Elusive Marine Mammals Explored

Charting under-recorded areas to study the abundance and distribution of cetaceans using Multi-Method approaches and Platforms of Opportunity

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Marijke Nita de Boer

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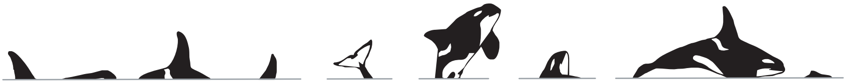
ADDENDUM

CHAPTER 1

INTRODUCTION

Killer whale



Marine mammals are relatively poorly known compared to terrestrial mammals. Unlike pinnipeds (seals, fur seals and walruses), which periodically haul out on land or ice, cetaceans[1] are generally elusive and live a fully aquatic life which consequently makes them difficult to study. According to the Cetacean Specialist Group of the International Union for Conservation of Nature, 45 out of 87 known species of cetaceans are listed as Data Deficient (IUCN, 2013), meaning that there is not enough information to ascertain their status properly. Moreover 23% of all species are considered to be threatened or near threatened.

Another factor that complicates cetacean research is that many typically range over vast areas of ocean, but often also concentrate their activities in smaller, localised regions, so-called *hotspots,* for periods of time. For most species such distribution patterns are largely unknown and in particular those occurring further offshore where it is more difficult to carry out research, logistically as well as in terms of costs. All of this renders research on cetacean population dynamics and ecology rather complex. Whales and dolphins that occur in coastal waters have been relatively more closely examined compared to offshore or high sea species (Connor et al., 2000). Albeit even in coastal waters relative little information is available in particularly regarding the more elusive species.

Nevertheless, the acquisition of population and ecology data are essential to determine both the requirements of conservation management actions and the effectiveness of such actions. In this respect information on population status and distribution patterns is particularly important in the process of designating protected areas (*e.g.* Special Area for Conservation-SAC or Marine Protected Area-MPA). The key role of protected areas will be to protect their critical habitat, comprising the most crucial areas where feeding, breeding and calving take place as well as areas important for socialising, nursing and resting (Hoyt, 2011). It is imperative to understand the importance of areas of high cetacean density, even when these are only of a temporary nature. Defining and prioritising the protection

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[1] The order **Cetacea** includes the marine mammals commonly known as whales, dolphins and porpoises. *Cetus* (Latin) is used in biological names to mean ‘whale’. It comes from the Ancient Greec *kētos*, meaning ‘whale’ or ‘any huge fish or sea monster’.

of critical habitats becomes rather complex and time-consuming because the distribution and activity of cetaceans not only varies with season but also between subsequent years and even over decades.

Cetaceans are generally surveyed using single-method approaches, which – partly because of the elusive nature of cetaceans – rarely produce a complete picture. Each survey method provides different information, *e.g.* fine-scale habitat use, (semi-) residency, foraging techniques, group composition, density and abundance. A multi-method approach, using both systematic and opportunistic methods, may yield much more comprehensive results regarding the fine-scale distribution of a population. This is the central theme of this thesis.

Research on the status of cetaceans and the function of the habitats they inhabit usually serves conservation management purposes. Therefore, in this Introduction I first outline the main cornerstones for the conservation of cetaceans and their habitats. I then discuss the benefits and shortcomings of data acquired through (low-budget) Platforms of Opportunity. This is followed by the central aims and objectives and the methodology approaches that are used in the main chapters of the thesis. Finally I provide the outline of the thesis and explain the links between the chapters.

1.1 THE CONSERVATION MANAGEMENT OF CETACEANS

Cetaceans have intrinsic value as species, and also for the role they play within ecosystems as top predators. They are offered strict protection under law in many parts of the world today, yet, multiple threats make conservation research, and the development of associated management and legislative measures, a priority (Clark et al., 2010).

Within Europe, the **EU Habitats Directive** has been the basis for the conservation of European wildlife and their habitats for the last twenty years. The Habitats Directive describes both habitats and species that are to be protected, based on which Special Areas of Conservation can be designated. Regarding cetaceans, all species occurring in Europe are listed in Annex IV of the Directive, requiring strict protection, and two species, the harbour porpoise (*Phocoena phocoena*) and bottlenose dolphin (*Tursiops truncatus*), are additionally listed in Annex II, requiring the development of **Special Areas of Conservation (SAC),** where appropriate, as part of the Natura 2000 network (Box. 1.1).The guidelines for site selection of proposed porpoise SACs states that the area should contain key sites, that are used regularly by high numbers of the species and they ‘must be clearly identifiable areas representing the physical and biological factors essential to the species life and reproduction’. In order for these sites to be identified, the species’ interactions with their physical and biological environment must be better

BOX 1.1 ARTICLES OF THE EU HABITATS DIRECTIVE

Article 3(1) of the Directive states that a coherent ecological network of Special Areas of Conservation (SACs) that should enable species' habitats to be maintained or, where appropriate, restored at a favourable conservation status (FCS). Article 3(2) requires Member States to contribute to the creation of Natura 2000 in proportion to the representation within their territory of Annex I habitats and Annex II species.

Article 4(1) notes that 'for aquatic species which range over wide areas, such sites will be proposed only where there is a clearly identifiable area representing the physical and biological factors essential to their life and reproduction.'

Article 12(1) requires Member States to establish a system of strict protection which includes prohibiting the deliberate capture or killing and disturbance of listed species. Additionally Article 12(4) requires Member States to monitor incidental capture and killing to ensure that this does not have a significant negative impact on the species concerned.

Under Article 17, Member States must report on the status of each cetacean species in its waters every six years through the surveillance developed under Article 11. In 2007, the conservation status of the majority of cetacean species was assigned as ‘unknown’ or ‘not assessed’ (the latter assigned to species were very little information was available). These assessments reflect the difficulties in monitoring marine species and also the low encounter rate of many species.

understood. Information on fine scale distribution, both spatial and temporal, is therefore required.

Internationally, there is now also a much greater emphasis on the need for trans-boundary reporting. For example, the **Convention on the Conservation of Migratory Species of Wild Animals (CMS)**, usually referred to as the Bonn Convention, came into force in 1985 and encourages the development of multilateral agreements for species that cross national jurisdictional boundaries.

Most European cetaceans are highlighted as priority species under the CMS, being listed under Appendix I (migratory species threatened with extinction) or Appendix II (migratory species that would significantly benefit from international co-operation). With respect to cetaceans in Europe, the CMS promoted regional conservation agreements for cetaceans in the Mediterranean and Black Seas (**ACCOBAMS**) and the Baltic and North Seas (**ASCOBANS**). This latter agreement obliges parties to co-operate in order to achieve and maintain a favourable conservation status for small cetaceans in the agreement area.

The **OSPAR** Convention for the Protection of the Marine Environment of the North-East Atlantic seeks to protect the marine environment and establish marine protected areas **(MPAs)** for threatened and declining species, particularly on the high seas. MPA is a common generic term, although in various jurisdictions, MPAs are called marine conservation zones (MCZs), marine reserves, marine parks, special areas of conservation (SACs), marine wildlife refuges, national marine sanctuaries, or more than 250 other names in use worldwide (Hoyt, 2011). **MPAs** are used successfully in many parts of the world for cetacean conservation (Hoyt, 2011)[2] and could provide similar benefits in European waters. As highly mobile marine species, cetaceans present definite challenges in attempts to develop conservation measures, particularly as there are still many gaps in our knowledge. With this is mind, it will be important to develop MPAs in a precautionary manner (Clark et al., 2010). This means ensuring they are sufficiently large (at least in the early stages), flexible, and adaptive to new information in order to provide us with buffers against uncertainty and ensure that spatially and temporarily critical habitats have been protected. The main types of MPAs in the European waters are SACs for habitats of European importance, Special Protection Areas (SPAs) for birds and Marine Conservation Zones (MCZs) for nationally important habitats and species. These sites will contribute to an ecologically coherent network of MPAs. Again this underlines the need for up to date information on species abundance and distribution.

More extensive overviews covering international legal aspects of marine mammal conservation were recently carried out by Parsons et al. (2010) and Hoyt (2011).

1.2 PLATFORMS OF OPPORTUNITY

In order to meet the monitoring requirements within the EU as described above and bearing in mind that the monitoring of cetaceans can be logistically complex and financially costly, this study in particular focuses on a series of different types of ‘alternative’ survey platforms, also known as ‘Platform of Opportunity’. A Platform of Opportunity can be e.g. a ferry, oceanographic or fisheries research vessel,

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[2] http://www.cetaceanhabitat.org/management_plans1.php

oil exploration vessel or a whale-watching boat. These vessels typically cross an area of sea for other purposes. Manning such vessels yield low-cost approaches of collecting large quantities of data and this has meant that surveys conducted from Platforms of Opportunity are increasingly used by cetacean research groups (e.g. Kiszka et al., 2007). Confusingly, the term 'Platform of Opportunity' is often used to describe opportunistic records, rather than platforms. Such records, for example sighting logs (Mörzer-Bruyn, 1971; Braham and Dahlheim, 1982; Moore et al., 1999; Kiszka et al., 2004), whaling records (Mizroch, 1984; Gregr et al., 2000; Gregr and Trites, 2001) or strandings records (e.g. Jung et al., 2009; Peltier et al., 2013) can be used to provide alternative or additional sources of information on the distribution and diversity of cetaceans in any given area and often on a long-term basis. However, opportunistic records are not effort-based (i.e. no information is available regarding the duration of systematic observations) and are therefore less suited for analyses purposes. In some cases, opportunistic records can provide data for various analysis concerning the distribution, occurrence and density of small cetaceans (Loos et al., 2010), to model the timing of migrations or to predict critical habitat (Gregr et al., 2000; Gregr and Trites, 2001).

An effort-related study carried out from a Platform of Opportunity is better defined as one in which the platform is opportunistic, but the research is dedicated (i.e. effort-related). From this platform typically a project is carried out with a primary objective but which can nevertheless provide opportunity to other 'secondary studies' with different objectives to be carried out alongside. Important is that these 'secondary studies' do not interfere with the primary study/activity. Despite the sometimes confusing term, the conception 'Platform of Opportunity' is already widely used and in this thesis any dedicated data collected from Platforms of Opportunity (PO) are abbreviated as PO-based.

POs that are particularly suitable are those that allow the simultaneous collection of cetacean data along with environmental and physical oceanographic data (e.g. bathymetric data, water samples, fisheries data, etc.) which enhances the interpretation of results (Wall et al., 2006) and assists in marine mammal habitat management. Examples of PO-based cetacean studies include the multidisciplinary framework and scale of the Southern Ocean Global Ocean Ecosystems (SO GLOBEC) program which provided a rare opportunity to dedicated studies, including cetacean observations (Thiele et al., 2004). Similarly, the PELGAS cruises with a prime objective to carry out acoustic studies to assess stocks of small pelagic fish provided suitable POs for dedicated cetacean and seabird surveys (Certain et al., 2008). In recent years ferries have been used for cetacean research and appear to be efficient and cost-effective for long-term monitoring programmes of cetaceans (e.g. Wall et al., 2006; Kiszka et al., 2007). Such POs provide the opportunity to undertake repetitive surveys along a 'fixed line' which can be conducted regularly throughout different years whilst providing information on long-term patterns in cetacean occurrence (MacLeod et al., 2007a). Other studies have been using wildlife operators (Hauser et al., 2006, Ingram et al., 2007; Fazio et al., 2012). Fixed-point platforms, such as islands, headlands or oilrigs, also are a type of PO from where one can systematically scan for cetaceans (e.g. Fijn et al., 2012).

Data from POs remain underutilised because their analysis presents several challenges (Williams, 2003). The main problem is that the routes for POs are not determined by the research design, but are often dependent on logistics, navigation or influenced by scenery (in case of a cruise vessel). They may therefore be restricted to a particular route, certain time of the day or phase of tide. Therefore, these survey track-lines fail to provide equal coverage probability (either systematic or random sampled), and basic statistical design requirements are compromised (Viddi et al., 2010). However, when the track-line is predetermined by a commercial design (e.g. fixed shipping routes), the distribution of opportunistic effort may be assumed to be independent of the target species. Relating animal sightings to effort can then be used directly to infer relative distributions (e.g. Kiszka et al., 2007; MacLeod et al., 2008) and absolute densities within the confines of the area surveyed (Williams et al., 2006). Other POs, such as wildlife tour operators determine the track line *in situ*, often according to prevailing environmental conditions (e.g. López et al., 2004; Hauser et al., 2006; Ingram et al., 2007). Such platforms can collect more accurate visual and behavioural data by diverting from the track-line to confirm species, gender or group size (Evans and Hammond, 2004), but accounting for a diversion from the track-line by the platform in order to approach animals and/or the response of the study animals to the platform can be indeed challenging. Indeed, wildlife tour operators in particular may change their course and speed to increase the time spent in the vicinity of the animals during each trip. Such operators also typically visit locations where they believe they have a better chance of finding animals and as such the sighting rates of species will be relatively high. Another disadvantage of POs, for example ferries and cruise vessels, is that the speed of the vessel may be a source of bias in terms of not spotting certain deep-diving cetaceans and this may present a difficulty in terms of spotting and identifying cetacean species in general (Compton et al., 2007), and comparing results with other studies.

The main benefits of using POs is that they raise the possibility of collecting data at sea with relative minor cost and as such it is by far the cheapest way to collect data on cetacean distribution, relative abundance and behaviour (Evans and Hammond, 2004) and Table 1.1. This type of data collection is particularly important because it allows carrying out more research in offshore habitats and furthermore enables long-term monitoring in specific areas of interest (MacLeod et al., 2008). The changes in patterns of occurrence over time within a particular study area can potentially be investigated by undertaking repeated surveys along ‘fixed’ transects and as a result, surveys can be conducted more frequently, providing information at a fine-scale and on seasonal and inter-annual changes (MacLeod et al., 2008). Nowadays, PO-based data are increasingly used for modelling

Table 1.1 The benefits and shortcomings of different types of Platforms of Opportunity, including references to the relevant chapters of this thesis and to several examples found in literature.

Platform of Opportunity	**Benefits**	**Shortcomings**
Island/Oil rig - fixed platform	Long-temporal	Poor spatial coverage
	No responsive movement	Might be difficult to travel to/from
Chapter 5-6	Fine-scale detection of trends/ changes	Housing/Accommodation is needed
e.g. Cremer et al. (2009); Todd et al. (2009); Fijn et al. (2012)	Allow comparisons over time (seasons)	Cannot divert track to confirm ID
	Defining habitat-use, local population census	
Ferry	Long-temporal	Poor spatial coverage
	Large-stable platform	Fast speed may influence findings
	Allow comparisons over time (seasons)	Cannot divert track to confirm ID
	Fine-scale detection of trends/ changes	Seasonally only in some cases
e.g. Kiszka et al.(2007)	Commercial sponsorship	
MacLeod et al.(2008); De Boer (2012a)	Onboard accommodation	
	Relative abundance measures	
Supply vessel	Long-temporal	Poor spatial coverage
	Allow comparisons over time (seasons)	Seasonality (in some cases)
	Fine-scale detection of trends/ changes	Small/unstable
	Possible onboard accommodation	Housing/Accommodation may be needed
	May divert track to confirm species/numbers	Weather dependent
Chapter 3-4 *e.g. De Boer (2012a)*	Commercial sponsorship	Responsive movement
	Relative abundance measures	
Oceanographic/fish(ery) monitoring	Short-temporal	Limited spatial coverage (depending on primary research design)
Chapter 2	Oceanographic data may be available	Weather dependent
e.g. De Boer et al. (1999)	Onboard accommodation	Fast speed may influence findings
De Boer (2000ab,2001)	May divert track to confirm species/numbers	Influenced by vessel activities
Karpouzli and Leaper (2003); Wall et al. (2006)	Large-stable platform	Irregular speed Responsive movement
	Relative or rough abundance estimates	

Table 1.1 *Continued.*

Platform of Opportunity	**Benefits**	**Shortcomings**
Cruise vessel	Long-temporal	Poor spatial coverage
	Allow comparisons over time (seasons)	Fast speed may influence findings
	Fine-scale detection of trends/changes/range	Seasonality (summer)
	Possible onboard accommodation	Effort influenced by knowledge
	May divert track to confirm species/numbers	Alerts received by others
e.g. Williams et al. (2006); Compton et al. (2007)	Commercial sponsorship	
	Relative or rough abundance estimates	
Wildlife operator	Long-temporal	Limited coverage (coastal)
	Allow comparisons over time (seasons)	Effort influenced by knowledge
	Fine-scale detection of trends/changes	Small/unstable
	Divert track to confirm species/numbers	Irregular speed
e.g. Leaper et al. (1997)	Beneficial to operator: attract customers by the research	Responsive movement
De Boer (2003, 2012b); Isojunno et al. (2012)	Mark-recapture estimates	Alerts received by others
	Distribution and habitat-use	
Geophysical (seismic) vessel	Long-termporal (annual or bi-annual)	Poor spatial coverage
	Under-recorded areas	Cannot divert track to confirm ID
	Fine-scale detection of trends/changes/range	Slow speed may influence findings
	Large/stable	Influenced by vessel activities (seismic)
	Oceanographic data may be available	
Chapter 4, 7-9	Commercial sponsorship	
e.g. Parente and de Aurajo (2011); Weir (2011)	Onboard accommodation	
	Relative abundance measures	

purposes, for example to provide information on cetacean ecology (Moura et al., 2012) or, given good coverage, distance-sampling data can be modelled to estimate abundance (Hedley et al., 1999; Hedley and Buckland, 2004). Williams (2003) also found that one can use PO-based data to model the role of measurement error on abundance estimation. This measurement error was found to be a potential source of bias and it was highlighted that POs could be used to train observers on protocols, and to learn to use range-finding photogrammetric equipment well before conducting dedicated surveys, which would eliminate this source of bias, as well as allowing the estimation of abundance in some cases (Williams, 2003). Furthermore, by identifying areas of predicted high density through the collection of PO-based data, these may improve stratified designs for future line-transect surveys (Williams et al., 2006). Other published records list benefits such as aiding photo-identification studies (e.g. Mayr and Ritter, 2004) and guiding whale-watching activities (Ritter, 2003).

Summarising, PO-based data have definite flaws, because of the trade-offs of control over study design, the non-standardized sampling effort, the limited field time (short temporal), poor spatial coverage and the restrictions of the sampling techniques (Table 1.1). The precision of estimates from PO-based data will never match those of dedicated sightings surveys. For these reasons it is often highlighted that data generated by POs should be taken merely as initial insights into cetacean distribution and as important starting points for designing systematic surveys (Evans and Hammond, 2004). However, this view falls short in recognising the values of the PO-generated data. This approach can provide essential data for conservation management in e.g. countries bordering vast sea areas and/or having limited financial means. Even in (most) European countries, they are of value in bridging the gap in time-windows between large-scale systematic surveys (e.g. 10-11 years between the two large-scale surveys of Small Cetacean Abundance in the North Sea and Adjacent waters (SCANS I and II). PO-based data can also be the only source of information relative to cetaceans in under-recorded areas and in particular those areas where there is a need to estimate an abundance index for conservation or management purposes (e.g. Leaper et al., 1997; De Boer, 2000a; Wall et al., 2006; Brito et al., 2009; Weir, 2011; Palacios et al., 2012).

Unfortunately relatively few publications are forthcoming from PO-based studies due to the identified shortcomings surrounding such data and inherent difficulty to pass peer-reviews of acknowledgeable journals. Nevertheless, the potential conservation benefit justifies using these methods in areas where abundance is unknown, and where lack of funding makes dedicated surveys unlikely to occur (IWC, 2001). In such areas, perhaps conservation strategies could be implemented based on relative scarcity or highly localised distribution, even if accurate estimates of abundance cannot be derived.

1.3 PROBLEM DEFINITION

Cetacean populations change in size and distribution over time and information on spatial and temporal variation in cetacean abundance is needed to understand their population dynamics. Besides for scientific interest, such information serves to assessing direct (*e.g.* bycatch - incidental capture in fishing gear) and indirect (*e.g.* pollution) anthropogenic effects. However, it is nearly impossible to detect changes in cetacean abundance with current levels of financial investment, effort, technologies and survey design.

Resources for conducting cetacean surveys are often limited and there are often logistical constraints. This holds especially for cetaceans in offshore waters and these can therefore only be studied infrequently or hardly at all. Some large-scale surveys in offshore waters have added a great deal to the knowledge of cetaceans within European waters (Hammond et al., 2002, 2013; Evans et al., 2003; Camphuysen et al., 2006; Certain et al. 2008; T-NASS, 2008; Gilles et al., 2009; CODA, 2009). Because of their high costs such surveys are rare and produce data points with large time windows hampering e.g. population trend analysis.

Most studies have been conducted in coastal areas but even those may be hampered by irregular or little survey effort. For example survey effort may be challenged by weather conditions, strong tidal currents, logistical constraints (limited boats available) and/or time of year (e.g. winter months with limited daylight, dominated by low temperatures and/or high winds). As a consequence, the research is planned during those months of the year and preferably targets those places where data collection is expected to be most successful. This is often the only way to make sure that a high enough sample size is achieved for the different types of analysis needed to answer the research questions. Equally relevant are questions relating to the availability of suitable survey platforms, permission to survey the areas, ability to collect the data adequately without violation of important assumptions, and the availability of appropriately experienced and trained personnel (e.g. Hammond, 2010). The answers to these questions will ultimately define the survey design.

With the generally limited resources available for marine mammal conservation orientated research, I developed and implemented more flexible survey designs, using multi-methods approaches (Fig. 1.1). This differs from situations where one designs the survey following a research question, often using a single method, and next defines the ‘tools’ needed (i.e. primary survey platform; Fig. 1.1). The system presented here shows how a survey is designed following a specific research requirement (e.g. assessing the fine-scale spatial and temporal distribution of a species) by firstly identifying what tools are available (i.e. dedicated research platform, including POs) and next which suite of methods can be implemented (i.e. multi-methods).

