also available then any detected distributional shifts, or changes in population size, of these top predators may be indicative of more far-reaching changes, or even disruption, to ecosystem processes.

It is perhaps as a natural heritage resource in their own right, however, that cetaceans are increasingly the focus of conservation research. The array of potential threats to cetacean populations has never been greater. Anthropogenic effects in the form of oil and chemical pollution, disturbance, noise pollution, habitat degradation and even deliberate persecution persist, although impacts on populations remain either minimal or obscure. While hunting currently poses little or no threat, notwithstanding the fact that the minke and pilot whales are still exploited by Norway and the Faroe Islands in the north-east Atlantic, interactions with fisheries do result in detectable changes at the population level. It is now widely accepted that fisheries have played a

major role in the dramatic decline of porpoises in the Baltic in recent decades (ASCOBANS 2002), and there is also serious cause for concern that current or recent bycatch levels of porpoises in the North Sea and Celtic Sea may be unsustainable (Harwood *et al.* 1999; Tregenza *et al.* 1997).

For whatever reason, populations of some species in the north-east Atlantic have been extirpated from localised areas (e.g. the harbour porpoise in the eastern Channel) or even from much larger areas (e.g. the grey whale in the Atlantic).

The increasing diversity of possible threats to cetacean populations has seen a concomitant rise in the number of government agencies and non-governmental organisations (NGOs) devoted to their study. The former have instigated investigations on national and international scales, while NGOs have focused mostly on more restricted areas. In the UK, the principal and longest established NGO that carries out conservation research into cetaceans in British and Irish waters is the Sea Watch Foundation, which has been doing so in collaboration with other, smaller NGOs since 1973. The UK Government's advisor on nature conservation, the Joint Nature Conservation Committee (JNCC, formerly the Nature Conservancy Council), has also, since 1979, been carrying out research on the distribution of cetaceans from a much wider sea area of the north-east Atlantic. In association with other European government bodies and NGOs (listed in the Acknowledgements), the JNCC acts as a focus for the collation of effort-related sightings data of cetaceans over the north-west European continental shelf. The Sea Mammal Research Unit, part of the UK Government's Natural Environment Research Council and now also of the University of St Andrews, Scotland, has also been pursuing collaborative research on cetaceans with international counterparts since its formation in 1978. These organisations, with the longest track records of cetacean research in Europe, and their collaborators have contributed cetacean sightings data to a co-operative venture, the Joint Cetacean Database (JCD), and it is the data from this resource that are depicted in this Atlas.

The JCD comprises the most comprehensive information on the distribution of cetaceans in north-west European waters and this Atlas contains the most complete quantitative description of cetacean dispersion in this region. The distributional data herein presented for many of the more commonly occurring species are, for the first time at this broad geographical scale, effort-related; the user of the Atlas is thus accorded a greater degree of

interpretative scope than previously available. The Atlas and database therefore aim to function as a practical conservation tool; as a first step in an audit of the occurrence of cetaceans at this scale their use can, with caution (see Methods), enable the proper contexting of new information on cetacean distribution and abundance, and they may also inform efforts to identify areas that might be particularly important for cetaceans. Indeed the database has already fulfilled this latter function with respect to the possible identification of Special Areas of Conservation for harbour porpoise (Bravington *et al.* 2002; Evans and Wang 2003).

The JCD is the product of a very fertile collaboration between different organisations both within the UK and in Europe as a whole. In the longer term, the JCD has the potential for growth as the existing collaborators continue to collect and contribute data, and as new partners join the venture. Such development should widen the scope and utility of the database and may enable identification of seasonal patterns of cetacean dispersion as well as habitat associations; perhaps it will foster more process-related research.

This Atlas aims to provide an account and snapshot of the distribution of all 28 cetacean species that are known certainly to have occurred in the waters off north-west Europe in the last 25 years, but including also narwhal and melon-headed whale for which records are as recent only as the 1940s. It cannot function as a 'where to watch cetaceans' guide and the reader is advised to read carefully the Methods chapter in order to aid interpretation of the maps. Most of the book comprises chapters covering individual species. In the majority of these, a brief account of the natural history of the species is presented, including information on identification, behaviour and social organisation, diet, and habitat preferences, inasmuch as such information is known. There follows some details of the species' worldwide distribution and its status in the north Atlantic, and then a description of its occurrence in north-west Europe accompanied by a map depicting this.

The Methods chapter describes data collection methods, database establishment, brief details of the analytical methods that were applied to render the data from many sources compatible, and the important section on map interpretation. In other chapters, the nature of the marine environment of the study area is described and information is presented on the current legislative instruments aimed at protecting cetaceans.



The topography of the Atlantic Ocean floor is dominated by a central S-shaped ridge extending from the Arctic Ocean south as far as the Southern Ocean. This immense mountain range - the mid-Atlantic ridge, divides the Atlantic into two roughly parallel troughs, which are in turn sub-divided into smaller basins by transverse ridges that emerge to form islands such as Iceland, the Faroes, and the Azores. Much of the North Atlantic Ocean here reaches depths of 1,000-5,000 m. Further east, the continental shelf of north-west Europe gives rise to the islands of Britain, Ireland and their satellites. The seas off north-west Europe, including the North Sea, the Irish Sea and the English Channel, are much shallower and only in a few places exceed a depth of 200 m. On the northern edge of the Bay of Biscay, to the north-west of Ireland, and west of the Outer Hebrides, the continental shelf slopes very steeply from 200 m to 2,000 m or more over a distance of a few kilometres.

The Atlantic region

The current pattern of the North Atlantic is dominated by the great sweep of the North Atlantic Gyre, a roughly circular system of relatively warm waters driven by the North East Trade Winds between 10° and 30° N, and by westerlies between 40° and 60° N. The Gulf Stream (or North Atlantic Drift or Current as it becomes known further north) affects profoundly the climate of Europe. It has its origins near the Bahamas and sweeps across the Atlantic and extends far into the Barents Sea, the main branch passing to the north-west of Scotland. It has several offshoots; the Canary Current turns southwards, another turns east towards southern Ireland, southern England and Brittany, the Irminger Current turns north towards east Greenland, and another current turns into the North Sea between Scotland and Norway. The speed of the main circulatory currents is usually about 10 km per day whereas the Gulf Stream is much faster and can exceed 125 km per day.

The two deep troughs that lie between Britain and Rockall and Britain and the Faroe Islands are important features in determining deep water circulation in the region (Ellett *et al.* 1983). Cold, sub-zero waters of the Arctic flow southwards at depths below 500 m in the Shetland-Faroe Channel but are deflected westwards by the Wyville Thomson Ridge, which rises to a depth of about 500 m). The northeastwards flowing North Atlantic drift interacts with this deep water in a complex and turbulent manner, particularly on each side on the Channel. This turbulence can force deeper water, richer in nutrients towards the surface where it will enhance productivity. Similar turbulence caused by the steep sides of the offshore banks and seamounts also may enhance primary productivity over distances of several hundreds of metres.

The Norwegian Rinne is a trough that lies just west of southern Norway and also influences oceanic circulation in the region. Some of the water moving northeastwards to the west and north of the British Isles turns southwards into the North Sea at several points. A relatively small flow enters via the Fair Isle channel between Orkney and Shetland, with larger flows southwestwards to the east of Shetland and along the western edge of the Rinne.

The open ocean is exposed to wind, and gales are frequent with big seas built up by the prevailing westerlies, resulting in the regular mixing of the surface layers and the dispersal of plankton and fish. Gelatinous animals and planktonic crustaceans dominate the fauna of the surface waters, whereas at c. 300-600 m deeper, various species of cephalopod may aggregate, forming prey patches for several species of cetacean such as sperm whale, the beaked whales, pilot whales and pelagic dolphins. Fish are less abundant in the deep ocean than over the shelf although they may form seasonal aggregations or concentrate over banks.