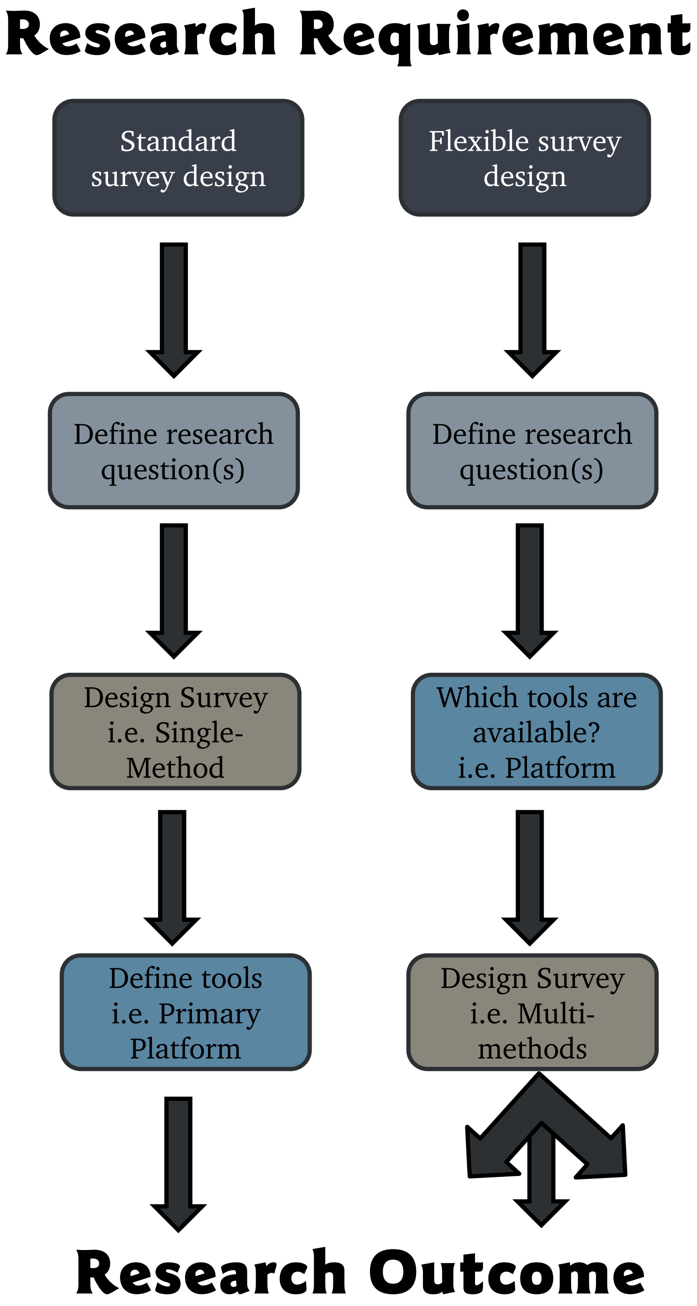


Figure 1.1 *Designing a survey following e.g. a management problem or out of scientific curiosity, addressed by a formulated Research Requirement, using a standard design (left) or a flexible survey design (right).*

The overall goal of this thesis is to demonstrate the complementary value of applying POs and implementing multi-method approaches, and using the acquired different data sets to obtain fine-scale distribution and abundance data in areas that have received little or no effort. Such data sets are highly desirable, especially as spatial planning is becoming the framework for management of human activities within the marine realm.

1.4 RESEARCH OBJECTIVES

The distribution, abundance and habitat-use of cetaceans can be studied using various techniques including mark-recapture, distance-sampling techniques and habitat modelling. This PhD in particular focusses on the use of multi-methods and how, amongst others, PO-based data can complement systematic surveys. In this thesis I present a series of examples of PO-based and multi-method approaches. By adopting flexible survey designs my aim is to gain a better insight into the fine-scale distribution and abundance of cetaceans in areas which have received little spatial or temporal survey coverage.

In Chapters 2-6, I use data collected through both standard and flexible survey designs in three different study sites (SW England, Wales and the Central North Sea) each with their own characteristic cetacean fauna. These particular studies were set-up following specific research requirements:

(1) In SW England conservation concerns had been raised about the scale of the bycatch of the wintering common dolphins;

(2) In Wales, there was a distinct data gap regarding the poorly known Risso's dolphin and the elusive harbour porpoise especially in coastal areas where human activities might need to be managed in relation to the fine-scale and localised distribution of small cetaceans;

(3) In the Central North Sea, a geophysical seismic survey was planned along the Dogger Bank. Following a request by the German Authorities a marine mammal survey was designed to calculate abundance estimates.

I analyse data collected using the different methodology approaches, in order to highlight potential issues surrounding single-method approaches and whether multi-method approaches may provide more comprehensive results regarding the fine-scale distribution, abundance and habitat-use of cetaceans.

In Chapters 7-9, I investigate the relevance of PO surveys for the conservation management of cetaceans in under-recorded areas. The presented studies differ in that they do not follow a survey design as described above (Fig. 1.1). Instead, I follow a 'backdoor approach' and use PO-based data obtained in two tropical equatorial regions (Gabon and Suriname). Due to the scarce cetacean information available for these regions, I asses the value of POs in regards to using such data as baseline data. If such studies can produce suitable information and publications, then this approach may be expanded to other under-recorded areas and help feed research requirements when limited budgets or lack of supporting infrastructure such as survey vessels are hampering cetacean surveys.

1.5 STUDY METHODS

The fact that many cetacean species are wide-ranging and not easily studied at sea makes abundance estimations and the monitoring of trends problematic. To deal with that, different survey methods for monitoring cetacean populations and analysing these data have been developed. Which method is the most appropriate depends on the intended use for the estimates, the species and its characteristics, and the available resources (Hammond, 2010). The methodologies used to visually study cetaceans also vary depending on the species concerned and availability of research platforms. Studying cetaceans often requires an expensive research platform such as a sea-going vessel or a fixed-wing aircraft or helicopter. Small boats, airships and fixed (land-based) viewing stations are also used when appropriate.

Below I describe the presently most used methods.

1.5.1 IDENTIFICATION STUDIES

Early fieldworkers demonstrated that it was possible to repeatedly find and recognise naturally marked individuals on separate occasions. Artificial tagging, where a tag was shot into a whale, gave further insight into migration patterns but the disadvantage was that the tag could only be recovered after the whale was killed (Brown, 1978). An interesting example is that of a recent discovery of a 100 year old patented harpoon point that was found imbedded in a dead bowhead whale (*Balaena mysticetus*) that was harvested under a subsistence quota system monitored by the International Whaling Commission. The metal projectile was traced back to an 1879 patent and a narrow window of time in which it was likely to have been fired, indicated that this whale was between 115-130 years old when it died (Haag, 2007). Other studies involved the physical capture of individual animals to mark them in some way (painting, branding, tagging), upon releasing and then later physically recapturing them. The tagging of marine mammals with electronic tags (such as satellite positioning tags) is also increasingly undertaken to track their movements and how these relate to the ocean environment (e.g. Bailey et al., 2009). The ability to predict the movements of apex marine predators, based upon an understanding of what drives their movements, has a key role to play in marine conservation management (e.g. Block et al., 2011).

Other avenues explored using natural marks to identify individual cetaceans without physically capturing them (e.g. Whitehead and Payne, 1981; Payne et al., 1983; Ford et al., 1994) launched a new era of long-term field research for cetaceans (and other species). For example, different species have different natural markings used for photo-identification studies: humpback whales (*Megaptera novaeangliae*) have distinctive colour patterns on the ventral surface of their flukes (e.g. Katona et al., 1979) whilst right whales (*Eubalaena glacialis)* have distinctive patterns of callosities on their heads (Payne et al., 1983; Kraus et al., 1986) and killer whales (*Orcinus orca*) have distinctive dorsal fin shapes and notch patterns in addition to variation in saddle patches (Bigg, 1982). Photo-identification (Photo-ID) data are subsequently used to calculate abundance by so-called mark-recapture techniques. Direct counts of the total number of dolphins in a population to generate an *absolute abundance* are not possible except under rare circumstances where long-term, year-round studies of well-marked animals are conducted (Wells, 2003). Therefore, it is necessary in most cases to rely on an estimate of the abundance, one that ideally is as robust as possible. These techniques are now widely used in marine mammal research, particularly to estimate movement and population parameters such as survival rates and population size (e.g. Hammond et al., 1990; Wilson et al., 1999; Wells, 2003; Evans and Hammond, 2004). The mark-recapture methods used recognisable individuals where such animals are ‘marked’ and ‘recaptured’ using photographs. Mark-recapture techniques rely on sampling and re-sampling individual animals and the *abundance estimate* obtained therefore reflects the number of animals using the study area during the study period.

Estimating the abundance forthcoming from mark-recapture is based on the idea of marking a number of animals in a population and then using the proportion of the marked individuals re-captured in a subsequent sample of animals as an estimate of the marked proportion in the population at large (Hammond et al., 1990).

A number of assumptions have to be made particularly relating to the recognisability, representativeness of sampling and capture probabilities and these assumptions are further described in chapter 5. A capture history describes whether or not an animal was captured in a series of sampling events (captured *vs* not-captured). These methods require at least two sampling occasions but if multiple sampling is employed, either ‘open’ or ‘closed’ population models can be used (e.g. Hammond et al., 1990). Capturing as many animals as possible, i.e. making average capture probability as high as possible, is a good way to get close to representative samples and minimize the problem of heterogeneity of capture probabilities (Hammond, 1986). How well this can be achieved is clearly a matter of the size, residency and range of the population but also the amount of resources available.

1.5.2 FIXED-POINT CENSUS METHODS

Fixed observation points are for example headlands, islands or oil rigs. Marine mammals on or near land, such as pinnipeds, sea otters, or walruses, are more commonly counted from land-based viewing points or using aerial photography (Forney, 2002). A few populations of whales migrate close to shore and have been surveyed successfully from land-based stations (e.g. Scheidat, 2001). Smaller cetaceans can also be studied using a fixed-point providing that they approach the viewing point within range to allow visual detection (e.g. Visser et al., 2010; Camphuysen, 2011; Fijn et al., 2012).

Fixed stations in offshore areas, such as oil and gas platforms, can also be used to monitor cetaceans (e.g. Cremer et al., 2009). Such structures can act as artificial reefs attracting wildlife (e.g. Hostim-Silva et al., 2002; Guerin et al., 2007) and cetaceans can occupy areas around these structures in order to exploit the local availability of food resources (Cremer et al., 2009). Moreover, in the North Sea, fishing is not permitted within the 500-m exclusion zone around such installations, further enhancing the properties of these "reefs" as refuges for marine life and offshore installations may play an important role as nocturnal feeding stations in the North Sea (Todd et al., 2009). However, if cetaceans regularly cluster around installations within the 500-m exclusion zones, then the obtained densities should not be extrapolated to the wider area as this would overestimate the true population status.

Systematic land-based monitoring has frequently been used to identify coastal areas important for particular species and to determine variation in numbers both seasonally and over the longer term (e.g. Evans and Hammond, 2004; Camphuysen 2011). Fixed stations have a number of advantages over line transects because the data collected are easier to standardise and are generally cheaper to finance (Evans and Hammond, 2004). As such they might also allow a longer temporal coverage. In addition, there are no issues with movement of the observer that may affect sightability. Animals are also less likely to respond to the station (as often is the case with moving platforms which may attract dolphins to bow-ride or cause cetaceans to actively avoid the platform). A major disadvantage however is that the occurrence of animals in a particular restricted area is monitored and not the population at large. When covering a broader geographical coverage two or more fixed stations along a coast can be used (e.g. Photopoulou et al., 2011). Another option is to complement offshore (boat-based) line-transects with land-based records (e.g. López et al., 2004; Hartman et al., 2008; Brito et al., 2009).

The use of land-based methods is described in chapter 6.

1.5.3 LINE-TRANSECT SURVEYS

Line-transect sampling from ship or aerial surveys follow designed transect lines that achieve equal coverage probability in a survey area (as described in Buckland et al., 2001). This method is currently the state of art and regarded as an effective method for estimating density and abundance of cetaceans at sea. The basic idea behind line-transect sampling is to estimate the density for the target species in strips sampled by surveying along a series of transects, and to extrapolate this sample density to the entire survey area. Hence, line-transect sampling provides an estimate of the number of animals in a defined area at a particular time or over a period and therefore differs from estimates based on mark-recapture analysis (Hammond, 2010).

In line-transect sampling, the distance to each detected animal needs to be accurately measured in order to estimate the probability of detecting an animal as a function of the perpendicular distance to the transect line. The method then estimates the density along a set of transects via a detection function fitted to the perpendicular distances of observed groups of animals to estimate the effective strip-width of the strip searched on each side of the transect. The density estimated is then extrapolated to the whole study area on the basis that placement of transects provides equal coverage probability throughout the area. An example of a large-scale line-transect survey is the SCANS survey carried out in 1994 and in 2005 (Hammond et al., 2013) where both sea-going vessels and fixed-wing aircraft were used. These large-scale studies were designed to estimate the abundance of small cetaceans.

Numerous other studies using line-transect sampling are carried out in order to estimate cetacean abundance include, for example bottlenose dolphins and hector’s dolphins (*Cephalorhynchus hectori*; Mullin and Fulling, 2003; Slooten et al., 2004), the Trans North Atlantic Sighting Surveys (T-NASS; e.g. Víkingsson et al., 2007) and harbour porpoise abundance in Dutch EEZ from aerial surveys (Geelhoed et al., 2013).

Survey approaches, which require a dedicated survey vessel for line-transect sampling, were used in the present PhD study (Chapters 2-4).

1.5.4 SPATIAL MODELLING

An extended method to estimate animal abundance using line-transect sampling is spatial modelling (Hedley et al., 1999; Buckland et al., 2004) which is often flagged as a cost-effective decision tool for species management (Isojunno et al., 2012). This method combines line-transect sampling with spatial analysis to predict animal abundance based on the relationship of animals observed to environmental factors, as well as taking into account the probability of detecting animals. This method has been used to estimate the abundance of cetaceans in several studies (Williams, 2003; Cañadas and Hammond, 2006). One advantage of this new method is that it does not require transect lines to be distributed over the whole area and is thus an appropriate method for analysing data collected from dedicated surveys with a non-systematic design or from a PO (Gómez de Segura et al., 2007). Another advantage is that spatial distance sampling models allow the estimation of abundance in any subset of the study area and the creation of surface maps of animal abundance. An additional advantage of spatial modelling is that the inclusion of environmental features when predicting abundance may increase the precision of the estimate (Gómez de Segura et al., 2007).

In this thesis (Chapter 6) I studied the habitat preferences of cetaceans using Generalized Additive Models (GAMs).

1.5.5 ACOUSTIC MONITORING

Passive acoustic monitoring (PAM) is increasingly used as a tool to study the presence, relative abundance, migratory movements and behaviour of cetaceans (e.g. Moore et al., 2006; Mellinger et al., 2007). In addition, PAM has recently proven useful in combination with remote sensing and oceanographic data loggers to investigate the relation between marine mammal behaviour as inferred from acoustic data and environmental factors such as chlorophyll a, temperature and sea ice (Stafford et al., 2009). Static acoustic devices, for example Porpoise Detectors (T- and C-PODs) and PopUps, are also useful for providing information on cetaceans within a particular area. The additional advantage is that such monitoring can also be carried out on a regular or continuous basis at relatively low cost (e.g. Swift et al., 2002). Due to the low frequencies of their species-characteristic sounds signals of baleen whales propagate for long distances, allowing for monitoring large areas (e.g. Payne and Webb, 1971; Clark and Ellison, 2004). However, odontocetes are also monitored acoustically by using towed hydrophone arrays (Lewis et al., 2007) but also using static hydrophones, such as T or C-PODs, which were designed for studies of habitat use and echolocation behaviour of harbour porpoises (Cox et al., 2001; Koschinski et al., 2003; Carlström, 2005; Verfuß et al., 2007). Such devices are especially useful for providing information on area usage and can do so at relatively low cost although the costs of equipment, maintenance, expertise and replacement of broken gear due to their exposure to challenging environmental conditions may run high. An important advantage is that acoustic devices can be operated during darkness and poor visibility and are relatively independent of sea states. For some species, such as sperm whales (*Physeter macrocephalus)*, it has been possible to estimate their abundance from towed hydrophone surveys (e.g. Lewis et al., 2007). However, the disadvantages include that they only record vocalising animals and in particularly small dolphins can be difficult to detect on species level.

Acoustic monitoring took place during some of the fieldwork involved in this study, including T-PODS (De Boer et al., 2006) and towed hydrophone arrays (Ansmann et al., 2007; Chapter 9) but for this thesis the acoustic detections merely served to confirm species identification (i.e. Chapter 9).

1.6 STUDY DESIGN

The research presented in this thesis covers a time span of 13 years during which data were collected using different methodology approaches and using POs. The study uses two long-term and three short-term datasets. The four target cetacean species, the different study sites and the methodology approaches are summarized in Table 1.2. Where possible, a multi-method approach is used, *e.g.* at least two different survey techniques are applied at any one time following standard and flexible survey designs (Table 1.2; Fig. 1.2). Chapters 7-9 of this thesis focus on under-recorded areas, including the offshore tropical waters off Gabon and off Suriname (Fig. 1.2.).

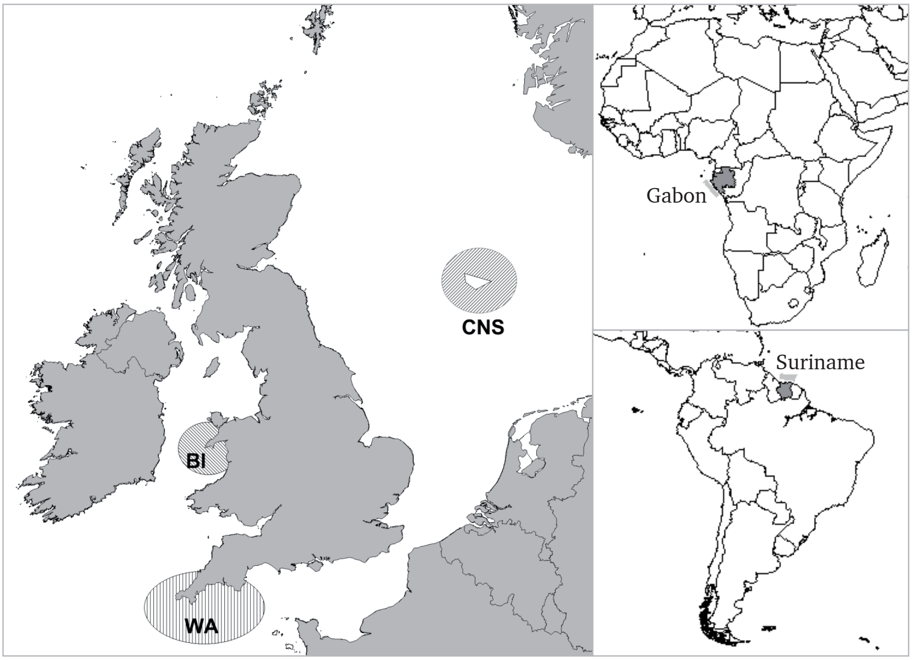


Figure 1.2 Different study areas: Bardsey Island (BI); Central North Sea (CNS); the Western Approaches (WA); Gabon (West Africa) and Suriname (South America).

Table 1.2 Overview of the different study sites and methodology approaches used in this thesis.

Methodology approaches	**Bardsey Island**	**English Channel**	**Central North Sea**	**Gabon**	**Suriname**
Platform of Opportunity	Island (fixed-point) Inter-Island ferry Dory (fishing boat)	Fisheries Monitoring Supply vessel Wildlife Operators Headland (fixed-point)	Supply vessel Seismic vessel	Seismic vessel	Supply vessel Seismic vessel
Survey Method:					
Photo-identification	Yes	Yes *(not used for thesis)*	No	Yes *(not used for thesis)*	Yes *(not used for thesis)*
Fixed-point census	Yes	Yes *(not used for thesis)*	No	No	No
Line-transect survey	Yes	Yes	Yes	No	No
Spatial modelling	Yes	No	No	No	No
Acoustic monitoring	Yes *(not used for thesis)*	Yes *(not used for thesis)*	No	No	Yes *(recordings used to verify species ID)*
Use of Multi-Method approach	Yes	Yes	Yes	No	Yes
Use of strandings records	No	Yes	No	No	Yes
Use of sighting records	Yes	No	Yes	No	Yes
Target species	Risso's dolphin Harbour porpoise	Common dolphin Harbour purpoise	Minke whale Harbour porpoise	Tropical cetacean community	Tropical cetacean community
Survey period	1999-2007 (continued by WDC[1])	2004-2009 (continued by MDP[2])	2007	2009	2012

[1] WDC-Whale and Dolphin Conservation; [2] MDP-Marine Discovery Penzance

1.6.1 TARGET CETACEAN SPECIES

Four different cetacean species were selected as target species for this thesis. The decision to select these species was made on the basis of the data available and the information requirements from a conservation and management perspective. These species were the harbour porpoise (*Phocoena phocoena*), short-beaked common dolphin (*Delphinus delphis*), Risso's dolphin (*Grampus griseus*) and the northern or common minke whale (*Balaenoptera acutorostrata*).

In order to assess the cetacean tropical community off Surinam and Gabon, inventory surveys were carried out. The species encountered are not separately discussed here but described in Chapters 7-9.