Along the shelf slope, the Atlantic Ocean water masses meet the less saline waters of the continental shelf, which receive freshwater inputs from rivers in Britain, Ireland, and

continental Europe. Although there is relatively little mixing along this boundary, currents of slightly warmer water move northwards along this shelf edge from the Celtic and Irish Seas to Shetland carrying plankton, including fish eggs and larvae, from south to north. Turbulence brings deep water up the shelf slope to within 200 m of the surface, resulting in enhanced productivity of plankton and associated aggregations of cephalopods and fish such as blue whiting and mackerel. These in turn attract concentrations of pelagic seabirds and species of cetacean such as the larger baleen whales, pilot whales, killer whales, common, and Atlantic white-sided dolphins (Evans 1990).

Most of the continental shelf on the Atlantic side is exposed to the prevailing southwesterly winds, and saline oceanic water crosses the shelf edge between Malin Head in north-west Ireland and Barra Head in the Outer Hebrides, often intruding over other parts of the shelf in winter. Along the west coast of Ireland, the Irish Shelf Current flows northwards and then eastwards along the north coast. Waters to the west of this, governed by the North Atlantic Current, are separated by the Irish Shelf Front and flow north off the northern half and south off the southern half of Ireland (McMahon *et al.* 1995).

Frontal systems occur where two water masses of different densities meet; such density differences may be generated by temperature or salinity or both. The main front in the Atlantic region is the Irish Shelf Front that occurs to the south and west of Ireland (at c. 11°W) around the 150 m isobath and exists year-round (Huang *et al.* 1991). This front marks the boundary between water over the Irish shelf (often mixed vertically by the tide) and offshore North Atlantic water. The turbulence caused by the front may bring nutrients from deeper water to the surface where they may promote the growth of phytoplankton, especially of diatoms in spring, but also dinoflagellates where there is increased stratification.

These may in turn be fed on by swarms of zooplankton and associated with these, aggregations of fish, seabirds and cetaceans.

The Central region including the Irish Sea

The Irish Sea is shallow (less than 100 m deep in most places) and largely sheltered from the winds and currents of the North Atlantic although its relatively high salinity indicates the influence of oceanic water from the south. In the Irish Sea, the inshore Coastal Current carries water from St George's Channel northwards through the North Channel, mixing with water from the outer Clyde. Southerly winds can strengthen this current, increasing the northward transport of water from the Irish Sea into the Sea of Hebrides, with northerlies retarding the current. Strong tides flow through St George's Channel and the North Channel in and out of Liverpool Bay and the Solway Firth, leaving an area of almost permanently slack water off the Irish coast north of Dublin. At the boundary between the fast moving mixed water of the tidal stream and the stratified slack water, the Irish Sea Front forms between the south coast of the Isle of Man and the coast of County Dublin (Pingree and Griffiths 1978). Such tidal mixing fronts are often zones of high biological activity (Pingree *et al.* 1978), where plankton growth and activity can be much higher than in adjacent stratified and mixed zones, due to elevated nutrient levels. The Irish Sea Front exhibits little variability in either position or structure and is particularly well-developed in August (Simpson 1981; Huang *et al.* 1991).

Waters immediately to the north of the front at this time hold high concentrations of harbour porpoises.

Seasonal fronts occur at several other locations immediately west of Britain, including the Celtic Sea Front west of the Pembrokeshire Islands and the Islay Front between Islay and the coast of Northern Ireland (Pingree *et al.* 1978; Simpson 1981). The Islay Front persists through the winter due to stratification of water masses of different salinity (Hill and Simpson 1989). Similarly, where tides are only moderate, uneven bottom topography can have a considerable mixing effect, as for example in the Sea of Hebrides.

Also, eddies that occur downstream of headlands and islands (Pattiaratchi *et al.* 1986), and narrow channels that produce very strong local tides (Pingree and Mardell 1986), can lead to mixing, which results in small-scale convergences, divergences and shear zones that occur in a tidal rhythm (Hamner and Haury 1977), favouring biological productivity and associated aggregations of fish, seabirds and cetaceans (Evans 1990; Webb *et al.* 1990).