Harbour porpoise (Phocoena phocoena)

The harbour porpoise (Factsheet in Addendum) occurs throughout north-west European continental shelf seas from the Barents Sea and Iceland south to the coasts of France and Spain. Genetic studies summarised by Evans et al. (2009) indicate that the population in the North Atlantic could consist of up to 15 distinct subpopulations or stocks.

The three international cetacean surveys–SCANS I, SCANS II and CODA (Cetacean Offshore Distribution and Abundance in the European Atlantic beyond the continental shelf) – provided the first broad-scale estimates of porpoise numbers and distribution in European waters. The population estimates for the wider North Sea region are approximately 341,000 individuals (CV=0.14) in 1994 and 385,600 (CV=0.20; covering a wider area) in 2005 (SCANS-II, 2008). Their abundance and distribution in the southern North Sea has changed significantly with a southern shift in distribution which is also reflected in Dutch coastal waters (Camphuysen et al., 2008; Reijnders et al., 2009; Camphuysen, 2011). It is not clear why the porpoise distribution has changed southward but this may result from changes in prey availability (Camphuysen, 2004; MacLeod et al., 2007b).

Despite the difficulties in collecting porpoise data some EU member states have designated Natura 2000 sites on the basis of their importance for this species. Germany, for example, has designated the Sylt Outer Reef in the North Sea on the basis of its high density of harbour porpoises and mother-calf pairs. However, no coastal/marine SACs has been explicitly identified for porpoises in the UK. There is clearly a need for greater knowledge regarding the habitat use and habitat preference of porpoises at a variety of spatial scales that are essential to their life and reproduction – as required under Article 4(1) of the Habitats Directive (Box. 1.1).

Short-beaked common dolphin (Delphinus delphis)

Short-beaked common dolphins (Factsheet in Addendum) generally occur in offshore waters although they do approach 'offshore' islands or peninsulas. During the winter months, common dolphins aggregate in the western approaches of the English Channel (western Channel) and in particularly off the West and South coasts of Ireland and Southwest England. Densities in these areas are much higher in winter than in summer (Evans, 1992; Pollock et al., 1997; Macleod and Walker, 2004; MacLeod et al., 2008).

The (summer) abundance of common dolphins in UK, Ireland, France and the Iberian Peninsula was studied during the SCANS II survey in 2005. Using data from both the shipboard and aerial the estimate was 56,221 animals (CV=0.234; Hammond et al., 2013). Another abundance estimate was obtained from the CODA surveys off the continental shelves of Britain, Ireland, France and Spain in July 2007 (118,264 CV=0.38); CODA, 2009).

There are grave concerns for the future populations of common dolphins as fisheries heavily impact them. Strandings each year of hundreds of dead common dolphins on French and adjacent UK coasts have been a phenomenon of the recent decades (Ross and Isaac, 2004; Peltier et al., 2011).

Risso's dolphin (Grampus griseus)

Risso's dolphins (Factsheet in Addendum) are a typical offshore dolphin but appear to be semi-resident near 'offshore' islands which have good access to deep water feeding grounds (Baird, 2002; Hartman et al., 2008). Unlike many regions of the world where Risso's dolphins are generally confined to deep water, records from the UK suggest a widespread distribution over the continental shelf, including the Western Channel, the Irish Sea and the west coasts of Scotland and Ireland, extending east into the North Sea (Evans et al., 2003).

The only abundance estimates available for European waters are for the Mediterranean Sea (Gannier and Gannier, 1994; Gómez de Segura et al., 2006) and the status of Risso's dolphins in Northwest European waters remains unknown (e.g. Wharam and Simmonds, 2008).

Because of their offshore preference and rather elusive nature, Risso's dolphins are a poorly understood cetacean species. The UK represents the extreme northern range limit for Risso's dolphins showing little genetic diversity compared to Risso's dolphins elsewhere (Gaspari et al., 2007). Essentially nothing is known about the structure and size of this species' population. Risso's dolphins are assessed as 'Least Concern' in the IUCN Red Data List (IUCN, 2013). Only very recent, the European Cetacean Society at its 2013 annual meeting passed, by consensus, a resolution (only the second in its history) that called *'for urgent attention to be paid to the conservation of Risso's dolphin, particularly the establishment of protected areas and other appropriate measures for this species and recommends its inclusion in Annex II of the Habitats Directive.'*

Northern Minke whale (Balaenoptera acutorostrata)

The northern minke whale (Factsheet in Addendum) occurs widely in the northeast Atlantic and the North Sea, although this species is less common in the southern North Sea (Evans et al., 2003; Reid et al., 2003). In the northern North Sea, minke whales are mainly seen from April to October (Northridge et al., 1995; MacLeod et al., 2007a; Robinson et al., 2007; Weir et al., 2007) although they can be seen year-round (Macleod et al., 2004). Most studies of North Atlantic minke whales have been carried out at a large spatial scale (Hammond et al., 2002; Skaug et al., 2004) or more locally, in coastal waters (Naud et al., 2003; Macleod et al., 2004; Robinson et al., 2007, 2009; Tetley et al., 2008).

The total estimate of minke whale abundance for the North Sea (10,786 CV=0.49) in 2005 was not significantly different from the figure of 7,250 (CV=0.21) obtained in 1994 (SCANS-II, 2008). Overall there is a lack of knowledge regarding the seasonal distribution of minke whales in offshore habitats (MacLeod et al., 2007).

1.6.2 STUDY SITES

The decision to select the European study sites was made on the basis of the information requirements from a conservation and management perspective. The central theme that connects these study sites is that for each study site there was a lack of cetacean data available. A secondary consideration was the availability of suitable POs.

Bardsey Island offered a long-term opportunity to study the relatively poorly known Risso's dolphin and the elusive harbour porpoise. This site had not received much effort coverage in the past due to its location and in particular challenging weather and logistical constraints. Little information is available regarding small cetaceans in Welsh waters, and their fine-scale habitat-use at specific sites (e.g. De Boer et al., 2002; Pierpoint, 2008). In the coastal areas there are many human activities that need to be managed in relation to the localised distribution of small cetaceans that standard large-scale surveys may not be able to identify. However, the identification of distribution patterns and site fidelity is a fundamental pre-requisite for developing effective conservation strategies.

The **Western Approaches** had received poor survey coverage during the winter months when there was an apparent immediate information requirement regarding the bycatch on the wintering common dolphins. The Western Approaches of the English Channel (Western Channel) supports a diverse fish fauna including many commercially important species. As a result, the area is intensively trawled by pelagic fisheries, in particularly during the winter months from October to May (ICES, 2005). These intense fishing activities coincide with relatively high levels of cetacean strandings. In recent years, several hundred corpses have washed ashore in south west England each winter. The majority of 'fresh' carcasses which were recovered or examined were clearly diagnosed as having died through capture in fishing nets (Ross and Isaac, 2004). High levels of common dolphin bycatch have been recorded in pelagic trawl fisheries such as the UK sea bass pair trawl fishery, but the limited monitoring of pelagic fisheries to date precluded an assessment of total mortality levels (Ross and Isaac, 2004). The winter population size and structure of common dolphins and other small cetaceans in the Western Approaches also are very poorly known.

The **Central North** Sea had previously been surveyed during summer but during other parts of the year little information was available from dedicated cetacean surveys. With the designation or adoption of the Dogger Bank as an international nature conservation area under the EC Habitats Directive, and as part of the OSPAR network of Marine Protected Areas in the North East Atlantic Ocean, it has become a marked priority area for survey effort. An opportunity to study cetaceans within the Dogger Bank area was afforded in 2007, in particularly during a period that previously has received little survey effort for the Central North Sea area (spring time rather than summer).

The paucity of information on cetaceans in **central West African** waters indicates a general need for research to study the distribution and abundance of cetaceans and also to study potential threats (Perrin and Van Waerebeek, 2007; CMS, 2012). The main purpose of this study is to contribute information on the distribution and relative abundance of cetaceans sighted during a geophysical survey in Gabonese waters and where possible to relate the occurrence of different species with oceanographic parameters such as sea surface temperature and depth.

There is a similar marked gap in the knowledge of cetaceans in **Suriname waters** and baseline data are needed for future investigations and monitoring as well as for conservation and management. The aim of this study is to describe a timely overview of baseline data and to provide this to UNEP's Marine Mammal Action Plan for the Wider Caribbean Region. Only recently, it was emphasized that more systematic at-sea surveys, photo-ID and behavioural studies are needed in order to assess the status of cetaceans not only in Suriname waters but within the Guianas as a whole (Brichett, 2012).

1.7 THESIS OUTLINE

This thesis comprises eight research chapters (Chapters 2-9) with an introduction (Chapter 1) and a synthesis (Chapter 10). Chapters 2-6 focus on the distribution, abundance and habitat-use of specific cetaceans in three study areas. In each of these study areas I follow a multi-method approach and explore how different datasets can complement each other and thereby strengthen the outcome of the research. Chapter 7-9 contain research papers that are examples of how Platforms of Opportunity can be used to collect data on distribution, relative abundance and behaviour of cetaceans in under-recorded tropical regions. Each research chapter represents a paper that is either published, in press or submitted.

Chapter 1 introduces the present study, providing 1) an outline of the main cornerstones for the conservation of cetaceans and their habitats serving as a basis for management orientated surveying and monitoring; 2) a review of the different survey methods and research platforms and in particular a discussion on the benefits and shortcomings of PO-based data. The context and the methodology approaches used in this study are detailed for each study area.

Chapter 2 describes the winter population of the short-beaked common dolphin in the Western Approaches of the English Channel. I present the first abundance estimate of this species on winter pelagic trawl-fishing grounds in this area. The research vessel was employed either as a PO or a primary dedicated vessel (following predetermined line-transects). The research presented here provided baseline data on the distribution and abundance of common dolphins in a period that has traditionally received little survey effort. The PO-based data proved valuable to explore how survey speed affected cetacean responsiveness to the survey vessel. The data showed the importance of the western Channel as a winter habitat for common dolphins and further highlighted that this winter population could well become depleted as a result of bycatch.

Chapter 3 investigates the interactions between short-beaked common dolphins and pelagic pair-trawl fisheries in the western Channel. Pooling data from the systematic line-transect surveys (see Chapter 2) with PO-based data I identified those areas where pelagic pair-trawl fisheries overlap with common dolphin 'hotspots'. The research presented here showed that the overlap between pelagic fisheries and the common dolphin hotspot is causing direct mortality through bycatch and, together with recent range-shifts, may have contributed to a localised decline of this species in this winter hotspot since 2007. Compiling the different data sets showed that there was a significant difference in the age and gender-composition of carcasses (inshore vs offshore). The survey results from this project will supplement on-going research and conservation work in the region regarding bycatch. Data were contributed to the Joint Cetacean Protocol project to investigate the status of cetaceans within the ASCOBANS area.

Chapter 4 examines the spring distribution and density of minke whales along an offshore bank, *the Dogger Bank*, in the Central North Sea. This study explores the use of a multi-method approach and contributes information at a fine-spatial scale and a long temporal coverage and, as such, provides ecological information regarding foraging minke whales. Unique for this study was that the longer temporal coverage highlighted the problem of timing a dedicated survey properly and showed that PO-based data can successfully be used to identify areas and periods of high density to improve designs for future line-transect surveys. With the designation or adoption of the Dogger Bank as an international nature conservation area, it has become a marked priority area for survey effort. The research presented here provided baseline data on distribution and density of minke whales in a period that has traditionally received little survey effort and as such will supplement on-going research and conservation work in the region.

In Chapter 5, photo-identification data collected from Bardsey Island (Cardigan Bay, Wales) between 1997 and 2007 are used to estimate the local abundance of Risso's dolphins using two different analytical techniques: (1) mark–recapture; and (2) a census technique based on the total number of identified individual dolphins. This study demonstrates that the combination of systematic and opportunistic photo-ID studies has complementary value as a population assessment tool in generating the first local abundance estimate for Risso's dolphins in UK waters. From the conservation perspective, these studies confirm the regular seasonal and long-term site-fidelity of Risso's dolphins in these waters. The results of this study may provide assistance to include the Risso's dolphin in future regional conservation strategies including the envisaged marine protected areas.

Chapter 6 identifies the key core-areas for harbour porpoises and Risso's dolphins using data collected from four different look-out points on Bardsey Island between 2001 and 2007. The habitat preferences were analysed using Generalized Additive Models (GAMs) and showed that porpoises and Risso's dolphins appeared to be linked to topographic and dynamic cyclic variables with both species using different core areas. This fine-scale study provided insight into the temporal fine-spatial distribution of two species that studies conducted over broader geographic scales do not achieve. Understanding which topographic and cyclic variables drive the patchy distribution of porpoises and Risso's in a Headland/Island system may form the initial basis for identifying potentially critical habitats for these species.

Chapter 7 summarises information on cetaceans that were observed off Gabon (West Africa) during an extended PO survey (March-August 2009). Cetaceans in tropical West African waters face various threats but the cetacean fauna is poorly known. This study therefore added to the limited data available from this region. It was shown that the Gabonese waters have a broad cetacean diversity, especially with a large and diversified delphinid community. The study also highlighted that variations in oceanographic conditions likely resulted in a temporal variation in species composition. Sightings of Atlantic spotted dolphin (*Stenella frontalis*) were the first at-sea sightings confirmed for these waters, although not unexpected given their distribution and abundant presence in surrounding waters. The poorly known Clymene dolphin (*Stenella clymene*) was the most abundant cetacean and the described observations present a new state record for Gabon.

Chapter 8 provides insight into the behaviour of rough-toothed dolphins (*Steno bredanensis*) and the first record of an all-white rough-toothed dolphin calf. There is little documentation concerning rough-toothed dolphins and this study contributes to the knowledge of this species in tropical West African waters. In June 2009, a group of rough-toothed dolphins was encountered off Gabon. The dolphins showed extensive body-scarring including scars caused by cookie-cutter sharks (*Isistius brasiliensis*) and scars indicative of entanglement in fishing gear. On one occasion, the dolphins were seen in close proximity of a Fish Aggregating Device. One of the calves was nearly uniformly white still possessing a very faint outline of the characteristic caped pigmentation pattern. The calf was seen swimming in close association of a normally pigmented adult. Reports of unusually pigmented cetaceans are infrequent and this record represents the first of an all-white rough-toothed dolphin.

In **Chapter 9** the offshore cetacean community in Suriname waters is described based on the first dedicated cetacean survey (May-September 2012) carried out in this region. Pooling all available data (strandings/sightings records and PO-based data from December to October) I established the first confirmed list of cetaceans that occur in Suriname waters and concluded that the offshore cetacean community in Suriname is best described as primarily a tropical community, dominated by odontocetes (dolphins and sperm whales). The study provides baseline data and contributes to the knowledge of the different cetacean species that occur in this under-recorded tropical equatorial offshore region.

Chapter 10 Synthesis. This synthesis draws together the major findings of previous chapters, discusses the implications and relevance of using PO-based data for estimates in numbers and distribution as well as conservation management purposes. Finally, I make recommendations to fill existing data gaps through the optimisation of future PO survey efforts and how such data can be implemented as part of multi-method approaches and/or feed multiple data-sets.

CHAPTER 2

WINTER ABUNDANCE ESTIMATES FOR THE COMMON DOLPHIN (*DELPHINUS DELPHIS*) IN THE WESTERN APPROACHES OF THE ENGLISH CHANNEL AND THE EFFECT OF RESPONSIVE MOVEMENT

Published as: De Boer MN, Leaper R, Keith S, Simmonds MP (2008). Winter abundance estimates for the common dolphin (*Delphinus delphis*) in the Western Approaches of the English Channel and the effect of responsive movement. Journal of Marine Animals and Their Ecology 1(1): 15-21.

Short-beaked common dolphin

2.1 ABSTRACT

A survey using line-transect techniques was conducted during two winters providing the first estimates of common dolphin, *Delphinus delphis,* abundance (number of dolphins) on winter pelagic trawl fishing grounds in the English Channel. Independent teams of observers searched with binoculars or naked eye. These methods were intended to allow for the calculation of a correction factor for both animals missed on the trackline and for responsive movement. Results indicated that the naked eye observers missed 7% of the dolphins on the trackline, but that there was a strong responsive movement towards the vessel. Comparing initial locations of animals detected by the two independent teams showed that just using naked eye observations would result in apparent densities that were 1.5 times larger than the dual platform analysis. Using these factors the mean corrected winter density of common dolphins in the study area across both years was 0.74 dolphins/km^2 (CV=0.39) giving a mean abundance of 3,055 dolphins (95% CI=1,425-6,544). However, these estimates are most likely positively biased due to responsive movement not being fully accounted for. Nevertheless, the relative index for abundance (number of schools per 100 km effort, mean school size 5.1) was the highest recorded from comparable surveys in the North Atlantic and shows that the Channel is a very important winter habitat for common dolphins.

2.2 INTRODUCTION

The English Channel constitutes a relatively narrow link between the Atlantic Ocean and North Sea that appears to have had variable use by common dolphins over time (Murphy et al., 2006). Fish stocks in the Channel are heavily exploited here with pelagic fisheries operating during the winter months from October to May. In recent years, several hundred corpses of short-beaked common dolphins (*Delphinus delphis*) have washed ashore in southwest England each winter, many clearly diagnosed as having died through capture in fishing nets. In the case of many of the common dolphin corpses, the external damage is consistent with death in small-meshed mobile gear (i.e. trawl netting; Sabin et al., 2002). The conservation status of the common dolphin has therefore become of great concern (Tregenza and Collet, 1998; Morizur et al., 1999; Ross and Isaac, 2004). In recent years the UK has conducted monitoring of the winter sea bass fishery, which has been found to be responsible for a high rate of cetacean bycatch (DEFRA, 2003). However, there are still no estimates of total annual bycatch for this species in all fisheries combined (ICES, 2006).

Only a few studies to date have reported the abundance of the short-beaked common dolphin in the NE Atlantic or supplied an estimate or index of density and abundance (Hammond et al., 2002; De Boer and Simmonds, 2003; Cañadas et al., 2004; Macleod and Walker, 2004). However, these surveys differ in distribution of effort, vessel-type, survey methodology and the season in which they were carried out.

This study utilised a commonly used method for estimating animal abundance, distance sampling, and highlights the consequences of responsive movement of dolphins towards the survey vessel. Line-transect surveys were conducted in two subsequent winters (2004 and 2005) to estimate the first winter abundance of common dolphins in an area of the Western Approaches of the English Channel.

2.3 MATERIAL AND METHODS

2.3.1 SURVEY DESIGN

The survey was conducted from the *MV Esperanza*, a 72.3 m research vessel which traveled at either a ‘fast’ average speed of 8.6 knots or a ‘slow’ average speed of 5.3 knots. All data used for density estimation were collected in ‘passing mode’, where the vessel did not deviate from the track-line in response to sightings of the target species.

The two surveys were conducted during the winter months, between 21 January and 8 March 2004 and between 17 February and 26 March 2005 in the Western Approaches of the English Channel. The study area was divided into different survey strata and lay between 49° 20' N-50° 20'N and 3° 26'W-6° 10'W (Fig. 2.1). The western stratum (Stratum W) extended to the west and covered 4,743 km^2 and the eastern stratum (Stratum E) covered 4,129 km^2. Both strata coincided with an area where trawlers operate during winter.

The survey track followed a saw tooth (zig-zag) pattern inside a rectangle (survey stratum). The zig-zags (transects) were designed such that the offshore boundary of the stratum was drawn parallel to the major axis of the coastline. Each point within the specified survey stratum had an equal probability of being on a line. The overall orientation of the transect lines was also designed such that they were placed approximately across likely density contours.

2.3.2 DATA COLLECTION

To facilitate systematic data collection, the data-logging program *Logger 2000* (developed by IFAW to promote benign, non-invasive research) ran continuously throughout the survey on a laptop computer which was linked to the ship's Global Positioning System (GPS, a Furuno GP-80 satellite navigation system) through an NMEA (National Marine Electronics Association) interface. This program automatically recorded the ship's location every 15 seconds and provided a continuous visual display of the vessel's track on a map of the area. Data concerning sightings and the environment were entered manually.

2.3.3 THE PRIMARY PLATFORM

During both the 2004 and 2005 surveys, observations were conducted from a Primary platform. This was located on the outer bridge wings with an approximate eye height of 11.3 m and was visually and acoustically independent from the Secondary (tracking) platform. The two Primary observers scanned a 90 degrees sector (on port and starboard), forming an approximately 180 degrees combined survey area in front of the ship. Scanning was done with the naked eye. A third person acted as the data recorder, entering sighting information and environmental details. The observers were rotated every hour to avoid fatigue.

Once a sighting was made, Nikon 7 x 50 marine binoculars with in-built reticule scales were used to measure the vertical angle from the horizon to the sighting in order to estimate distance. The bearing to the sighted animals and the animal(s) headings were determined by using 'angle-boards' which were fixed to the ship's railings. These were aligned parallel to the ship's bow and the alignment checked and corrected throughout the survey.

Sightings data recorded from the Primary platform included the time, GPS position, bearing, distance, species identification (and degree of certainty ranging from definite-100%, probable-75% to possible-50%), presence of calf and/or juveniles, school size (maximum, minimum and best estimate), animal's heading, travel mode, group composition and behaviour.

The following environmental data were collected every hour, and when conditions changed: ship's position, heading and speed; wind speed and direction (using an OBSERMET Wind meter OMC 939); cloud coverage and glare conditions (in degrees); visibility; swell height; and sea state. Water depths were obtained using a Furuno Navigational Echosounder (FE-700).