The North Sea region and English Channel

The waters of the continental shelf are influenced not only by deep Atlantic water but also by the effects of land. Further east, such as in the eastern part of the English Channel and the Southern Bight of the North Sea, the effects of the Atlantic water diminish, although in winter there is a stronger inflow of warm, highly saline Atlantic water to the North Sea through the English Channel. This inflow, along with that mentioned earlier into the northern North Sea, together with the effects of the Earth's rotation, drive a cyclonic pattern of circulation in the North Sea (North Sea Task Force 1993).

Topographically, the North Sea comprises three parts: the Southern Bight (51-54° N) with water depths generally less than 40 m; the central North Sea (54-57° N) with water depths of 40-100 m (except for shallower areas on the Dogger Bank and coastal banks off western Denmark; and the northern North Sea (north of 57° N), which includes an area of shelf water 100-200 m deep and the Norwegian Rinne, with water depths from 200 m to

more than 700 m in the Skagerrak between Denmark and Norway (Holligan *et al.* 1989).

In the North Sea, the strongest tidal currents occur in the Southern Bight, the German Bight, off the eastern coast of Scotland, and between Orkney and Shetland. As elsewhere, the combination of variations in water depth and in tidal currents leads to the development of distinct hydrographic regimes during the summer months when a seasonal thermocline extends over most of the central and northern North Sea in response to solar warming. The transitional or frontal zones are characterised by strong horizontal gradients in surface or bottom water temperatures. In contrast to the shelf waters, which are well mixed in the winter by tidal action and winds, the deeper waters of the Norwegian Rinne exhibit thermohaline stratification throughout the year.

Examples of frontal zones may be found around the Frisian Islands and Helgoland, east of Spurn Head and Flamborough Head in Humberside, in the outer Firths of Forth and Tay, east of Buchan in Grampian, and between Orkney and Shetland (Pingree and Griffiths 1978; Holligan *et al.* 1989).

Seasonal changes in surface temperature are most pronounced in the southern and eastern parts of the North Sea, where the water is relatively shallow and influenced by the more extreme continental climate. Seasonal variations in surface salinity are relatively small, the most significant being the decrease in salinity of the Norwegian coastal waters during summer as a result of relatively fresh water flowing out from the Baltic Sea. There can, however, be large variations in mean temperature and salinity distributions from year to year depending upon climate.

The eastern sector and coastal areas of the English Channel are shallow, with depths rarely exceeding 50 m. Depths are greater in the central zone and generally slope from east to west reaching 100 m along the western edge, although a trough to the north-west of the Channel Islands, the Hurd Deep, reaches a depth of more than 170 m. Currents flow eastwards, bringing more saline water from the Atlantic. A frontal system (termed the Ushant Front) develops in summer in the transitional zone between cooler, tidally mixed Channel water and the warmer stratified water of the Atlantic (Pingree *et al.* 1978).

SURFACE CURRENTS IN THE NORTH-EAST ATLANTIC

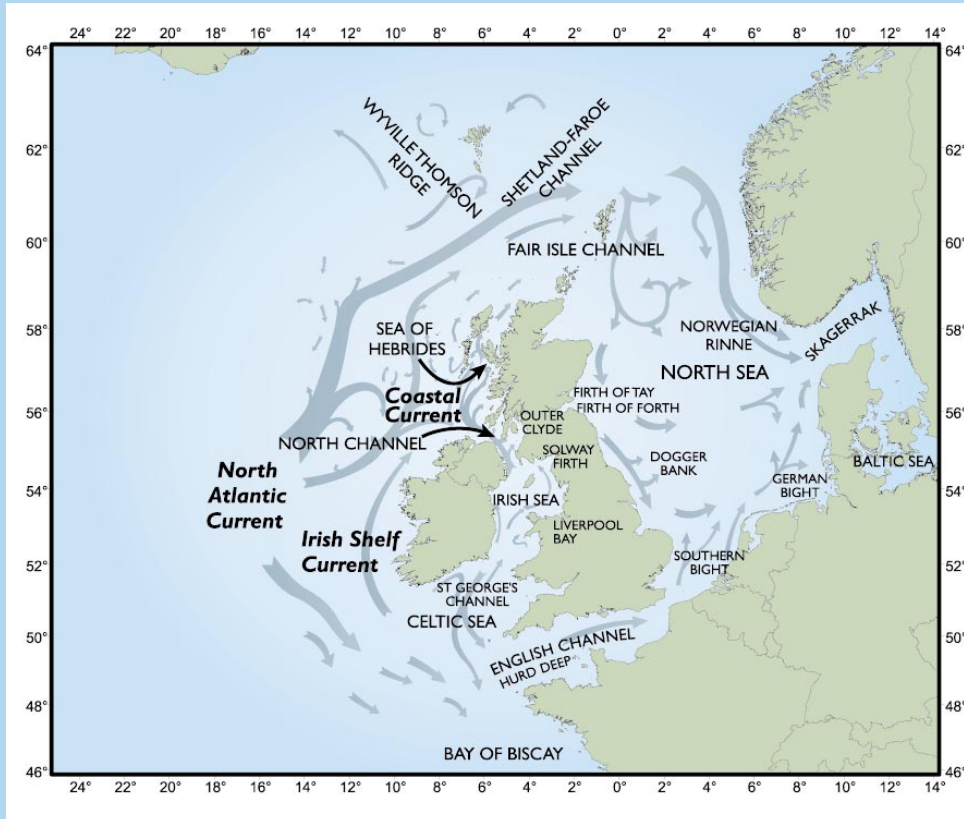


Figure 1

Schematic representation of major surface currents in the north-east Atlantic. The locations of selected habitat features are also indicated. (Adapted from Lee and Ramster 1981, Huang *et al.* 1991, Turrell *et al.* 1992, Hill 1993).

MAJOR FRONTS IN NORTH-WEST EUROPEAN WATERS



Figure 2

Locations of the major fronts in north-west European waters. The positions of the fronts indicated are approximate as there is a significant degree of temporal and spatial variation in their occurrence. (Adapted from Pingree and Griffiths 1978, Huang *et al.* 1991).



Data Sources

Data on cetacean distribution and abundance presented in this Atlas came from three main sources.

The Seabirds at Sea Team (SAST) of the JNCC has been studying the distribution and abundance of seabirds and marine mammals over the (European) continental shelf since 1979. The data from at-sea surveys have been joined with similar data collected by sister organisations in other European countries (see Acknowledgements) to form the European Seabirds at Sea (ESAS) database. This database contains 1.7 million seabird records and over 13,000 cetacean records (of c. 49,000 individual animals) relating to the year-round dispersion of these taxa.

The UK Mammal Society Cetacean Group, subsequently forming the Sea Watch Foundation, has been collecting sightings data on marine mammals from UK and Irish waters since 1973, from opportunistic sightings and effort-related recording. Around 3,000 persons have contributed data over this period although most information comes from a much smaller number conducting regular watches either from land or on offshore surveys. The resultant database comprises 53,000 sightings records, of which 37,000 are opportunistic and the remaining 16,000, representing 84,000 individual animals, are associated with quantified survey effort. (Subsequent to the present work more of the 37,000 'opportunistic' records have been linked to quantified survey effort). Although all months of the year and all regions of the British Isles have been covered, effort has been greatest between April and September; within 30 km of the coast, and in certain regions (off north and west Scotland, the Irish Sea, and the Channel).

The Sea Mammal Research Unit co-ordinated the EC-funded SCANS survey (Small Cetacean Abundance in the North Sea) in June and July of 1994. The project involved intensive line transect sampling over a wide area from 62° N throughout the North Sea, Skagerrak and Kattegat, into the Western Baltic, and through the English Channel and into the Celtic Sea. The survey was and remains the largest synoptic abundance estimate for

cetaceans in European waters, and covered about 20,000 km of trackline by boat and 7,000 km by air. Estimates of abundance were calculated for three cetacean species (Hammond *et al.* 2002).

Data from each of these three major sources were transformed to a common and simple format consisting of sightings records and effort records; this procedure is described further below. Only those sightings that could be associated with a measured amount of search effort were included in the subsequent analysis for the preparation of the maps in this Atlas. Overall, some 61,000 hours or 2,500 days of observation, and 31,000 sightings of 138,000 individual cetaceans are represented.