2.3.4 THE SECONDARY (TRACKER) PLATFORM

During the 2005 survey, observations were also conducted from a second platform. This Tracker platform was situated in the ship's crow's-nest, with an approximate eye height of 19.5 m, housing one observer ('Tracker'). The crow's nest contained two window frames which interrupted the view but allowed searching an uninterrupted combined area of at least 60 degrees (30 degrees on either side of the trackline with a free view beyond both frames to 120 degrees on either side) using Nikon 7 x 50 reticule marine binoculars mounted on a tripod. A digital voice recorder with a built-in digital camera (Olympus W-10) was attached to the binoculars and was used to record the following sightings data: time, reticules, heading, species ID and school size. The camera was facing down when photographing the bearing to the sighting to obtain images of reference lines on the deck. These lines were used to calculate the bearing to the sighting relative to the ship's heading using the methods of Leaper and Gordon (2001). The Tracker concentrated on searching at ranges beyond 1,000 m ahead of the vessel (prioritising sightings >1,500 m), trying to detect animals before they had responded to the approaching vessel, and recording re-sightings (tracking) until the animals had passed abeam.

The Tracker platform was not in operation throughout the survey. However, it was used whenever possible and when the ship was going at 'fast' speed and in a straight line.

2.3.5 DATA ANALYSIS

Only data collected from both platforms during 'fast' speed were used for conventional distance sampling analysis, whereas the Primary platform data collected during slow and fast speeds was used to study the effect of responsive movement.

The line transect method is based on certain assumptions. One of them is that all objects at zero perpendicular distance from the trackline are detected, that is '*g(0)*' equals one, where '*g(y)*' is the probability that an object at a perpendicular distance *y* from the line is detected. In practice, however, this is likely to not be a valid assumption for cetaceans as they can be missed for a number of reasons. This is the main reason why during line-transect surveys two independent data sets are often collected, because it allows for the calculation of a parameter, *g(0),* to account for animals missed on the trackline. If no correction is made for *g(0)* then this is a source of negative bias (Buckland et al., 2001). Another potential problem is that of a 'responsive movement' of the animals to the presence of the survey vessel, since another assumption is that animals do not respond to the surveyor before detection. Common dolphins are known to be strongly attracted to vessels and frequently approach to investigate and 'bow-ride'. If animals approach the vessel before detection, this would positively bias the density estimate.

In the 2005 survey, the methodology followed the Mark Recapture Distance Sampling method first described by Buckland and Turnock (1992). This method uses two sets of observation from the independent platforms to estimate a combined correction factor for *g(0)* and the effects of responsive movement. The underlying assumptions are that animals are detected by the Tracker platform before any responsive movement has taken place. In addition, the Tracker needs to search a sufficiently wide sector that animals should not be able to approach to within the field of view of the Primary platform without some chance of being detected by the Tracker.

Data from the Primary platform during double platform effort (predetermined transects and straight lines) were used to estimate the encounter rate (number of detections per km^2), while data from the secondary platform allowed the effective width of search from the Primary platform to be estimated.

Duplicate sightings (sightings seen by both platforms) were identified on the basis of time and sub-sequent re-sightings, species ID, best school size and heading of the animal(s). The eye-height for each observer was measured in order to convert radial distances calculated from the reticules and bearing data to perpendicular distance (Buckland et al., 2001).

Using the program *Distance 4* (Research Unit for Wildlife Population Assessment, University of St. Andrews, UK) the conventional estimate of density (groups/km^2) was obtained by equating the number of detections from the primary platform (n_p) with the number expected. When assuming *g(0)* equals 1, the equation is:

$$\hat{D}_p = \frac{n_p \hat{f}(0)}{2L} \qquad \text{(I)}$$

Where n_p is the number of primary detections, is the probability density of perpendicular distances x recorded from the primary platform and L is the length of transect (km).

The density estimate in (I) is biased if there is responsive movement in response to the platform before detection from the Primary platform or if the probability of detection on the trackline is less than unity. The estimate in the presence of both effects is then:

$$\hat{D}_c = \frac{n_p \hat{f}p(0)}{2L\hat{g}p(0)} \qquad \text{(II)}$$

Where $\hat{f}p(x)$ is the probability density of perpendicular distances prior to responsive movement, of animals subsequently detected by the Primary platform and where $\hat{g}p(y)$ is the probability that an animal detected from the Tracker platform at perpendicular distance y from the trackline of the Primary platform is subsequently detected from the Primary platform (i.e. the detection function for the Primary platform).

If the Tracker platform is not in continuous operation, the above procedure is carried out on data collected while both platforms were in operation and a correction factor is calculated as:

$$\hat{c} = \frac{\hat{D}_c}{\hat{D}_p} \quad \text{(III)}$$

The density for the entire survey area is then estimated by *cD*, where *D* is estimated from the sightings data from the Primary platform for the full survey, calculated assuming $g(0) = 1$ (using *Distance 4*). This estimate does not include any covariates and thus the assumption is that the estimate of $g(0)$ for the two platform effort is the same as for Primary platform only. The corrected abundance estimate is calculated by $N_c = c\ D\ A$ and the *CV* of the corrected abundance estimate can be calculated by equations outlined in Turnock et al. (1995). The upper and lower 95% confidence intervals for N_c can be calculated by using the Satterthwaite degrees of freedom procedure outlined in Buckland et al. (2001).

2.4 RESULTS

2.4.1 SURVEY EFFORT

The line-transect survey covered 728.5 km of transect and the double platform survey covered 514 km. A total of 129 sightings of common dolphins of approximately 759 animals were made during the line-transect survey. Other species that were also identified during the survey were: harbour porpoise (*Phocoena phocoena*), bottlenose dolphin (*Tursiops truncatus*), Risso's dolphin (*Grampus griseus*), striped dolphin (*Stenella coeruleoalba*), fin whale (*Balaenoptera physalus*) and minke whale (*Balaenoptera acutorostrata)*.

2.4.2 DENSITY AND ABUNDANCE

Common dolphin sightings first made aft of the beam were excluded. To ensure that only high quality data were used sightings made during Beaufort sea state >3 were removed and sightings beyond 600 m were eliminated before $f(0)$ estimation. Sightings made by the Primary platform were analysed for 2004, 2005 and pooled across both years.

Using the program *Distance 4*, we fitted detection functions to the perpendicular distance data to estimate the Effective half Strip Width (*ESW*) which is defined as $1/f(0)$, for the different survey years. To reduce bias in mean school size estimates due to the potential of a positive relationship between school size and perpendicular distance (x), a regression was performed to investigate the relationship between the probability detection function, $g(x)$, and observed school size (3). From this regression, an expected school size was estimated. Akaike's Information Criterion (AIC) was used to select among models fitted to the data. Out of the models tested, the half-normal key with cosine adjustment was found to be the best fit

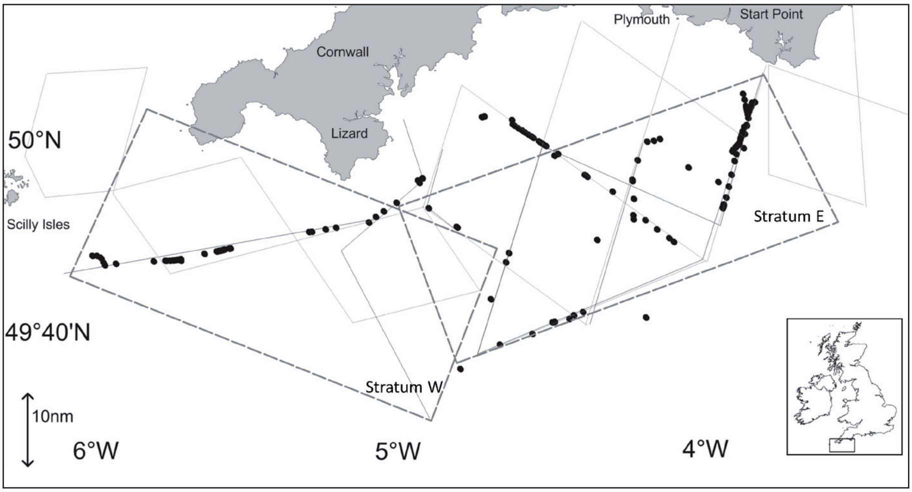


Figure 2.1 Map showing the transect layout (grey lines) with achieved effort (black lines) and survey strata (dashed grey lines). Sightings of common dolphins are plotted as black dots.

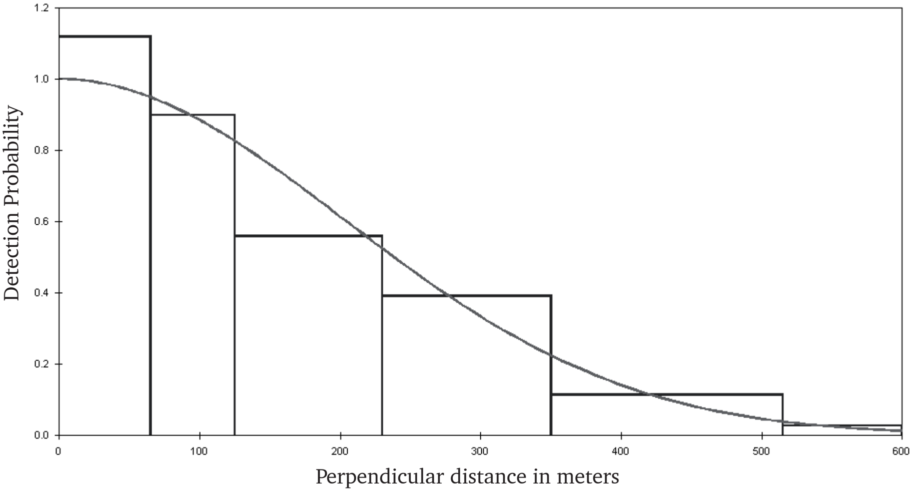


Figure 2.2 Histogram of perpendicular primary sighting distances and their fitted detection functions for common dolphins (n=108).

for both surveys. The distribution of perpendicular distances and fitted detection function for sightings data pooled across both years are shown in Fig. 2.2.

Having selected a model, we reviewed the options for variance estimation. Bootstrapping was carried out which incorporates uncertainty in model fitting and model selection. Although survey effort was achieved in both strata, some concerns are given to the western stratum (covered only in 2004) where there were large differences between the designed and the realized cruise tracks as a result of heavy shipping traffic in the area (Fig. 2.1).

For the eastern stratum (Stratum E; 4,129 km^2) the designed survey coverage was achieved so the density estimate should not be biased by non-uniform distribution of animals. The combined density estimate for both strata is more sensitive to non-uniform distribution of animals since only a relatively small proportion of the designed survey coverage was achieved in the western stratum due to heavy shipping traffic. The estimate of the density of individuals per km^2 (D) for Stratum E was calculated (Table 2.1) as outlined in Buckland et al. (2001).

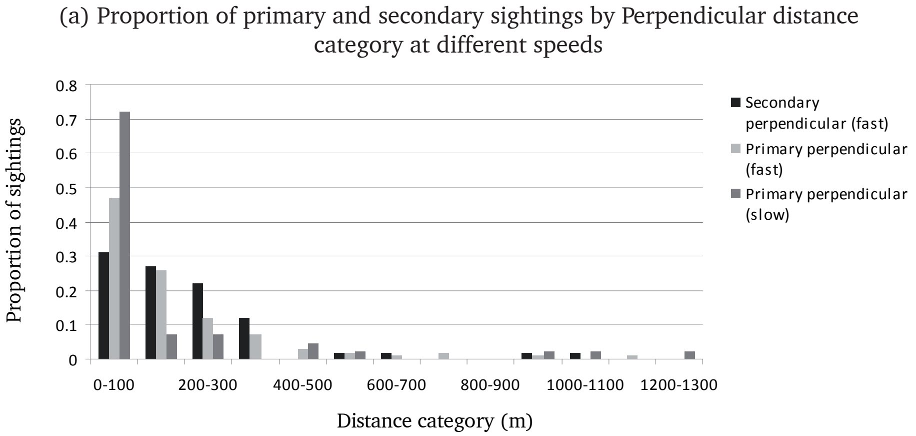
Table 2.1 Line-transect primary effort and winter density results estimated by Distance 4 (assuming g(0)=1 and no responsive movement) for common dolphins for Stratum E by stratification, where ESW =Effective half Strip Width and CV=coefficient of variation.

Parameter	**Value/Estimate**
Primary effort (L) in 2004+2005 (km)	573.9
Number of schools (n)	63
n/L	0.109
ESW (km)	0.253
Expected/mean school size (s)	5.063
Density (D) of individuals (ind/km^2)	1.097
%$CV(D)$	35.94

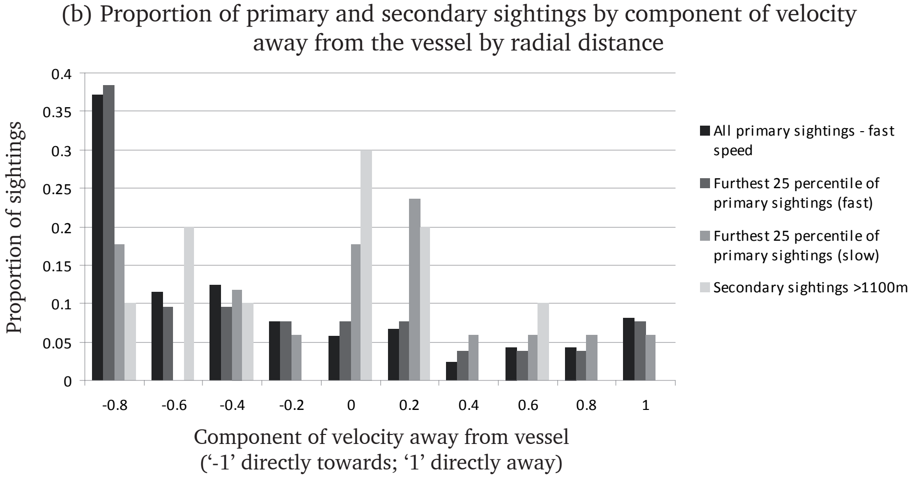
2.4.3 MEASURING THE EFFECT OF RESPONSIVE MOVEMENT AND SURVEY SPEED

We pooled data for all initial Primary sightings of common dolphins in sea state ≤ 3 (to make sure that higher sea states were not affecting the data) for both fast and slow speed modes (transects/straight lines) for the different survey years. The perpendicular distance plots (Fig. 2.3a) show substantial peaks in the first bin (less than 100 m) and this is consistent with responsive movement towards the vessel. We assume that there is no difference in observer behaviour between fast and slow vessel speeds, however, the peak at small perpendicular distances is considerably more pronounced at slow speed than at fast speed suggesting an effect related to the behaviour of the animals.

We explored responsive movement further by examining the estimated swimming directions of dolphins relative to the vessel. Taking the vector component of the dolphin's velocity away from the vessel, the results for the Primary platform are shown in Figure 2.3b. There is a distinct large peak close to '-1', *i.e.* the majority of sightings are of dolphins approaching the vessel. When only sightings with a distance in the 25 percentile furthest from the boat (>400 m) are included



(a) Proportion of primary and secondary sightings by Perpendicular distance category at different speeds



(b) Proportion of primary and secondary sightings by component of velocity away from the vessel by radial distance

Figure 2.3 (a) The proportion of primary and secondary sightings by perpendicular distance category (m) at different survey speeds: 'fast' and 'slow' and (b) the proportion of primary and secondary sightings by component of velocity away from the vessel (i.e. the cosine of the difference between bearing and heading). Where a value of '1' indicates movement directly away from the survey vessel, '0' perpendicular and '-1' directly towards the vessel.

in this analysis, there remain significantly more animals with headings towards the vessel than away (χ^2, p=0.001) although this effect is no longer significant for primary sightings made during slow speed mode (χ^2, p=0.8). Results from the Tracker platform also show significantly more animals heading towards the vessel (χ^2, p=0.003). Although the effect is no longer significant for sightings made at distances greater than 1,000 m (χ^2, p=0.2), there were nevertheless more than double (n=7) the number of sightings with animals heading towards the vessel than away (n=3). The observed distribution of headings will be affected by the sightability of the animal at different presentation angles (Palka and Hammond, 2001). The peak we observed was with animals heading directly towards the vessel which would be expected to show a smaller visual target. Thus these observations cannot be explained by presentation angle effects.

2.4.4 ESTIMATING A CORRECTION FOR BOTH $g(0)$ AND RESPONSIVE MOVEMENT

Using *Distance 4*, we used Tracker platform data to estimate $f_s(0)$; Primary data to estimate $f(0)$; and duplicates to estimate $f_{ps}(0)$. The error for the correction factor c was estimated by bootstrapping on sightings data from both platforms by transect and applying the estimation procedure to each of 199 bootstrap data sets (Table 2.2). The *CVs* of corrected density and abundance estimates and the Satterthwaite degrees of freedom (*df*) for the corrected density and abundance estimate confidence intervals were calculated (Table 2.2).

Table 2.2 Summary of variables required for the calculation of a correction for movement and for animals missed on the trackline using the Double Platform Effort data, where ESW =Effective half Strip Width and CV=coefficient of variation. The corrected density estimate for Stratum E is calculated using the correction factor (c).

Parameter	**Value/Estimate**
Double platform effort, *DP* (km)	514
Truncation distance, w (km)	0.6
Number of secondary detections, n_s	12
Number of primary detections, n_p	88
Number of primary detections after truncation at 0.600km	86
Number of duplicate detections, n_{ps}	10
ESW of secondary platform, $1/f_s(0)$	1/3.16 = 0.316
ESW for duplicates (km), $1/f_{ps}(0)$	1/3.53 = 0.283
Apparent *ESW* for primary platform (km), $1/f(0)$	1/5.15 = 0.194
Apparent density estimate, D_p (groups/km^2)	0.431
Corrected density estimate, D_c (groups/km^2)	0.291
Primary detection probability 'near' trackline, $g_p(0)$	0.931
Correction factor, c	0.675
Standard error of c, *s.e.* (c)	0.113
Provisional density (ind/km^2) for Stratum E in 2004+2005	1.097
Corrected density (ind/km^2) for 2004+2005 survey (Stratum E)	0.74 (*CV*=39%) 95% CI [0.34-1.59]

2.4.5 DISTRIBUTION

Common dolphins were widely distributed throughout the study area in both winters. It is worth noting that the relative index for abundance (number of schools per 100 km effort, mean school size 5.1) of common dolphins sighted (following pre-designed and not pre-designed transect/lines) was much lower in the French part of the Channel (south of the study area, 1.23 schools per 100 km) when compared to the study area (14.23 schools per 100 km). Areas of few or no sightings included waters to the east of the study area although survey effort was low. Waters to the west of the study area were not systematically surveyed due to unfavourable weather conditions.

2.5 DISCUSSION

The obtained estimated corrected density was 0.74 individuals/km^2 (95% CI 0.34-1.59; Table 2) and the corrected abundance estimate for stratum E was 3,055 animals (95% CI=1,425-6,544). There are no other abundance estimates that are directly comparable with these winter estimates for the study area. Other estimates are from ship surveys that took place some years ago and were conducted during the summer months (Goujon et al., 1993; Cañadas et al., 2004; Hammond et al., 1995) and during autumn (De Boer and Simmonds, 2003). The relative index for abundance, number of schools per 100 km effort (mean school size 5.1), can be compared and was much higher during this winter survey (10.9) than the SCANS 1994 summer survey in the Celtic Sea (Block A: 0.94; Hammond et al., 1995) and to the NASS 1995 summer survey in the Faeroes and western British Isles (Block E: 1.02) and in the offshore Atlantic (Block W: 7.5; Cañadas et al., 2004). The autumn relative index was also found to be much lower in the western Approaches of the English Channel (2.9; De Boer and Simmonds, 2003).

The double platform survey indicated that Primary observers only missed 7% of the dolphins on the trackline, $g(0)=0.93$, but that a strong responsive movement towards the boat resulted in apparent densities 1.5 times greater than based on the double platform data. Sample sizes for animals first detected at radial distances of greater than 1000 m were small ($n=10$). Although, the number of animals heading towards the vessel was not significantly different from the number heading away, it is possible that some animals were responding to the vessel at greater distances than they were detected. Thus the true correction factor could be much greater than 1.5. In addition, we observed that the *ESW* of the Tracker platform appeared to be rather narrow (316 m). It is likely that animals could approach the vessel from outside the Tracker's view and still be detected by the Primary observers. This means that the strip width for duplicates (ESW_{ps}) will be underestimated and is possibly the reason why the obtained ratio of c^{-1} (1.5) is small.

By comparison, Cañadas et al. (2004) estimated a correction factor of around 6 for a similar double platform survey using naked eye and 7 x 50 binoculars.

This study found that survey speed affected cetacean responsiveness to the survey vessel. In fact, it appeared that there were two effects when comparing the two survey speeds (fast *versus* slow). One is a ‘movement’ effect and the other is a ‘sightability’ effect. The perpendicular distance data show a more pronounced effect at slow speed which contrasts with a more pronounced effect at fast speed indicated by the heading data. The heading data for the fast speed mode indicated that there was still significant evidence of responsive movement even for the further 25 percentile of naked eye radial detection distances. For the slow speed data, however, the further 25 percentile of radial distances show no significant responsive movement. We conclude that this is probably due to an availability/detectability effect (*e.g.* surfacing behaviour changes the observer’s ability to sight an animal). Indeed, it could well be that dolphins that are approaching a fast moving vessel are more likely to surface in the ‘middle class’ of distances (around 200-300 m).

2.6 CONCLUSION

The winter diversity of the cetacean community in the Western Approaches of the English Channel, with a total of 7 different species seen during both surveys, highlights that the area is an important winter cetacean habitat. The dual platform data suggest that estimates for the winter population of the short-beaked common dolphins in the survey area from the same vessel may have been positively biased by at least a factor of 1.5 as a result of responsive movement. Uncertainties in the level of bias due to responsive movement are a problem for all current estimates of common dolphin abundance. Nevertheless, the observed relative index for abundance is among the highest recorded for common dolphins in the NE Atlantic indicating the importance of the western Channel as a winter habitat for this species.