European Seabirds at Sea data

Surveys are conducted from moving platforms by several organisations in Europe, largely using the methods described by Tasker *et al.* (1984) and Webb and Durinck (1992). Many ships of opportunity were used for surveys, including research vessels, fishery protection vessels, seismic vessels and ferries; dedicated survey vessels were also used on occasion. Data were collected when the vessel was steaming, usually at speeds greater than 5 knots; its position, speed and course were recorded using a Global Positioning System (GPS). Cetaceans were also recorded from a small number of aerial surveys using similar, standardised methods (Pihl and Frikke 1992; see also Pollock *et al.* 2000).

Environmental data such as wind direction and force, sea state, swell height and visibility were recorded every 90 minutes, or more frequently if environmental conditions changed during an observation session.

Although surveys were designed primarily for the detection of seabirds, all cetacean sightings were also recorded, usually within 10 minute intervals. While some methodological differences existed between surveys carried out by different organisations, generally all individual animals observed within 90° of the ship's track line out to a perpendicular distance of 300 m were recorded within distance bands: A = 50 m, B = 51-100 m, C = 101-200 m, D = 201-300 m; animals

were also recorded at distances greater than 300 m from the track line. During some surveys, including those conducted by the JNCC, observers used the naked eye to detect cetaceans, and binoculars to confirm species identification if necessary; however, during other surveys carried out by other organisations (mainly in the North Sea), binoculars were used to scan the sea within 2 km on both sides of the survey ship, and radial distance and angle to the animals were taken on first sighting. The species, numbers, age (if possible) and behaviour of the animal(s) were recorded during all surveys.

Base data allowed cetacean observations to be associated with specific locations, but within a 10 minute spread. Base position, speed and direction were recorded at the start and finish of each recording session, and also within sessions if the survey base changed speed or course. This allowed interpolation to define the position of the survey base, usually at 10 minute intervals, thereby allowing the association of species data with unique geographical locations.

Sea Watch data

From the early 1960s to the late 1980s, with the notable exception of certain land-based observation points (such as bird observatories), most sightings hosted by the Sea Watch database were opportunistic and not from dedicated watches. Subsequently, most sightings have been effort-related, usually from dedicated watches and made both from land and offshore.

Land-based watches were made mainly from headlands or islands of 1-3 hours duration, and, for a number of sites, conducted on a regular basis varying from frequent intervals (daily to weekly) between April and September to longer intervals (weekly to monthly) in winter (although some sites were not watched at all in winter).

During the course of the watches, visual scans with the naked eye were generally made to detect cetaceans, followed by binocular or telescope observations to confirm possible sightings and determine species identity, group size, presence of calves, and behaviour. Other information noted included behaviour (using standardised categories) and the presence of seabirds associated with the cetacean(s). Effort was recorded as the duration of the watch in minutes. Environmental data were usually collected at 10-30 minute intervals and included cloud cover, wind direction and force (using Beaufort scale), sea state, swell height, precipitation,

and visibility. Offshore observations were made from a variety of platforms of opportunity including research vessels, fishery protection vessels, seismic vessels, whale watching vessels and ferries, and cruises dedicated to cetacean surveys. Until GPS was available, regular positions of the vessels were usually taken by DECCA; during the 1980s, these were increasingly replaced by GPS, which could also directly record the speed and course of the vessel, usually at 10-30 minute intervals. Vessel speed varied with the size and nature of the vessel but was rarely less than 5 knots.

Environmental data including cloud cover, wind direction and force (using Beaufort scale), sea state, swell height, precipitation, and visibility, were also recorded at 10-30 minute intervals. Dedicated watches for cetaceans generally involved naked eye scans (followed up by binocular checks to confirm species identity) to record all individuals observed within 90° of one side of the ship's track line for larger vessels (e.g. ferries), and 180° forward scans for smaller vessels; the latter accounts for most observations. All sightings out to the horizon were recorded, along with the time of day and vessel's position on first sighting, and, for some surveys, radial distance and angle to the animal(s). Other information recorded included group size, relative size of individuals (for detection of immatures and calves), behaviour (using standardised categories), direction of movement where this was obvious, and group sizes and species of associated seabirds.

SCANS data

The SCANS survey was conducted over a short time period (June and July 1994), and involved nine ships and two aircraft on dedicated sightings tracks. Aerial data were not included in the production of the present Atlas. Each ship had two independent sightings platforms with two or three observers on each platform. One set of observers used binoculars to spot cetaceans ahead of the ship, while on the other platform observers used the naked eye to detect cetaceans closer to the ship. Times, angles and radial distances were recorded for each cetacean sighting. The trackline course and vessel speed was recorded throughout each survey day, and 99% of all survey effort was conducted in sea states of 4 or less. The methods are described in further detail by Hammond *et al.* (2002).

The SCANS survey covered 16 sea-area blocks, and within each survey block zigzag cruise tracks were made to accord

every point in the survey block a known non-zero probability of coverage. This survey design is intended to enable an unbiased estimate of abundance to be calculated regardless of the distribution of animals within each block. For the Atlas, only encounter rates were used, and both platforms on each ship were treated as independent vessels surveying close to one another at the same time (for harbour porpoises, fewer than 10% of sightings were duplicated by both platforms).

Data Treatment

As is clear from the above, data from each of the three major survey programmes are stored in different formats. The production of an Atlas in which all three data-sets are used therefore required a degree of data normalisation. Each of the three data-sets comprises records that may be described as 'sightings' records and 'effort' records. Sightings records provide information on the animals, including the species identity or other descriptor, the number of individuals and occasionally other details, including behaviour. The sightings record also provides a way of linking the sighting event with a 'leg' or unit of survey effort, where this is either an observation period of known duration or a distance travelled between a start point and an end point. Effort records include the start and end location, time and date of the observation period, details of the observer or observers, and certain key environmental parameters, including sea state.

In order to provide a standardised description of animal distribution, sightings rates are used to describe the perceived density of animals in particular areas. Usually, sightings rates are presented as encounters per km of survey track line, but because many data used in the Atlas were collected by stationary observers from vantage spots such as cliff-tops in timed intervals, the number of individuals sighted per unit time was deemed a more appropriate measure of sightings rate here.

The maps presented here depict the number of individuals of a particular species sighted per unit time of observation, resolved into 1/4 International Council for the Exploration of the Sea (ICES) rectangles (15' latitude x 30' longitude). The area of 1/4 ICES rectangles clearly varies with latitude, but is somewhat less than 1,000 sq km in the present study area. In presenting the data in this way, we make a number of important assumptions. We assume that species were identified correctly and that there is no bias in the estimated

numbers of animals per group for each sighting. More importantly, we assume that there are no other sorts of biases associated with the effort legs.

One of the most obvious sources of potential bias arises from the sea state conditions that prevailed during each observation period. For many cetacean species the probability of visual detection decreases with increasing sea state; this is especially true for less conspicuous species such as the harbour porpoise and the minke whale. As sea states are generally higher in offshore areas and in winter, sightings rates in such areas and in the winter months are likely to be biased underestimates. In order to compensate for this bias, correction factors were used in the calculation of sightings rates for several of the species under consideration. Sightings rates were modelled as a function of several co-variables including sea state using general additive modelling (GAM; Bravington *et al.* 2001). Smoothed functions relating sea state to sightings rate were generated for eight species or species groups (see below; fin, sei and humpback whales were treated as the same species with respect to detectability), and these were then used to adjust survey effort within each sea state category by an appropriate correction factor. In effect, survey effort in higher sea states was down-weighted compared with effort in low sea states.

Correcting survey effort for differences in sea state was the only measure that we applied to account for possible biases in the estimation of sightings rates. Although other factors might also affect the probability of sighting a cetacean, including the number of observers present, the speed of the observation platform (which can be zero), the eye height of the observer and the observer's experience, they were not used to correct sightings rates; in effect, therefore, we assumed that they did not bias sightings rates by area. These are important assumptions that militate against over interpreting details on the maps that we have produced.