A bycatch level for small cetaceans of more than 1.7% of the best available estimate of abundance has been deemed in the relevant international forum to be unacceptable (ASCOBANS, 2000). Based on our corrected estimate for Stratum E (the area overlapping with the current main fishing grounds) this would equal some 52 (24-111) animals. During the 2003/2004 fishing season, a bycatch of 169 common dolphins was recorded in the area in the UK bass fishery alone, producing an extrapolated total estimated mortality for the UK fishery of 439 animals (SMRU, 2004).

Little is known about the overall winter distribution of common dolphins in the NE Atlantic or their seasonal movements. The dolphin abundance estimate for the relatively small survey area in this study is small compared to overall abundance estimates for the NE Atlantic (ICES, 2006). Nevertheless, the high levels of bycatch reported in the Channel area raise both conservation and animal welfare concerns. If this area is only used by a subset of the total Northeast Atlantic population of common dolphins, or if the Northeast Atlantic hosts several different common dolphin populations, there is a risk of depletion within the Channel area. If local depletion were to occur, it is not clear whether common dolphins from further away would then start to exploit and re-populate the Channel area. There is some evidence of population structure within the common dolphins of the NE Atlantic (e.g. Lahaye et al., 2005; Murphy et al., 2006).

A more comprehensive and wide-ranging assessment of bycatch, including statistically robust observer programs in both pelagic trawl and also gillnet fisheries is urgently needed. The data from this survey show that the winter population of common dolphins in the English Channel could well become depleted as a result of bycatch.

2.7 ACKNOWLEDGEMENTS

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CHAPTER 3

INTERACTIONS BETWEEN SHORT-BEAKED COMMON DOLPHIN (*DELPHINUS DELPHIS*) AND THE WINTER PELAGIC PAIR-TRAWL FISHERY OFF SOUTHWEST ENGLAND (UK)

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Short-beaked common dolphin

3.1 ABSTRACT

During offshore and onshore studies (2004-2009) the interactions between pair-trawls and short-beaked common dolphins (*Delphinus delphis*) were studied to better understand the impact of bycatch. A 'hotspot' area where pair-trawls overlapped with high dolphin abundance was identified. We made comparisons between boat-based data collected in absence and presence of pair-trawlers. The relative abundance and group-size of dolphins was significantly higher in presence of pair-trawlers. Dolphins were observed associating with towing and hauling procedures. Significantly more carcasses occurred in areas with hauling-activity than those without. Body-temperatures obtained from carcasses found near operating pair-trawlers indicated that bycatch mostly occurred at night. During necropsy studies difficulties were encountered in identifying the fishing-gears responsible. Strandings data highlighted that the number of dead stranded dolphins was probably much higher than previously reported and there was a significant difference in the age and gender-composition of carcasses. Mature/sub-adult males appeared at greater risk from entanglement in pair-trawls offshore, whilst females with young appeared more vulnerable to inshore gillnets. Our findings show that the overlap between pelagic fisheries and the common dolphin hotspot is causing direct mortality through bycatch and, together with recent range-shifts, may have contributed to a localised decline of this species in this winter hotspot since 2007.

3.2 INTRODUCTION

Globally, much is unknown about interactions between fisheries and cetaceans (Read et al., 2006). Incidental catch in fishing gear (bycatch) forms a major threat to the conservation of cetaceans in European waters (e.g. Parsons et al., 2010). This has long been acknowledged by inter-governmental bodies such as ASCOBANS (Agreement on the Conservationof Small Cetaceans of the Baltic, Northeast Atlantic, Irish and North Seas), DEFRA (the UK Department for Environment, Food and Rural Affairs), ICES (International Council for the Exploration of the Sea) and Non-Governmental Organisations such as WDCS (Whale and Dolphin Conservation Society) and Greenpeace (e.g. working reports from ASCOBANS 2000; WDCS:

Ross and Isaacs, 2004; DEFRA, 2009 and Parsons et al., 2010). In the eastern Atlantic and western Mediterranean, the common dolphin (*Delphinus delphis*) is the most frequently bycaught dolphin. This species is one of the most abundant dolphin in these areas, although, following a recent decline, not so common any more in most of the Western Mediterranean (Bearzi et al., 2003). The fisheries responsible for bycatch include tuna driftnets, pelagic trawls, bottom set-nets, beach seine-nets and long-lines (Morizur et al., 1999; Silvani et al., 1999; Silva and Sequeira, 2003; Tudela et al., 2005; Rogan and Mackey 2007; Fernández-Contreras et al., 2010; preliminary reports: Goujon, 1996; working report: Tregenza et al., 1997). With pelagic drift nets now prohibited, pelagic trawls and bottom-set gill-nets pose the main threat to common dolphins in European waters (working report from ICES, 2005). Increases in reported bycatch lead to the adoption of new EU council regulations aiming to reduce cetacean bycatch (EC 2004). These regulations also require observer programs to monitor cetacean-fisheries conflicts and study the use of pingers in certain fisheries for larger vessels in the in EU-waters (e.g., North Sea, English Channel, Celtic Sea and Baltic; Parsons et al., 2010).

During the winter months, common dolphins move from their summer offshore habitats to aggregate in the western approaches of the English Channel (western Channel) and in particularly off the West and South coasts of Ireland and Southwest England. Densities in these winter areas are much higher than in summer (MacLeod et al., 2008; De Boer et al., 2008; working reports: Evans, 1992; Pollock et al., 1997; ICES, 2005; preliminary report: Macleod and Walker, 2004). Aggregations of dolphins in the western Channel also occur whilst this area is heavily exploited by fisheries using different gear including lines, traps, bottom-set gillnets, trammel-nets, bottom and pelagic trawls (López et al., 2003; Silva and Sequeira, 2003; Fernández-Contreras et al., 2010; project report: Northridge et al., 2006). Indeed, the western Channel is reported to have some of the highest fishing pressures in UK waters (Witt and Godley, 2007; Lee et al., 2010).

During winter there is high pair-trawl effort in the western Channel which mainly targets seabass (*Dicentrarchus labrax*) which come to the area to spawn (working report ICES 2005). Pair-trawlers tow a large funnel-shaped net between two boats; the net has a very wide opening both horizontally and vertically. Within the region, most research regarding cetacean bycatch has focused on static gear such as gillnets and more recently on acoustic devices (pingers) to decrease the bycatch of dolphins in fishing nets (e.g. trammel-, gill- and pelagic trawl-nets; Leeney et al., 2007; Gazo et al., 2008; Berrow et al., 2009). Conversely, fewer studies have been carried out on cetacean bycatch in trawl fisheries. Twenty-five cetacean species have been reported killed in trawl-gear worldwide (Fertl and Leatherwood, 1997). Other studies have focused on foraging associations between cetaceans and trawl-fisheries (e.g. Waring et al., 1990; Couperus, 1993, 1994, 1997; Fertl and Leatherwood 1997; Morizur et al., 1999; Chilvers and Corkeron, 2001; Fortuna et al., 2010). Cetacean bycatch has been reported in pair-trawl gear in the Celtic Sea and English Channel (working report: Northridge et al., 2006) and more recently also in the northern Adriatic Sea (Fortuna et al., 2010) and off northwest Spain (Lopez et al., 2003; Fernández-Contreras et al., 2010).

Common dolphin strandings in the Northeast Atlantic have shown a consistent spatial and seasonal pattern with pronounced winter peaks in the UK, Ireland, and the Atlantic coasts of France, Spain and Portugal (Simmonds, 1997; López et al., 2002; Silva and Sequeira, 2003; Leeney et al., 2008; Peltier et al., 2012; working reports Tregenza and Collet, 1998; Sabin et al., 2004; ICES, 2005). Fishing gear is rarely found on stranded cetacean carcasses, however, traumatic lesions such as abrasions, amputations, penetrating wounds, fracture of limb bones, mandibles or missing teeth are often visible (Kuiken, 1994; Kuiken et al., 1994; Garcia Hartman et al., 1994). Stranded cetaceans with such lesions, can therefore be used as evidence of cetacean bycatch, however, they neither provide estimates of total bycatch nor, in most cases, which gear type was responsible. The reasons are that 1) only a small percentage of bycaught carcasses wash ashore with the remainder sinking or decomposing at sea (Williams et al., 2011; Peltier et al., 2012), 2) many stranded carcasses may also go unrecorded due to the length and remoteness of the coastline concerned, and 3) not all carcasses can be retrieved or are fresh enough for necropsy to confirm the cause of death and, in the case of bycatch, the type of fishing gear responsible.

Following a record number of common dolphin strandings in Southwest England in 2003 (project report: Sabin et al., 2004) dedicated cetacean surveys were launched to study the overlap in distribution of common dolphin and their interactions with fisheries in winter. To this end, (1) additional shore-based studies (2006-2009) were carried out targeting those remote coastal areas where stranded cetaceans could possibly go unrecorded and (2) boat-based studies were carried out offshore (winters 2004-2005) in order to monitor the pelagic pair-trawl fisheries. This allowed us to observe the entire fleet and study cetacean-fisheries interactions as they occurred, and to collect and study stranded animals that might have otherwise gone unrecorded. Our at-sea surveys differ from observer programs which take place onboard fishing vessels, which do not allow for density comparisons between dolphins that associate with fisheries and those that do not.

The main objectives of this study are a) to study the winter distribution of the common dolphins and their interactions with pelagic pair-trawl fisheries in the western Channel, b) to identify those areas where pelagic pair-trawl fisheries overlap with common dolphin ‘hotspots’, c) to compare the age and genders of common dolphin carcasses found onshore to those offshore, and d) to determine the proportion of unrecorded stranded carcasses; and e) to examine stranded carcasses for lascerations indicative of bycatch. Given that both fishermen and dolphins are likely to target areas of high fish abundance we hypothesize that dolphin abundance is higher and hence interactions are more likely in areas with pair-trawl activity compared to areas where such activity does not occur.

3.3 METHODS

3.3.1 BOAT-BASED SURVEYS

Surveys were carried out during winter between 21 January and 8 March 2004 and 17 February and 26 March 2005 in the western Channel. The main study area (23,761 km^2) was between 49° 20'N-50° 20'N and 3° 20'W-6° 10'W (Fig. 3.1). The Greenpeace vessel MV Esperanza (72.3 m in length) was employed in either a fisheries monitoring role or a dedicated research role (following predetermined line-transect survey lines) in order to estimate the abundance of common dolphins (De Boer et al., 2008). During search-transits and fisheries monitoring, the vessel was used as a Platform of Opportunity (PO) vessel (without control over ship's route or speed). Survey effort continued throughout all daylight hours and was suspended when Beaufort Sea State (BSS) exceeded 4 or visibility dropped to < 1 nmile. Observations were conducted from the outer bridge wings at an eye height of 11.3 m. Two observers (one on each side) scanned a 180 degrees area in front of the ship (De Boer et al., 2008). The group-formation of the dolphins were classified as 'tight' (one group of animals which remain within one body length from each other), 'loose' (one group of animals which are more than 2-5 body lengths from each other), 'groups loose' (different groups are in the area, but each group is loosely grouped) or 'groups tight' (different groups are in the area, but each group is tight). The behaviour of the dolphins was recorded, *e.g.* 'bow-riding' (gliding/swimming on pressure wave in front of boat), 'breaching' (lifting the whole body above surface and hitting the surface with the lateral body surface) and 'approach'

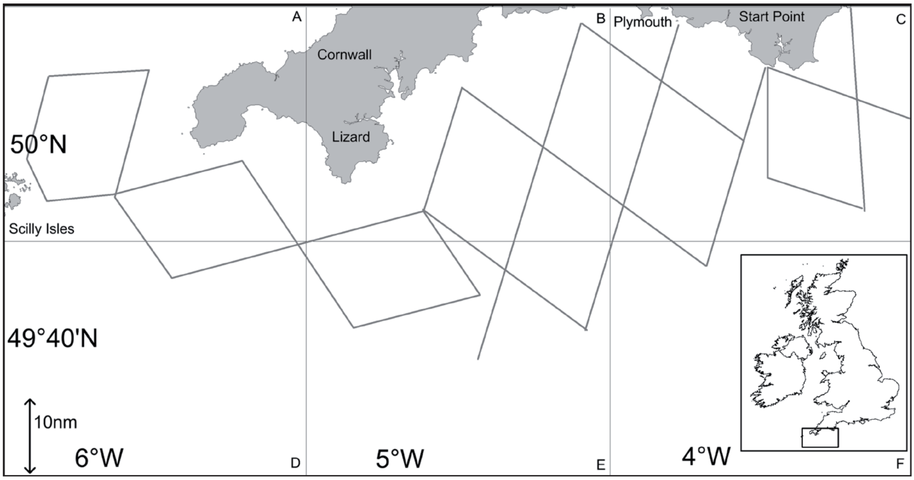

Figure 3.1 Study area with 6 strata (A-F) and predetermined line-transect design (grey lines) in the Western Approaches of the English Channel.

(approaching the vessel up to a few meters; preliminary report: De Boer et al., 2004). The group-size was recorded as a maximum and minimum estimate on which we based a best estimate (not accounting for animals underwater). Any changes in group composition (groups joining or leaving) were recorded to ensure that the best estimate of group size related to the group first sighted.

Effort was carried out in the absence of fisheries (Non-Fisheries Related effort, NFR) and during fisheries monitoring (from this point onwards called Fisheries Related effort: FR) with pelagic trawlers present in the general area (within 2 km). The position of pelagic pair-trawlers was recorded during hauling and subsequent launching operations (24 hours). FR effort also took place in areas where pair-trawlers were not engaged in either hauling or launching, but were solely engaged in trawling activities. When the research vessel was within good visual range of fishing operations any sightings with dolphins and trawler-positions were repeatedly plotted and apparent interactions monitored. Survey effort consisted of pre-determined transects and PO effort (straight tracks) when the vessel was in searching mode or in transit. The same survey protocols were used during FR and NFR effort. Survey speed was on average faster during NFR compared to FR effort (7.0 *vs* 5.2 nautical mile h^{-1}), When possible, survey efforts continued during high sea states (BSS > 4) however recorded sightings were regarded as incidental and are not included in the analysis.

In order to confirm if dolphins were entangled in fishing gear, a RIB (rigid-hulled inflatable boat) was used to monitor (non-dedicated) the nets within 100 to 200 m of the trawlers before, during and after hauling (during slight sea conditions, BSS < 4 and good visibility only).

Dead dolphins found offshore

Dead dolphins found floating were collected, identified to species and photographed. The maturity status of common dolphins was based on length (dolphins < 1.88 m are considered immature; derived from Murphy et al., 2009 and in some cases corroborated through necropsy). Basic body measurements, assessment of decomposition state (as defined in DEFRA, 2002), body temperature measurements and detailed morphological external examinations were carried out. Bycatch casualties were diagnosed following the criteria proposed by Kuiken et al., (1994), including (1) clean amputated fin or fluke, (2) incision wound in abdominal cavity, (3) circumscribing skin abrasions on beak, fin or fluke, (4) skin indentations or incisions apparently produced by net material or a sharp instrument, (5) loss of superficial slices of tissue/skin on edges of fins. In addition, blood or froth discharge from mouth and blowhole, skull fracture, tooth rake marks and skin infections were noted (Stockin et al., 2009). In order to determine if carcasses found at sea had recently died, the body temperature was measured using a digital thermometer inserted via the anus, with a non-flexible 17 cm probe (810-926 ETI-Ltd; until 6 February 2004) or a flexible 100 cm probe (MM2050/TM-electronics; from 14

February 2005 onwards). Carcasses collected at sea were secured for later necropsy studies and stored in a container maintained at -10°C. These were subsequently sent to the veterinary laboratories of the Institute of Zoology, London. When freezer storage availability became scarce the carcasses were deposited back to sea, together with all carcasses which were already in advanced states of decomposition. To avoid double reporting and recording, carcasses were measured, photographed and where possible tagged around the tailstock before depositing. The tags were made of metal showing a tag-ID and a contact telephone number to which recovered bodies could be reported.

Data analysis (winters 2004&2005)

The relative abundance was measured as the number of individuals per km effort. A grid of 10 min latitude by 10 min longitude cells was used totaling 54 cells. Those cells with a survey effort < 5 km were excluded from analysis. We employed statistical tests using the statistical package PASW for windows (SPSS, Inc., version 18) in order to adequately answer the following basic questions. Firstly, potential differences in data collected in the two winters were studied by segregation of the relative abundance per grid cell by survey year. No significant difference was detected between the two winters (Mann-Whitney's U=1,215.5, p=0.088) and in subsequent analysis the two data sets were pooled.

To determine whether the dolphins were randomly distributed throughout the survey area or if they appeared to aggregate in particular grid cells, a one-sided Kolmogorov-Smirnov goodness-of-fit test was used to check if the relative abundance of the dolphins differed from a uniform distribution. To compare the relative abundance of dolphins in presence (FR) and absence of trawlers (NFR) a Mann-Whitney's non-parametric test was used. In order to compare the group-size of dolphins between the two winters and between the presence and absence of pair-trawl fisheries (FR *vs* NFR) an independent sample t-test was preferred as the Mann-Whitney's non-parametric test is less powerfull and the group-size data fitted a (log) normal distribution. To determine whether the carcasses were randomly distributed over the survey area or were concentrating in particular grid cells, a Chi-squared goodness of fit test was used to investigate whether the observed number of carcasses differed from an expected Poisson distribution. We used a Chi-squared goodness of fit test to check if the sex ratio of the dead dolphins found offshore and onshore differed from the expected unity.

3.3.2 SYSTEMATIC COASTAL SURVEYS

Systematic coastal surveys were conducted during the winter months between 11 January-24 April 2006, 4 December 2006-22 March 2007, 8 January-27 February 2008 and 17 January-5 March 2009. Remote coastal areas were specifically targeted where, during the winter months, human visitation was expected to rarely occur, as opposed to the more frequently visited beaches where strandings were more readily reported to the UK Cetacean Strandings Investigation Program (CSIP). The coastal sites that we targeted had various degrees of remoteness which depended not only on topography and tidal time windows but also on weather conditions and daylight hours which could make access very difficult for a member of the public who was not motivated or properly equipped to enter such a remote area. Wind speed / direction and other variables were recorded for each coastal survey. A total of 37.6 km of remote coastline was divided into 35 coastal sites which were systematically and repeatedly surveyed following spring tides and favourable weather conditions.

Stranded cetacean carcasses

Each cetacean carcass located was examined and photographed on site. When a carcass was found to be relatively fresh, and evacuation was possible, it was secured for necropsy and transported to the Veterinary Lab (VLA) in Truro (Cornwall). Carcasses not secured for necropsy were left in-situ and marked with a unique black plastic-tie secured around the tailstock for future identification and prevent double reporting. At the end of each survey period all strandings data was compared to that from the CSIP to determine which of the strandings would have otherwise gone unrecorded. Details of those ‘unrecorded’ carcasses were then forwarded to the UK-stranded cetacean database.

3.4 RESULTS

3.4.1 BOAT-BASED SURVEYS

NFR survey effort occurred over 2,122.9 km and FR effort over 404.7 km (16% of total effort). Overall less effort was carried out in 2005 (NFR: 348.0km, FR: 56.7 km) due to persistent bad weather. Common dolphins were frequently encountered with 269 NFR sightings of 1,392 dolphins and 41 FR sightings of 386 dolphins. Although incidental sightings were not included in the analysis, it is worth noting that 21 incidental sightings (98 dolphins) occurred in presence of operating pair-trawlers and 161 sightings (1,871 dolphins) in absence of this fishery (BSS > 4; Fig. 3.2-3.3).

Fisheries vs Non-fisheries

The dolphins were not uniformly distributed throughout the survey area ($K\text{-}S\ D_{max}=3.21$ $p<0.001$). Most NFR effort was carried out over the entire study area and concentrated South of Start Point and Southeast of the Lizard (Fig. 3.2) whereas FR effort was concentrated in the eastern part of the survey area (Fig. 3.3). The highest NFR relative abundance for common dolphins was measured

Southeast of the Scilly Isles (3.2 dolphins km^{-1}), South of the Lizard (2.6 km^{-1}) and Southwest of Start Point (1.7; Fig. 3.2). The highest FR relative abundance for common dolphins was measured Southwest of Start Point (6.8 dolphins km^{-1}; Fig. 3.3). The overall relative abundance for FR dolphins (1.0 dolphins km^{-1})

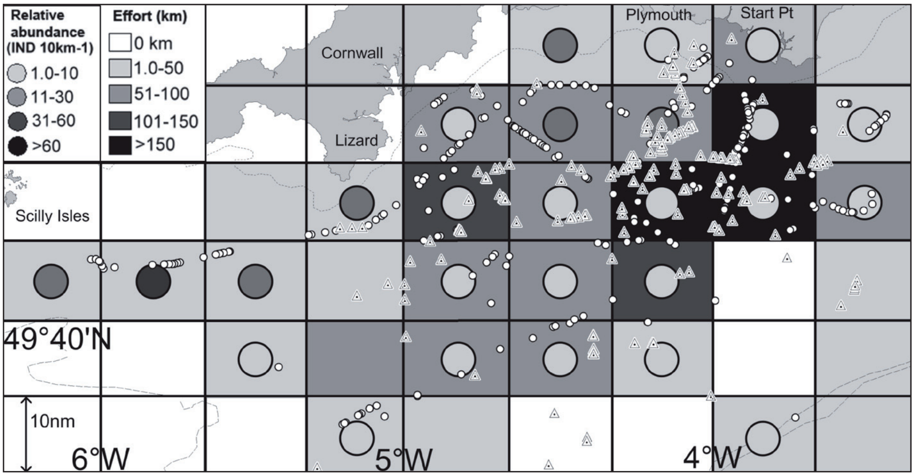

Figure 3.2 *Distribution of NFR effort and spatial distribution of common dolphin relative abundance. Common dolphin sightings are plotted as dots and incidental sightings are plotted as triangles. Depth-contours: 50 m (dotted); 100 m (dash-line).*

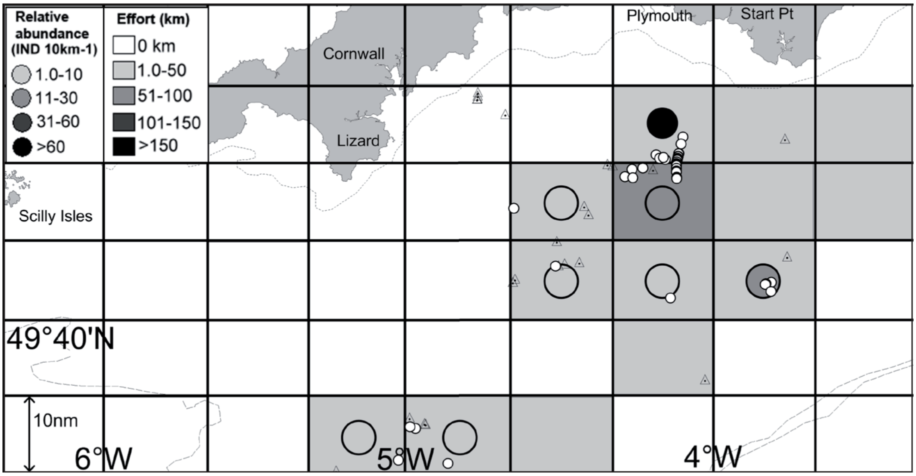

Figure 3.3 *Distribution of FR effort and spatial distribution of common dolphin relative abundance. Common dolphin sightings are plotted as dots and incidental sightings of common dolphins in vicinity of fishing vessels are plotted as triangles. Depth-contours: 50 m (dotted); 100 m (dash-line).*

was found to be significantly higher than that of NFR dolphins (NFR: 0.7; Mann-Whitney's U=1,993.00, p=0.0001). When only focusing on those grid cells where NFR and FR effort overlapped the relative abundance for common dolphins was still found to be higher during FR effort (1.0 dolphins km^{-1}) compared to NFR effort (0.6 dolphins km^{-1}), however, this was no longer significant (Mann-Whitney's U=127.50, p=0.089).