In order to assign all observations and the survey effort associated with them to their appropriate 1/4 ICES rectangles or cells, each observation was first allocated to the cell in which it occurred. For effort data where the start and end locations fell within a single cell, the observation duration was allocated to that cell. Where parts of more than one cell were surveyed during the course of an effort leg, the respective amounts of time (effort) spent in each of the cells were apportioned to the appropriate cells.

For each year and each month of the year, the total amount of time spent observing during each sea state category, and also the number of individuals of each species seen, was calculated for each cell of the study area. Effective effort was then computed for each cell (by area/time combination) by multiplying search effort (minutes) in each sea state category by the appropriate correction factor obtained from the general additive modelling, and summing the totals. Sightings rates were then computed as the number of individuals sighted per cell divided by effective search effort for that cell. These corrected sightings rates were then used in the maps. To reiterate, effective effort was calculated in this way for eight species or species groups and for these, therefore, effort was species-specific. For other species there were too few data to allow estimation of correction factors, so in these cases sightings rates are presented as numbers of animals observed per unit search time, uncorrected.

Map Interpretation

The maps of cetacean occurrence in the study area presented here are of three types: (a) those that depict the distribution, relative abundance and associated effort for those species for which sufficient data allowed estimation of correction factors (individuals/standardised hour). Maps of this type are presented for the following species: humpback whale, minke whale, sei whale, fin whale, short-beaked common dolphin, white-beaked dolphin, Atlantic white-sided dolphin, Risso's dolphin, long-finned pilot whale and harbour porpoise; (b) those that depict similar information for those species for which sufficient data did not exist to allow estimation of correction factors (individuals/hour). Maps of this type are depicted for sperm whale, northern bottlenose whale, selected beaked whales *Mesoplodon* spp., common bottlenose dolphin, striped dolphin and killer whale; and (c) sightings locations of rarely recorded species; two maps of this type are presented showing locations of northern right whale, blue whale and pygmy sperm whale, and of Cuvier's beaked whale, Sowerby's beaked whale and false killer whale. No maps are presented for species very rarely recorded or identified in north-west European waters, namely beluga, narwhal, Fraser's dolphin and melon-headed whale. The data used for each map span all years of data collection, from 1979 to 1997, so possible inter-annual shifts or differences in distribution are not reflected in the maps; rather, the maps represent an integrated picture or 'snapshot' over this 20 year period. Neither can these annual maps indicate any

seasonal differences in distribution; maps depicting monthly distributions will be presented elsewhere (www.jncc.gov.uk).

On all maps except those for rare species, each individual grid cell, i.e. 1/4 ICES rectangle, is shaded to indicate the level of search effort achieved in that cell. The darker the shading, the more survey coverage achieved, while empty cells or blocks of cells indicate no survey coverage. The red dots that overlie this grid of rectangular cells indicate by their size the relative sightings rates for each species. Note that the minimum and maximum sightings rates on each map vary, as there are order of magnitude differences in the sightings rates between species. The maps cannot therefore be used to compare inter-specific differences in relative density. The red dots are intended solely to indicate relative density for a particular species, thereby enabling comparisons to be made only between areas for individual species.

The fact that sightings rates for some of the species presented here have been derived from search effort data that have been standardised for sea state differences also means that the grey effort shading differs among the species maps. Thus, for each species where sea state corrections have been applied to actual search effort, the corrected search effort is species-specific. Hence, search effort for the same cell in different species maps may differ (and frequently does).

It is worth reiterating that there are many potential biases associated with these data as presented. We have assumed that none of these biases is systematic, but in fact this is unlikely to be the case and only a detailed statistical analysis of the data will establish the nature and extent of any biases. The patchy nature of the observational coverage, however, should always be borne in mind when interpreting these maps. A chance sighting of a large school of animals during a relatively short observation period may lead to an apparently high relative density in a local area. However, the grey background shading indicating effort levels should enable the reader to filter the more extreme examples of such cases. Nevertheless, it would be inappropriate to infer too much about local densities of animals at the individual cell level. In our interpretation of these maps we have tried to avoid any such over-interpretation, and rely instead on general statements about relative animal densities at a regional level.