There was no significant difference between the estimates of relative abundance for carcasses found floating at sea in those areas where FR and NFR effort overlapped (0.02 carcasses km^{-1} for FR, 0.003 carcasses km^{-1} for NFR effort; Mann-Whitney's U=82.50, p=0.870). When taking the whole survey area into account, also no significant difference regarding the relative abundance for carcasses was found (p = 0.685).

The average group-size of FR common dolphins was significantly higher (9.41, SD 11.25, n=41; Student's T-test, p=0.032) compared to the average group-size of NFR dolphins (5.44, SD 5.36, n=269). Overall, the average group-size differed between the two winters, with a significantly higher group-size (NFR+FR) in 2004 (6.96 SD 7.99 n=162) compared to 2005 (4.78, SD 4.78 n=148; Student's T-test, p=0.002).

Interactions

The hauling positions of pelagic pair-trawlers (in all weather conditions; Fig. 3.4) mainly occurred in those grid cells where dedicated FR effort took place. The highest number of hauls per 100 km^2 were recorded to the southwest of Start Point (>0.5 hauls per 100 km^2, Fig. 3.4). In 2004, pair-trawlers were observed hauling their nets at an average distance of 43.7 km (SD 12.33, n=18) from the coast whilst in 2005 this was 53.81 km (SD 19.45, n=23). The difference in closest distance to the coast of the hauling positions did not significantly differ between the two survey years (Mann-Whitney's U=144, p=0.098).

Interactions between the fisheries operations and dolphins were noted on ten occasions. These interactions included 'Approach', 'Bow-riding', 'Breaching' (between the pair trawlers). The dolphins were also observed surfacing in the vicinity of the nets or approaching these during setting or hauling, or just before the hauling procedure. However, no dolphins were observed entangled in nets.

A total of 23 dolphin carcasses - of which 21 were identified as common dolphins and two unidentified - were found drifting (Appendix I, Fig. 3.4). Eleven common dolphin carcasses were found during dedicated effort of which seven were found during FR effort. In addition, 12 carcasses were found during bad weather (BSS > 4) of which eight were found in presence of pair-trawlers. Four carcasses were tagged and deposited at sea but none were ever reported as stranded. Most carcasses located in 2004 were found drifting in an area ranging 26-40 km south of Plymouth and southeast of Start Point (Fig 3.4). In 2005, six carcasses were found in an area ranging from 37-77 km south of Plymouth, one carcass was

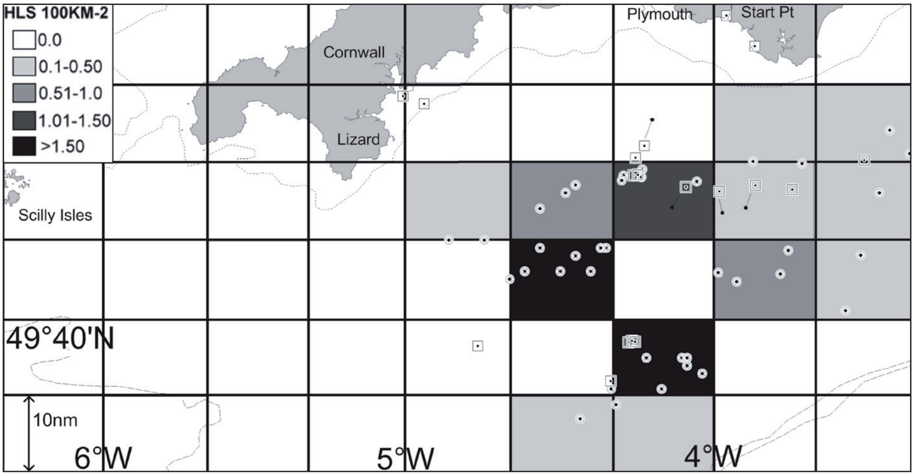

Figure 3.4 Position of pair-trawlers during hauling (2004-2005; open dots). Dead dolphin locations (pointed squares) and tagged dead dolphins (flagged). Depth-contours: 50 m (dotted); 100 m (dash-line).

reported near Falmouth and two carcasses were found in the French Channel (Appendix 3.1). The mean distance to shore of the carcasses found in 2004 (excluding those carcasses found floating within 2 km's of the coast) was 32.78 km (SD 10.37, n=12) whereas the 2005 data revealed carcass locations to be significantly further offshore (excluding those found in the French Channel; 64.44 km, SD 16.65, n=6; Student's T-test, $p < 0.001$). A Chi-Square test considering those carcasses found in the survey area (irrespective of their effort status) showed a significant higher observed number of carcasses than expected, especially in areas with hauling activity ($\chi 2$=11.17, df=2, p=0.004).

Other species

Occasionally other cetaceans were observed in presence of pair-trawlers, including harbour porpoise (*Phocoena phocoena*), bottlenose dolphin (*Tursiops truncatus*), Risso's dolphin (*Grampus griseus)*, minke whale (*Balaenoptera acutorostrata)* and *Balaenoptera sp. (*probably *B. physalus*). On two occasions basking sharks (*Cetorhinus maximus*) were seen in direct vicinity of operating pair-trawlers.

3.4.2 SYSTEMATIC COASTAL SURVEYS

A total of 1,364 surveys targeting remote coastal sites between the Helford Estuary on the Lizard Peninsula and Pendeen (Fig. 3.5) were carried out during the winters of 2006-2009 over 675.5 hours of effort. The wind direction during the 2006-2009 winters was mainly from the southwest. Most carcasses were found during periods

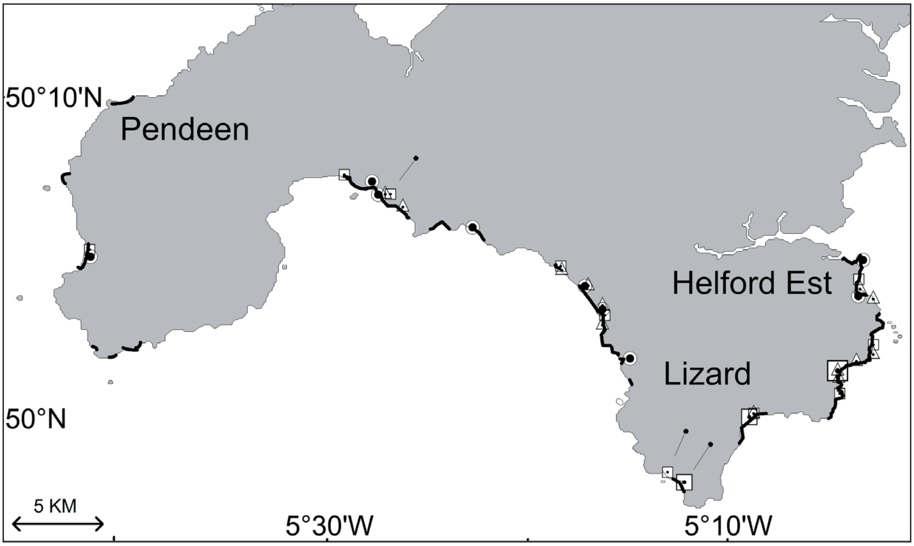

Figure 3.5 *Overview of remote coastal areas (bold black lines) and stranding locations (2006-2009). Common dolphin (dotted squares), harbour porpoise (dotted circles) and dolphin sp. (dotted triangles). Common dolphins secured for necropsy are flagged.*

Table 3.1 *Overview of carcasses found during coastal studies (2006-2009) and those classified as unrecorded. Information on cause of death (bycatch) and total number of carcasses reported to the CSIP are included (columns C and D).*

	Systematic coastal study (low human visitation)			**Study area (all areas)**	
Species	**A** Total carcasses found	**B** Total classified as unrecorded carcasses	**C** Suspected Bycatch (of A)	**D** Carcasses reported to CSIP (relevant to study area)	**E** Total carcasses in study area (B+D)
Common dolphin	19	11	13	24	35
Harbour porpoise	9	4	3	10	14
Dolphin sp.	13	7	1	2	9
Other	0	0	0	2	2
Total	41	22	17	38	60

of prevailing SW to SE (56%) winds. In particular the 2009 winter period was affected by persistent northwesterly winds and was characterised by a relatively low number of strandings (Appendix 3.2). A total of 41 cetacean carcasses were located stranded (Appendix II), including 19 common dolphins, 9 harbour porpoises and 13 unidentified dolphins (Table 3.1, Fig. 3.5). Three carcasses were secured for necropsy studies whilst the remainder of the carcasses were either too decomposed or found in areas where removal was logistically not feasible. Of the 41 cetacean carcasses found during this study, 22 carcasses were found on the more remote coastal sites and as a consequence were never reported to the CSIP. This represents 36.7% of the total number of strandings occurring within the area over the course of this study (*n*=60; Table 3.1).

3.4.3 EXTERNAL AND NECROPSY EXAMINATIONS

During the coastal studies, lacerations on 13 of the total 19 stranded common dolphins were indicative of bycatch. During boat-based surveys, dead dolphins 1-5 were found as a group (Appendix 3.1, Fig. 3.6f). A large piece of heavy netting (approximately 35 m in length) was found near the carcasses. Dolphins 6, 7, 9 and 10 were advanced decomposed. Dolphin 8, 9, 10 and 12 were tagged and deposited to the sea. Dolphins 5 and 11 could not be recovered. Dolphins 1-4, 16 and 19-21 had body temperatures well above the ambient sea water temperature of 9.4°C (mean body temperature was 20.6°C, range 14.9-30.1°C, Appendix 3.1). The external examinations of dead dolphins found offshore revealed the following injuries; severe wounding to the rostrum including deep lacerations (Fig. 3.6c), distorted jaws/ missing teeth, fluid/froth protruding from mouth and blowhole (Fig. 3.6b), cuts in dorsal-fins, flippers and flukes (Fig. 3.6d).

All eleven necropsies performed on dolphins found offshore revealed injuries consistent with bycatch. Interestingly, dolphins 19-21 (Appendix 3.1) were found close to pair-trawlers that had finished hauling and showed injuries due to partial eviscerations which affected the temperature readings (Fig. 3.6a). All dolphins were in very good nutritive conditions and recently had ingested prey. Necropsy reports provided no other evidence for cause of death other than bycatch. Some external netmarks were believed to be of thinner material than those expected from pelagic trawl-gear. During coastal studies, three common dolphins were secured for necropsy (Fig 3.5; Appendix 3.2). The reports concluded that two carcasses were too autolysed and thus the cause of death could not be determined yet one dolphin displayed some evidence of physical trauma prior to death. The third dolphin had a poor body condition and suffered from parasitic/bacterial pneumonia.

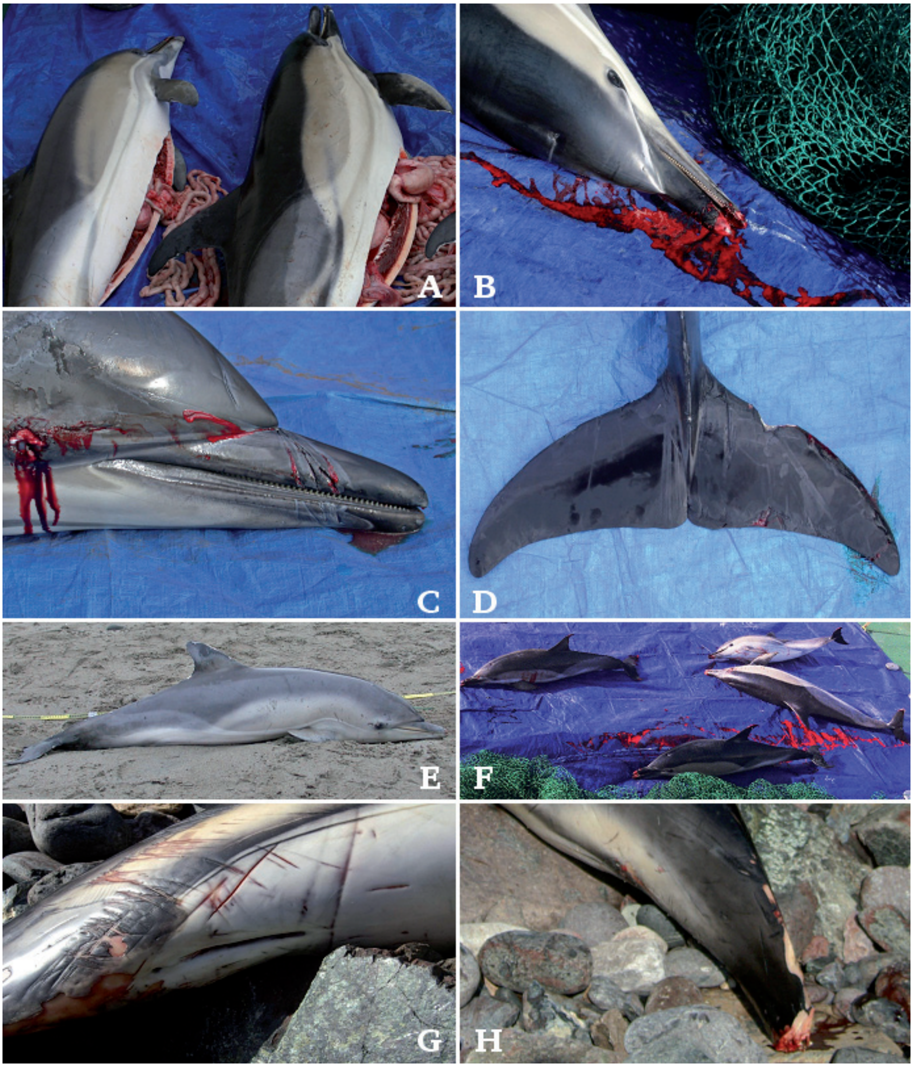

Figure 3.6 Lascerations indicative of bycatch. Partial evisceration (A); Froth protruding from blowhole (B); Lacerations surrounding rostrum (C); Severed fluke (D); Stranded juvenile common dolphin (E); Four carcasses recovered at sea (F); Deep lacerations surrounding body (G); Amputated fluke (H).

3.4.4 GENDER AND MATURITY

The sex ratio of the dead dolphins found offshore was skewed in favor of males (14 males: 5 females) and was statistically different from unity ($\chi 2=4.263$, df=1, $p=0.039$) whereas an even spread of both sexes was observed for onshore strandings (8 males: 9 females; $p=0.808$). A higher percentage of common dolphins found stranded onshore were immature (53 %) whilst this was lower for carcasses found offshore (33.3 %).

3.5 DISCUSSION

3.5.1 DATA LIMITATIONS

Given that the at-sea surveys had an opportunistic nature it is important to point out several limitations which may lead to biased results: (1) unsystematic sampling effort and (2) variations in survey speed. In this study there was an uneven amount of FR and NFR effort which may have caused bias (e.g. William et al., 2006). However, the sampling effort in this study was independent of the dolphin distribution and we assume that the bias in this data-set is probably low. The average survey speed during FR effort was lower compared to NFR effort (5.2 *vs* 7.0). Different survey speeds are thought to influence the degree of responsive movement of common dolphins (De Boer et al., 2008; NFR line-transect data).It was found that there was a strong responsive movement towards the boat being more pronounced for faster speeds. Because the relative abundance of dolphins appeared higher in FR areas (surveyed with relatively slower survey speeds) any bias from different survey speeds could not have caused the higher estimated differences from FR effort.

3.5.2 BOAT-BASED SURVEYS

Previous studies concerning interactions between cetaceans and pair-trawl fisheries have used observers onboard fishing-vessels (Morizur et al., 1999; Lopez et al., 2003; Fernández-Contreras et al., 2010) This study revealed that by using a fisheries monitoring vessel we were able to study the entire pair-trawl fleet which operated within the study area (17 pair-trawlers from two nationalities: France and Scotland). We compared the group-size and relative abundance of the dolphins in the presence and absence of pair-trawlers and observed any interactions that occurred. The disadvantages of this approach were that no observations could be carried out during hours of darkness and that bycatch could not be observed directly.

The common dolphins observed in the present study aggregated within a relatively small but heavily fished 'hotspot' (10,300 km^2). Most FR effort occurred in the eastern part of the study area where the highest relative abundances were found. Importantly, the relative abundance for common dolphins to the south (French Channel) was reported to be ten times lower (De Boer et al., 2008). The summer density of common dolphins in western shelf waters is estimated as 0.056 dolphins/km^2 (CV 0.61; project report: SCANS-II, 2008) which is an order of magnitude lower than the winter density reported for this area (0.74 dolphins/km^2; CV 0.39; De Boer et al., 2008). We conclude that the apparent 'hotspot' in the eastern part of the survey area presents a main winter feeding ground for common dolphins and that this is where pair-trawl fisheries mainly occur. The highest aggregation of operating pair-trawlers in this hotspot comprised of French vessels, with ten pair-trawlers (20 vessels) operating alongside each other (March 2005). The identified hotspot corresponds with a previously described main winter fishing-ground for seabass (working report: Pawson et al., 2007).

In January 2005, a ban came into force stating that UK pelagic pair-trawlers could not operate within the UK 12-nmile limit (working report: DEFRA, 2009). The geographical distribution of UK pair-trawl effort in 2005 may therefore differ from that in 2004. The effect of this is difficult to assess although the Scottish pair-trawl winter fishery prior to the ban typically operated around the 12-nmile limit from January onwards (working report: Northridge et al., 2005). Moreover, the banning of this fishery within the UK 12-nmile limit was not extended to those vessels of other EU-Member States (such as France) which continued to operate between 6 and 12-nmiles (working report: DEFRA, 2009). In the present study the average distance to shore of the carcasses found at sea in 2005 was significantly further offshore compared to 2004. However, the distance to shore of hauling pair-trawlers did not significantly differ between the two winters.

Fisheries vs Non-fisheries

The relative abundance of common dolphins and their mean group-size were significantly higher in the presence of operating pair-trawlers (Table 3.2). Common dolphins were observed in significantly smaller groups in 2005 compared to 2004. Similar observations were made during the experimental-mitigation work onboard the UK pair-trawlers, where the mean group-size of bycaught dolphins was also reported lower in the 2004/2005 winter compared to previous winters (working

Table 3.2 The number of common dolphins, dolphin groups and the average group-size recorded in the different survey strata (A-F; Fig. 1) during NFR and FR effort.

	NFR			**FR**		
Strata	Number of dolphins/ stratum	Number of groups/ stratum	Average group-size/ stratum	Number of dolphins/ stratum	Number of groups/ stratum	Average group-size/ stratum
Stratum A	0	0	0	0	0	0
Stratum B	426	69	6.66	5	1	4.33
Stratum C	631	133	4.64	341	30	11.89
Stratum D	172	25	6.86	0	0	0
Stratum E	111	29	4.34	10	5	2.00
Stratum F	52	13	8.29	30	5	6.00

report: Northridge et al., 2005). The formation of larger groups probably benefits the predation on large patches of prey, where prey is abundant enough for each member of the group to profit (Neumann, 2001). It is therefore likely that the prey was distributed over many small patches in 2005 which resulted in the dolphins separating into smaller groups to make foraging more effective.

Interactions

This study provided the first index of abundance for offshore dolphin carcasses (FR: 1.73 carcasses/km) with significantly more carcasses recorded in areas with high hauling-activities. Interactions with fishing operations were reported on ten occasions with dolphins mainly associating with hauling and towing procedures. Other studies have reported that the hauling procedure of trawls increases the chance of cetacean bycatch (Waring et al., 1990; Couperus 1993, 1994, 1997; Fertl and Leatherwood 1997; Morizur et al., 1999; Pierce et al., 2002; Fernández-Contreras et al., 2010). Interactions between trawlers and foraging dolphins as well as other cetaceans occur during towing, hauling and discarding activities (Couperus, 1994, 1997; Chilvers et al., 2003; Gonzalvo et al., 2008; Fortuna et al., 2010). Common dolphins have been reported to enter pelagic pair-trawl nets apparently feeding on fish whilst facing into the oncoming water stream (working report: SMRU 2004). Common dolphins in European waters have been reported to mainly feed on Gadidae (whiting *Merlangus merlangus* and *Trisopterus* sp.), Gobiidae, horse mackerel (*Trachurus trachurus*) and Atlantic mackerel (*Scomber scombrus; e.g.* De Pierrepond et al., 2005). It is therefore likely that the common dolphins in the present study were not feeding on sea bass but rather on smaller pelagic fish species such as sardines (*Sardina pilchardus*) and mackerel.

During those times when conditions were suitable to allow for close-up monitoring of the hauling of the nets (using the RIB), no bycaught dolphins were observed entangled in the nets. It may be that most dolphins became bycaught during darkness when close-up monitoring was not feasible. Indeed, it has been reported that cetacean bycatch in trawlers (Northeast Atlantic) occurs particularly at night (Morizur et al., 1999; Lopez et al., 2003). Conversely, most common dolphin bycatch observed in Spain occurred during day-light trawling activity (Fernández-Contreras et al., 2010). In the present study, carcasses were recovered with relatively high body-temperatures indicating recent death.

In order to relate carcass body-temperature to time after death we used the study of Cockroft (1991). He investigated the post-mortem cooling rate of a striped dolphin (*Stenella coeruleoalba*), which is similar in shape and size to common dolphin, left in waters with a temperature of 15°C. The body-temperature dropped 10°C (from ~35-25°C in approximately 4 hours). The cooling rate for dolphins in this study was probably faster because the sea water temperature was lower (9.4°C) compared to that in Cockcroft (1991). Therefore, we suggest that the 'hottest' carcasses (both found in the morning hours with core body temperatures of 26.9 and 30.1°C; Appendix 3.1) recovered in 2005 behind pair-trawlers, and following hauling, had been dead for only a few hours. This would confirm that in the present study the dolphins were typically bycaught during darkness.

3.5.3 COASTAL SURVEYS

A total of 22 dolphin and porpoise carcasses were located within the study area on the more remote sites and these 'unrecorded' carcasses represented 36.7% of the total number of strandings (*n*=60; Table 3.1). This indicates that the actual strandings figures for the study area were much higher than the current database would suggest. Cetacean stranding monitoring programs typically rely on reports from the public or, in the case of some countries (Portugal, Belgium), monthly or bimonthly dedicated coastal surveys. This study facilitated the first comprehensive effort-related shore-based survey covering the more remote shorelines within the UK. Further, it is worth noting that due to the challenging nature of the Cornish coastline, we believe many more potential, yet largely inaccessible, stranding sites exist (based on high-resolution topographical maps) and as such the percentage of unrecorded strandings could be as high as 50%.

3.5.4 EXTERNAL AND NECROPSY EXAMINATIONS

The thin lacerations surrounding the rostrums of stranded carcasses located during coastal studies were likely indicative of entanglement in gillnetting. Common dolphins were indeed observed in the vicinity of this inshore fishery. The deep lacerations and broken rostrums observed on some of the stranded carcasses may have been inflicted by heavier fishing gear. It seems unlikely that these were related to pair-trawl fisheries as this fishery had moved beyond the12-nmile limit. However, trawlers (not paired) did operate closer to shore and are believed to also contribute to common dolphin mortality (preliminary report: Northridge and Kingston, 2009). Three separate fisheries might thus be involved in the bycatch of dolphins in the area.

All necropsy reports of carcasses found offshore confirmed bycatch as cause of death. However, the results highlight the difficulty of interpreting the type of fishing gears involved. The lacerations found on three dolphins in 2004 and three dolphins in 2005 were considered more suggestive of gillnets. It may be possible that pair-trawlers occasionally 'scoop-up' gill or tangle-nets which already contain dead dolphins, or dead dolphins previously caught in such gear, as the study area is the most intensive fishing-ground in the UK. However, it does seem unlikely that this would be the case for six of the carcasses collected over the two consecutive winters. Four of these carcasses had high body temperatures (Appendix I) suggesting a relatively recent death. Importantly, those carcasses recovered in 2005, which had evidently been dead for only a few hours, were found directly behind operating pair-trawlers which had recently hauled their nets. The fresh carcasses recovered at sea proved very valuable for necropsy studies. At the time of the necropsy examinations, the CSIP had never before examined fresh carcasses confirmed to have been bycaught in pelagic pair-trawl gear in order to establish definitive signs (preliminary report: De Boer et al., 2004).

Detailed analysis of digital images taken at the ‘find scene’ proved a valuable tool in recording lacerations on carcasses. One carcass secured for necropsy appeared to have deteriorated significantly within a 24-hour period and so even deep lacerations surrounding the flanks were apparently largely masked. This carcass also had an amputated fluke which is a traumatic lesion specific for bycatch (Kuiken et al., 1994; Fig. 3.6g-h). The CSIP therefore reclassified this carcass as bycaught after receiving digital images taken at the ‘find scene’ from this study. This was the first occasion within the UK where the cause of death was re-classified as ‘bycatch’ using digital images following a necropsy examination from which no internal/external evidence was forthcoming. Our findings suggest that all carcasses should be accompanied by detailed digital images from the ‘find scene’ in order to help ensure the accuracy of future necropsies. Indeed, in the Netherlands and Belgium digital images from the ‘find scene’, and those taken prior to necropsy, have been used as evidence to aid properly classifying the causes of death (e.g. project reports: Haelters et al., 2004; Leopold and Camphuysen, 2006).

In the present study, none of the four tagged and released dolphin carcasses (at shore-distances of 32.6-36.1 km) were reported stranded along the Southwest coast. Tagging experiments on bycaught cetaceans off the French Atlantic coast (41±31.5 km from the coast) recovered only 8 cetaceans of a total of 100 tagged carcasses (Peltier et al., 2012). In Galician waters (NW Spain), 26.7% of tagged common dolphin carcasses were recovered stranded after drifting between 27 and 320 km (preliminary report: Martinez-Cedeira et al., 2011). The probability of a carcass washing ashore is dependent on the distance of the fishery from shore, depth of water and prevailing current, weather and sea conditions and presence of scavengers. Advanced stages of decomposition (where gas fills up the body interior) will also enhance the wind-drifting capacity of a carcass. We conclude that the tagged carcasses in the present study either did not strand or were not found and reported. However, it does indicate that strandings may only reflect bycatch closer to the coast in this particular area, due to prevailing currents and wind directions, and are not very indicative of offshore deaths.

3.5.5 GENDER AND MATURITY

Mixed-age groups of live common dolphins were observed further inshore, whereas groups without calves were seen further offshore. Similar observations have been made for Mediterranean common dolphins, however, it is not known why groups with calves prefer shallower waters (Cañadas and Hammond, 2008). The difference in the age/gender composition of dead common dolphins indicated that mature males and sub-adult males appear at risk from bycatch in pair-trawl gear further offshore, whereas closer inshore females with young appear at risk, most likely from inshore gillnets. Other studies also report that in gillnet fisheries calves and juveniles appear most vulnerable to bycatch (Ferrero and Walker, 1995; Silvani et al., 1999; Rogan and Mackey, 2007). A predominance of bycaught male common dolphins in pair-trawl fisheries has also been reported in other studies (Morizur et al., 1999; Fernández-Contreras et al., 2010) and when aged, most of these were immature (ICES, 2005; Northridge et al., 2006; Fernández-Contreras et al., 2010). A similar predominance of male common dolphins has been found in gillnet and other fisheries (Ferrero and Walker, 1995; Rogan and Mackey, 2007; Westgate and Read, 2007). This male-bias can be explained by possible differences in the habitat-use of common dolphins and diet known to occur among sexes and/or sexual maturity classes (Meynier et al., 2008; Viricel et al., 2008; Quérouil et al., 2009 and preliminary report: Van Canneyt et al., 2003). Indeed, a well-known male bias in the interaction between dolphins and boats (non-fishing vessels) has been reported off the Azores (Quérouil et al., 2009). Such differences could influence the respective chances of dolphins to become bycaught and best explain our findings.

3.5.6 DECLINE OF COMMON DOLPHINS

Within the study area, the UK pelagic pair-trawl fisheries observed a total of 428 common dolphins bycaught between 2001 and 2006 giving a mean bycatch estimate of 200 dolphins per annum (preliminary report: Northridge and Kingston, 2009). The annual bycatch estimate is much higher when taking into account other trawl fisheries that operate in the Channel and Biscay (620 bycaught animals, December 2003-May 2005) and the French bass fishery (680 animals, 2000-2003; working report: Northridge et al., 2006). Based on current bycatch rates, there is a risk in winter of local common dolphin depletion within the Channel (de Boer et al., 2008). Since 2007, there is an apparent decline in stranded carcasses (working report: Deaville and Jepson, 2010; Pikesly et al., 2011; this study Appendix 2) which may have been effectuated, or at least in part, by the12-nmile ban. A decline in observed bycatch in UK pair-trawl fisheries is also reported since 2007, following the introduction of pingers as a mitigation device (preliminary report: Northridge and Kingston, 2009). Trials with pingers used by French trawlers indicated a 70%-reduction in common dolphin bycatch (project report: Morizur et al., 2008). However, at-sea trials off Ireland indicated that pingers may not provide a consistently effective deterrent signal for common dolphins (Berrow et al., 2009). Low bycatch figures reported since 2007 may also be explained by less fishing-effort from 2007 onwards due to high fuel prices and low seabass availability (preliminary report: Northridge and Kingston, 2009). Alongside the decline in strandings and bycatch, a decline is also apparent in (live) common dolphin sightings

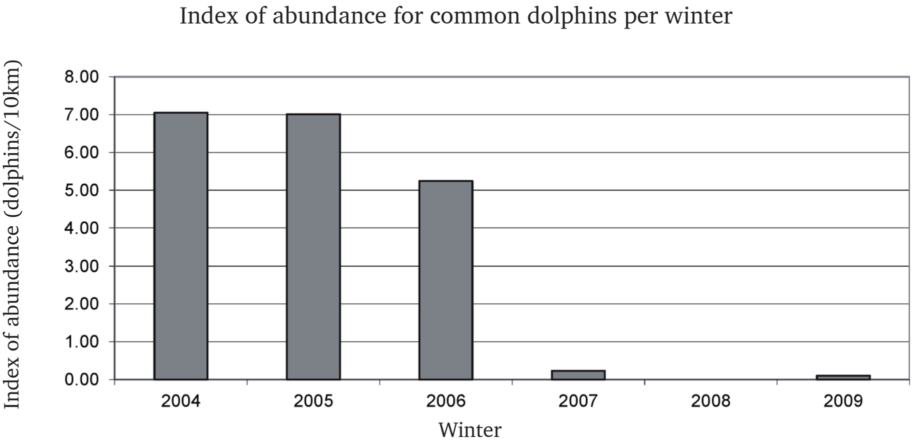

Figure 3.7 Common dolphin abundance index (NFR+FR; 2004-2005) together with additional data collected by the author during boat-based surveys (NFR; 2006-2009) within the study area.

since 2007 (Fig. 3.7). Recent boat-based studies in the region (English Channel/ Biscay) confirm this trend and a decline was noted in summer sightings of common dolphins (T. Brereton/Biscay Dolphin Research Programme, unpublished data in Robinson et al., 2010). As of now, reasons for the observed decline are uncertain.

Common dolphins have been reported to occur in localised hotspots of abundance with likely spatial and temporal (seasonal and interannual) variations (e.g. Cañadas and Hammond, 2008). Recent studies have shown a strong increase in common dolphin abundance towards areas of higher chlorophyll concentrations which in turn may reflect schooling pelagic fish concentrations (Cañadas and Hammond, 2008; Moura et al., 2012). Other studies suggest that sea temperature affects the distribution of common dolphins (Neumann, 2001; Lambert et al., 2011). Common dolphin numbers have increased in Scottish waters (MacLeod et al., 2005; Weir et al., 2009; Robinson et al., 2010) and this range-expansion has been suggested to be attributed to rising sea temperatures (e.g. MacLeod et al., 2008; Lambert et al., 2011; preliminary report: Brereton et al., 2010). It is likely that when range-expansion occurs a simultaneous decline may be seen elsewhere (Robinson et al., 2010). However, if the increase of common dolphins in Scotland is indeed related to increasing temperatures, than the abundance in the western channel is expected to increase, due to the northward migration of the dolphins from the western Iberian Peninsula where the highest abundance of common dolphin within European waters is found (e.g. Bearzi et al., 2003; Pierce et al., 2010). Range-changes of pelagic dolphins will ultimately move the problem as potential cetacean and trawl-fishery interactions are likely to occur elsewhere when spatial and temporal habitat-uses coincide.

In the Mediterranean, the common dolphin has declined over a relatively short period coincident with an increase in fishing effort (e.g. Bearzi et al., 2003; Cañadas and Hammond, 2008; Piroddi et al., 2011). The same may be true for the Western Channel although it is not clear what the impact of this will be on a wider population level.

Common dolphins are often seen in large groups and are, therefore, at risk of simultaneous entanglement. Further research is therefore required to investigate the interactions of common dolphins with pair-trawl fisheries and the related effect on community structure. It is evident that different types of fisheries are operating in offshore and inshore waters and are incidentally catching groups of dolphins which differ in age and gender. The consequences of this are potentially serious since specific gender/age group-compositions in bycatch contribute more to population growth-rate compared to random removal of individuals (Mendez et al., 2011).

Our findings show that there is a significant overlap between human pelagic fisheries and the common dolphin hotspot which is causing direct mortality through bycatch. This, together with recent range-shifts, may have contributed to a rapid but localised decline of this species in this winter hotspot since 2007. This study highlights the importance of rapidly introducing mitigation measures and we recommend that a closer examination of common dolphin mortality is made within UK waters both through observers onboard fishing vessels and through collection of at-sea data. This should also include increased efforts to recover many more fresh carcasses, preferably at sea, for detailed analyses. Given that there are likely to be strong spatial and temporal (seasonal and inter-annual) variations in the distribution and abundance of both common dolphins and fisheries, introducing biological factors into the analysis would lead to a clearer picture of how common dolphins use their habitat. This not only improves our understanding of the ecology of the species, but should also lead to more effective conservation measures.

3.6 ACKNOWLEDGEMENTS

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APPENDIX 3.1

*Dead dolphins found offshore. Dolphins 17-19 had a partial evisceration of the abdomen affecting temperature readings. Sea surface temperature was 8.9-10.4°C. *Dolphins not examined due to weather. ** Tagged dolphins deposited at sea.*

Dolphin	Date	Time	Position	Species	Sex	Length (cm)	Body Temperature °C (probe length)	Bycatch
1	06.02.2004	11:16	49°58.13'N, 004°14.52'W	*D. delphis*	♂	199	16.4 (17.0cm)	Confirmed
2	06.02.2004	11:20	49°58.21'N, 004°14.69'W	*D. delphis*	♂	190 (Immature)	22.4 (17.0cm)	Confirmed
3	06.02.2004	11:20	49°58.21'N, 004°14.69'W	*D. delphis*	♂	229	20.1 (17.0cm)	Confirmed
4	06.02.2004	11:20	49°58.21'N, 004°14.69'W	*D. delphis*	♂	170 (Immature)	17.8 (17.0cm)	Confirmed
5	06.02.2004	11:20	49°58.21'N, 004°14.69'W	*Dolphin sp**	?	n/a	n/a	n/a
6	08.02.2004	11:59	50°00.09'N, 003°30.01'W	*D. delphis*	♂	210	n/a	Suspected
7	08.02.2004	14:26	49°56.36'N, 003°44.23'W	*D. delphis*	♂	220	n/a	Suspected
8	14.02.2004	12:27	50°01.92'N, 004°13.42'W	*D. delphis***	♂	199	10.1 (41cm)	Suspected
9	15.02.2004	08:50	49°56.65'N, 004°05.22'W	*D. delphis***	♂	205	n/a	n/a
10	16.02.2004	10:25	49°56.12'N, 003°58.62'W	*D. delphis***	♂	180 (Immature)	n/a	n/a
11	16.02.2004	17:40	50°07.28'N, 004°56.89'W	*Dolphin sp**	?	n/a	n/a	n/a
12	07.03.2004	13:01	49°56.85'N, 003°51.50'W	*D. delphis***	♂	225	12.7 (49cm)	Suspected
13	27.03.2004	n/a	50° 18.50'N, 003° 57.20'W	*D.delphis*	♀	197	n/a	Confirmed
14	27.03.2004	n/a	50° 14.60'N, 003° 51.60 'W	*D. delphis*	♀	191 (Immature)	n/a	Confirmed
15	22.02.2005	09:13	50°00.37'N, 004°15.15'W	*D. delphis*	♂	219	9.5 (68cm)	Confirmed
16	08.03.2005	08:33	49°31.95'N, 004°20.07'W	*D. delphis*	♀	198	30.1 (60cm)	Confirmed
17 (France)	11.03.2005	11:31	48°45.55'N, 005°52.90'W	*D. delphis*	?	n/a	n/a	n/a
18 (France)	11.03.2005	15:52	48°16.48'N, 004°55.91'W	*D. delphis*	?	n/a	n/a	n/a
19	15.03.2005	08:40	49°36.88'N, 004°16.54'W	*D. delphis*	♂	183 (Immature)	26.9 (65cm)	Confirmed
20	15.03.2005	09:11	49°37.04'N, 004°15.86'W	*D. delphis*	♀	197	14.9 (65cm)	Confirmed
21	15.03.2005	09:19	49°36.96'N, 004°15.29'W	*D. delphis*	♂	185 (Immature)	15.8 (70cm)	Confirmed
22	17.03.2005	14:05	49°36.40'N, 004°46.29'W	*D. delphis*	♂	221	10.7 (10cm)	Suspected
23	26.03.2005	10:15	50°08.23'N, 005°01.06'W	*D. delphis*	♀	183 (Immature)	13 (13cm)	Suspected

APPENDIX 3.2

Stranded cetaceans located within the survey area (2006-2009). Length (beak-fluke notch), length (length of incomplete carcass), state of decomposition (pm=necropsy). # indicates strandings classified as recorded. HP=harbour porpoise; CD=common dolphin; D=dolphin sp; imm=immature.*

ID	Date	Time	Latitude (in decimals)	Longitude (in decimals)	Species	Sex	Length (cm)	State of Decomposition	Bycatch
1	13/01/2006	14:57	50.0333	-5.2600	HP?	n/a	n/a	Advanced	n/a
2#	15/01/2006	15:51	50.0267	-5.0950	CD	♀	197	Moderate	Suspected
3	20/01/2006	14:52	50.0550	-5.2800	CD	♀	199	Moderate	Suspected
4	29/01/2006	10:12	50.0683	-5.0790	HP?	?	84*	Advanced	n/a
5#	29/01/2006	10:23	50.0683	-5.0770	D	n/a	155*	Advanced	n/a
6#	29/01/2006	13:05	50.0033	-5.1650	CD	♂	172 (imm)	Moderate	Suspected
7#	06/02/2006	16:21	50.0317	-5.0800	D	♂	n/a	Advanced	n/a
8#	07/02/2006	13:27	50.0350	-5.0667	D	♂	199	Advanced	n/a
9	08/02/2006	09:54	50.0583	-5.2817	D	n/a	n/a	Advanced	n/a
10#	13/02/2006	14:05	50.1233	-5.4650	HP	n/a	n/a	Advanced	n/a
11#	14/02/2006	11:19	50.0033	-5.1650	CD	♀	177 (imm)	Slight	Suspected
12#	14/02/2006	12:50	49.9750	-5.2300	CD	♀	167*	Slight (pm)	Confirmed
13	18/02/2006	12:19	49.9700	-5.2166	CD	♂	157 (imm)	Slight (pm)	Suspected, physical trauma
14	03/03/2006	11:14	50.0633	-5.0667	D	n/a	n/a	Indeterminate	n/a
15	13/03/2006	09:27	50.0050	-5.1617	CD	♂	131 (imm)	Slight	Suspected
16	14/03/2006	11:57	50.0267	-5.0950	CD	♀	169 (imm)	Moderate	Suspected
17	14/03/2006	12:37	50.0150	-5.0933	CD	♂	218	Slight	Suspected
18#	20/03/2006	14:14	50.0050	-5.1617	D	n/a	154*	Advanced	n/a
19	14/04/2006	12:57	50.1167	-5.4500	CD	♂	210	Slight (pm)	No (starvation)
20#	15/04/2006	15:21	50.0883	-5.6880	HP	♂	143 (imm)	Advanced	n/a

APPENDIX 3.2 *Continued*

ID	Date	Time	Latitude (in decimals)	Longitude (in decimals)	Species	Sex	Length (cm)	State of Decomposition	Bycatch
21	04/12/2006	11:22	49.9700	-5.2167	CD	♀	174 (imm)	Moderate	Suspected
22	21/12/2006	10:45	50.0250	-5.0940	D	n/a	n/a	Indeterminate	n/a
23	27/12/2006	14:36	50.0267	-5.0950	D	n/a	n/a	Indeterminate	n/a
24	06/01/2007	17:01	50.0700	-5.2950	HP	n/a	n/a	Indeterminate	n/a
25#	08/01/2007	13:29	50.1167	-5.4600	HP	♀	114 (imm)	Moderate	Suspected
26#	11/01/2007	16:21	50.0883	-5.6890	CD	n/a	162 (imm)	Advanced	n/a
27	13/01/2007	15:33	50.1100	-5.4400	D	n/a	86*	Advanced	n/a
28#	21/01/2007	10:56	50.2283	-5.3900	CD	♀	158 (imm)	Moderate	Suspected
29	26/01/2007	15:27	50.0550	-5.2700	D	n/a	152 (imm)	Advanced	n/a
30	07/02/2007	14:06	50.0733	-5.0783	CD	♂	227	Moderate	Suspected
31	22/02/2007	12:06	50.0400	-5.0667	CD	n/a	n/a	Indeterminate	n/a
32#	13/03/2007	10:03	50.0800	-5.3140	D	n/a	107*	Advanced	n/a
33#	14/03/2007	09:37	50.0700	-5.2940	D	n/a	124*	Advanced	n/a
34#	17/01/2008	14:15	50.0583	-5.2820	HP	♂	141 (imm)	Moderate	Suspected
35	13/02/2008	14:32	50.0833	-5.0750	HP	n/a	84*	Advanced	n/a
36#	14/02/2008	14:38	50.0267	-5.0950	CD	♂	187 (imm)	Slight	n/a
37	20/02/2008	10:45	50.0733	-5.0783	CD	♀	193	Moderate	Suspected
38	27/02/2008	17:53	50.0800	-5.3150	CD	♀	203	Moderate	Suspected
39	18/01/2009	15:31	50.1167	-5.4540	D	n/a	210	Advanced	n/a
40#	20/01/2009	13:07	50.1000	-5.3850	HP	♀	122*	Moderate	Suspected
41#	27/01/2009	09:00	50.1267	-5.4867	CD	♂	200	Advanced	n/a

CHAPTER 4

SPRING DISTRIBUTION AND DENSITY OF MINKE WHALE (*BALAENOPTERA ACUTUROSTRATA*) ALONG AN OFFSHORE BANK IN THE CENTRAL NORTH SEA

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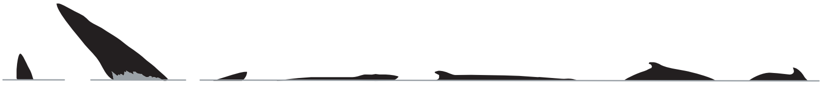
Minke whale



4.1 ABSTRACT

Minke whales were recorded in the central North Sea in an area characterised by frontal features and high productivity northeast of the Dogger Bank (4677 km^2). Survey efforts were carried out from 28 March to 2 July 2007, at a finer scale than in earlier studies in the region, using 2 vessels as platforms of opportunity and a dedicated line-transect survey vessel following distance sampling methods. The high density of whales indicated that this offshore bank slope is an important spring habitat for minke whales in the North Sea. In total, 77 sightings of minke whales comprising 130 individuals were recorded. The peak density of minke whales was estimated to be 0.029 whales km^{-2} (minimum estimate, 95% CI: 0.012 to 0.070) in May. During peak abundance, the minke whales temporarily congregated in the area, suggesting that the whales were taking advantage of the local spring abundance of sandeels. The density found was higher than previous studies have suggested for the central North Sea. The results correspond to recent observations of minke whale redistribution within the North Sea, and these may be related to a decline in sandeel availability elsewhere in the North Sea. Offshore banks that aggregate prey may therefore become increasingly important feeding habitats for minke whales and other top predators in the North Sea. The observed habitat preference of minke whales along this offshore bank appeared to be similar to that observed in coastal areas, and this suggests some degree of generality regarding the preference for this type of habitat.

4.2 INTRODUCTION

The northern minke whale *Balaenoptera acutorostrata* occurs widely in the northeast Atlantic and the North Sea, although this species is less common in the southern North Sea (Evans et al., 2003; Reid et al., 2003). In the northern North Sea, minke whales are mainly seen from April to October (Northridge et al., 1995; MacLeod et al., 2007b; Robinson et al., 2007; Weir et al., 2007) although they can be seen year-round (Macleod et al., 2004). Most studies of North Atlantic minke whales have been carried out at either a large spatial scale (Hammond et al., 2002; Skaug et al., 2004) or at fine scale targeting coastal waters (Naud et al., 2003; Macleod et al., 2004; Robinson et al., 2007, 2009; Tetley et al., 2008). There appears to be a general pattern of minke whales moving into coastal areas in the late summer, but overall there is little knowledge regarding the seasonal distribution of minke whales (and cetaceans in general) in offshore habitats (MacLeod et al., 2007b). One such offshore habitat is the Dogger Bank in the central North Sea, where Atlantic waters from the north meet and mix with waters from the English Channel (Pingree and Griffiths, 1978; Van Haren and Joordens, 1990). Most of the water column remains mixed throughout the year because of tidal mixing, while from May until September stratification occurs in deeper waters around this shallow sand bank (Pingree and Griffiths, 1978). Relatively high primary production values have been reported in summer (Riegman and Colijn, 1991), although this productivity on a small scale is patchy due to the complex hydrodynamics and the irregular occurrence of wind mixing.

The present study was conducted between 29 March and 2 July along the northeastern slopes of the Dogger Bank and partially overlapped with recently announced/proposed special areas of conservation (SACs) according to the Habitats Directive of the European Union (Annex I: sandbank habitat; Lindeboom et al., 2005; Diesing et al., 2009). The bank offers a suitable sandeel *Ammodytes sp.* habitat, and studies on fish, seabirds, and to a lesser degree cetaceans (e.g. Knijn et al., 1993; Stone et al., 1995; Evans 2003) show that it has a high biodiversity. Minke whales have mainly been reported to the north and west of the Dogger Bank with only few sightings to the northeast. Other cetaceans, such as the harbour porpoise *Phocoena phocoena* and white-beaked dolphin *Lagenorhynchus albirostris*, are more common (Hammond et al., 2002; Evans et al., 2003; Reid et al., 2003; Van der Meij and Camphuysen, 2006; SCANS-II, 2008; Gilles et al., 2009). According to the EU Habitats and Species Directive, the minke whale is not an Annex-II-listed species and therefore the proposed Dogger Bank SAC may only include the harbour porpoise under this Annex.

The distribution and abundance of minke whales on feeding grounds will ultimately depend on the distribution of their prey and underlying primary production. Factors such as water depth, seabed sediment, fronts, and tides also influence the distribution and abundance of minke whales (Naud et al., 2003; Macleod et al., 2004; Johnston et al., 2005a; Tetley et al., 2008; Robinson et al., 2009). The species also shows intra- and inter-annual variations in fine-scale distribution (Robinson et al., 2009), which highlights the need for long-term research effort in SACs.

The objective of the present study was to verify the distribution and density of minke whales and other cetaceans and to contribute to the understanding of the cetacean ecology along this offshore bank. Here we report on a complementary approach during a geophysical survey involving 2 research vessels used as platforms of opportunity (PO) and 1 dedicated line-transect (LT) survey vessel following distance sampling methods. The PO survey was conducted over a longer time span, and the results are used to (1) assess the cetacean community, (2) determine any observed temporal variability in occurrence, and (3) highlight the advantage of such surveys. The LT survey results are used to estimate the density of minke whales.

4.3 METHODS

4.3.1 STUDY SITE

The study site (4677 km^2) ranged from 2° 54' to 4° 33'E and from 55° 30' to 56° 18'N in an area northeast of the Dogger Bank stretching out over British, Dutch, Danish, and German waters (Fig. 4.1). The waters ranged in depth from 23 m (SE) to 70 m (NW) and ran from tidally mixed to temperature-stratified. A survey stratum of 848.6 km^2 was covered by both dedicated and opportunistic survey effort in German waters (Fig. 4.1).

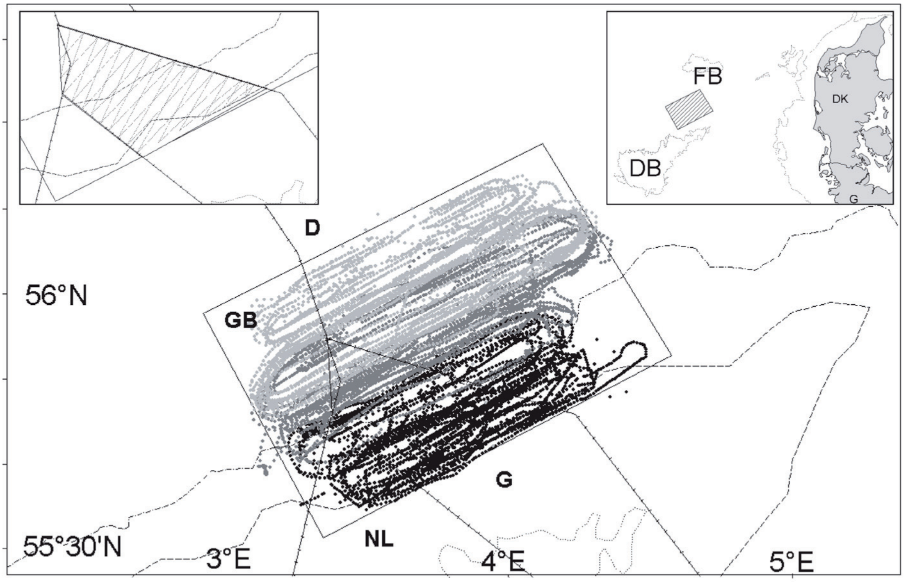


Figure 4.1 The central North Sea study area (rectangle) was surveyed by platforms of opportunity (PO) vessels with effort in April (in black), May (in dark grey) and June (in light grey). Line transects are displayed in the left inset image (dotted zigzag lines), where one set was covered 3 times and the other 2 times. The Dogger Bank (DB) and Fisher Bank (FB) are shown in the right inset image. International exclusive economic zone (EEZ) waters (Denmark [D], Great Britain [GB], The Netherlands [NL], and Germany [G]) and depth contours are shown: 50 m (dash-dot line), 40 m (dashed line) and 30 m (dotted line)

4.3.2 DATA COLLECTION

Observations were conducted during a geophysical seismic survey (28 March to 2 July 2007) involving 2 PO vessels: the 91 m RV 'Atlantic Explorer' (PO1) carrying out a geophysical survey and the 46 m support motor vessel (MV) 'Thor Provider' (PO2, 31 March to 13 June). In addition, the 38 m MV 'Andfjord' carried out a dedicated LT survey (23 April to 17 May). PO1 was sailing predetermined parallel survey transects and was accompanied by PO2, which sailed parallel and ahead of PO1. The PO vessels were in frequent communication regarding sightings and are regarded as one ('tandem') platform. The LT vessel was surveying at distances of ≥20 km away from the PO vessels and followed predetermined line transects placed randomly in a zigzag pattern in the central (German) part of the survey area. The vessels travelled at 4.5 knots (PO) and 6 knots (LT).

Experienced observers searched for cetaceans from the bridge deck (heights: PO2/LT: 6.25 to 7.0 m and PO1: 10.5 to 13.5 m). Dedicated watches were conducted during daylight with one observer on watch. After mid-June one observer remained onboard PO1, reducing the amount of effort due to planned breaks. Observers scanned with the naked eye and used binoculars (7 x 50 and 8 x 42) for identification and group-size estimations. Standard recording forms were used (JNCC, 2004). When a sighting was made, the vessel continued on the track-line. The radial sighting distance was determined using reticule binoculars or person-specific range sticks. The bearing to animal(s) and heading were determined by ship's compass or using an angle-board (LT vessel). Other sightings data included water depth (depth sounder or electronic sea chart), species identification (definite, probable, or possible), calf/juvenile presence, group-size (maximum, minimum, or best), composition, and behaviour.

4.3.3 DATA ANALYSIS

Data collected in slight Beaufort Sea States (BSS) 0 to 4, good visibility (>1 km) and low swells (<4 m) were used for density calculations. Duplicate sightings made from the PO vessels were verified (using time, position, composition, heading, and PO-communication data) and excluded. Both definite identification and probable identification of species were used.

4.3.4 RELATIVE ABUNDANCE

The relative abundance was measured as the number of sightings 100 km^{-1}. A grid with a resolution of 10 × 10 nm was created, and cells with a survey effort <10 km were excluded. The latitude and longitude were assigned to the centre of each grid cell when determining the mean water depth.

4.3.5 DENSITY AND RESPONSIVE MOVEMENT

Minke whale density (whales km^{-2}) was estimated from LT data following both conventional (CDS) and multiple covariate distance sampling (MCDS) approaches (Buckland et al., 2001; Marques and Buckland 2003) using Distance 4.1 (Research Unit for Wildlife Population Assessment). Essentially, the program fits a detection function to the distribution of perpendicular distances and this function is used to estimate the effective strip half-width (ESW). The density (whales km^{-2}) is given as:

$$D = \frac{n \cdot E(S)}{2L \cdot ESW \cdot g(0)} \qquad \text{(I)}$$

Where *n* is the number of detections, *L* is the length of transect (km), *E(S)* is the mean group-size, *g(0)* is the detection probability on the track-line. MCDS allows for the inclusion of environmental covariates in the estimation of detection probability. It is expected that the detection probability is positively correlated with group size but negatively correlated with the sea state (e.g. Buckland et al., 2001). The estimates of density generated here are based on a number of assumptions, including that the probability of detecting minke whales on the track-line, *g(0),* equals 1, *i.e.* every animal on the track-line is detected. Another assumption of the line-transect methodology is that animals do not respond to the approaching survey vessel before detection. This was investigated by using a vector component of the whale's velocity away from the vessels (*i.e.* the cosine of the difference between bearing and heading; De Boer et al., 2008).

4.4 RESULTS

4.4.1 SURVEY EFFORT AND SUMMARY OF SIGHTINGS

A total of 9902 km PO effort was completed during 96 days (Table 4.1). The southern, middle, and northern sectors of the study site were surveyed in April, May, and June, respectively (Fig. 4.1). 103 sightings were made, totalling 281 animals involving 6 species (Table 4.2). Some PO sightings remained unidentified (12.5%; Table 4.2). The LT survey covered 1452 km planned effort (Table 4.1) from 23 April to 17 May; 31 cetacean sightings were made, totalling 112 animals (Table 4.2).

4.4.2 MINKE WHALE DENSITY

To reduce bias in mean group size estimates due to the potential of a positive relationship between group size and perpendicular distance (x), exploratory analysis (regression of group size versus detection probability) was carried out. The detections were independent of group size and mean group size was used. Because of

Table 4.1 Extent of visual effort for platforms of opportunity (PO) and line-transect (LT) vessels, including the percentage of survey effort in Beaufort sea state ≤ 4 (% BSS).

Research Vessel	**Survey Period**	**Hours of Effort**	**Survey effort (km)**	**% BSS**
PO vessels	28 March – 2 July 2008	951	9901.7	81
LT vessel	23 April – 17 May 2008	318	1452	99
All vessels	28 March – 2 July 2008	1269	11353.7	83

Table 4.2 Information on sightings and individuals (in parentheses). The relative abundance (the number of sightings 100 km-1) for different species observed from PO and LT vessels are shown for all weeks (Weeks 1 to 14) and for 24 April-21 May (Weeks 5 to 8).

Species	**PO**	**LT**	**N/L – PO (Weeks 1 to 14)**	**N/L – PO (Weeks 5 to 8)**	**N/L – LT (Weeks 5 to 8)**
Minke whale	55 (70)	22 (60)	0.56	1.77	1.52
Humpback whale	1 (1)	0	0.01	0.04	0
Atlantic white-sided dolphin	8 (78)	2 (25)	0.08	0.14	0.14
White-beaked dolphin	5 (37)	0	0.05	0.07	0
Atlantic white-sided/white-beaked dolphin	1 (4)	1 (20)	0.01	0.04	0.07
Bottlenose dolphin	1 (1)	0	0.01	0	0
Harbour porpoise	15 (28)	6 (7)	0.15 0.45[a]	0.25 0.45[a]	0.41 1.27[a]
Unidentified dolphin	9 (50)	0	0.09	0.07	0
Unidentified whale	6 (8)	0	0.06	0.18	0
Unidentified cetacean	2 (4)	0	0.02	0.04	0
Totals	**103 (281)**	**31 (112)**	**1.04**	**2.58**	**2.13**

[a] *Because porpoises are notoriously difficult to observe in higher sea states, the relative abundance for porpoises was also measured for Beaufort sea states 0 to 2 only*

small sample size (n=22), models with single covariates were considered. Akaike's information criterion (AIC) was used, and the best fitting model was the half-normal key function with cosine series expansion (Fig. 4.2). The sea state was selected as a covariate in the analysis model. The density estimate was 0.029 whales km^{-2} (95% CI: 0.012 to 0.070, 0.51 CV). The vector component of the whale's velocity was explored, and this suggested no responsive movement of the whales prior to detection.

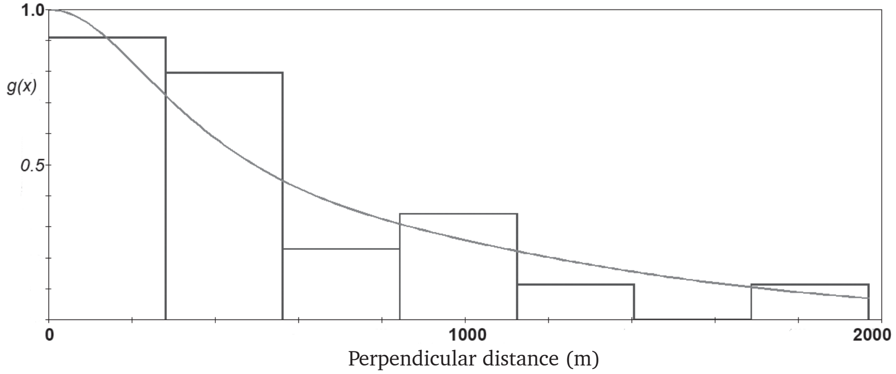


Figure 4.2 Perpendicular sighting distances, detection probability, g(x), and fitted detection function for minke whales in German waters of the study area, central North Sea.

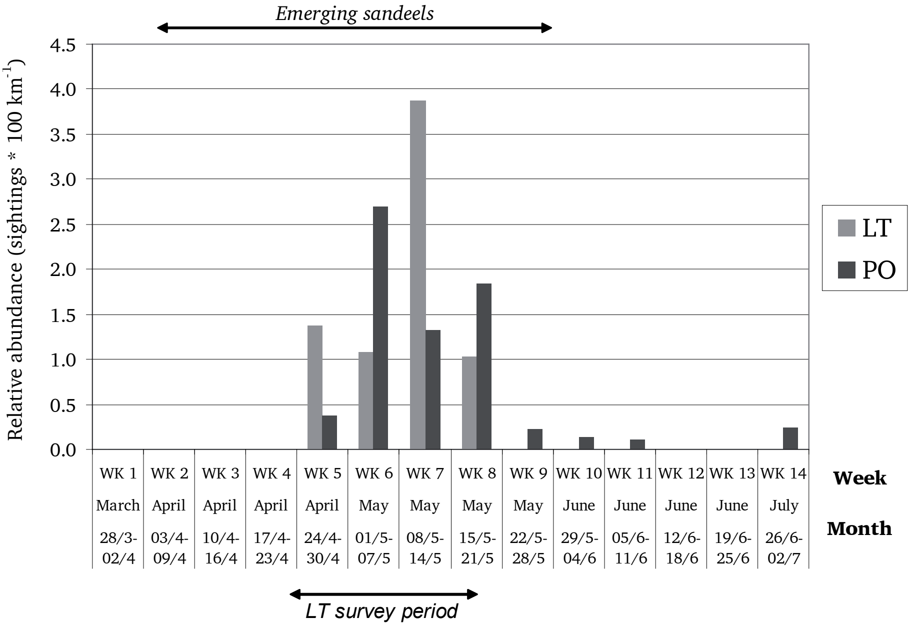


Figure 4.3 Relative weekly (WK) abundance of mink whales (whales 100 km^{-1}) from platform of opportunity (PO) and line-transect (LT) surveys.

4.4.3 PO VERSUS LT SURVEY

The first minke whale sightings were made on 26 April (LT) and 30 April (PO). The whales were relatively abundant for 4 weeks (Weeks 5 to 8 of the survey: 24 April to 21 May; Fig. 4.3). One juvenile was sighted. The LT effort was restricted by inclement weather conditions and finished on 17 May. During Week 8, the whales were observed in deeper waters. The PO surveys offered enough temporal coverage to show that whale numbers were nearing zero from Week 9 (Fig. 4.3). The mean water depth of minke sightings (PO) was <50 m (Weeks 5 to 6) and >55 m (Weeks 7 to 8), whilst this measured <50 m throughout the LT survey. The mean group sizes measured for minke whales were 1.26 (PO [±0.7 SD]; n=50, Weeks 5 to 8) and 2.7 (LT [±3.9 SD]; n=22). The latter was affected by a large group (20 whales); however, without this sighting the mean group size remained high (1.9). The average sighting distance (LT) was short (752 m) and explains why all animals could be identified to species. The relative abundance peaked during Week 6 (PO) and Week 7 (LT). Overall (Weeks 5 to 8) the PO survey measured the highest relative abundance (1.77 whales 100 km^{-1}; Table 4.2).

4.4.4 MOVEMENT & FORAGING BEHAVIOUR

Three types of foraging behaviour were observed (PO + LT): (1) whales making quick directional changes, (2) association with seabirds, and (3) lunge feeding. During Week 5, the whales were observed in the southwestern sector (Fig. 4.4A). In Week 6, the majority of whales had spread northeast and were congregating along the 50 m depth contour. In Week 7, the whales had moved further northeast, and by Week 8 the distribution was more spread out (Fig. 4.4C). A high relative abundance (2.04 whales 100 km^{-1}) was measured in water depths ranging between 50 and 59 m (Fig. 4.4F), and this was slightly lower (1.75) in depths ranging between 40 and 47 m (Fig. 4.4F). A high relative abundance (>6) was measured (at depth 69 m), but this was based on only one sighting. The latitudes of the sighting positions were plotted and confirmed a northerly movement of the whales ($p < 0.05$, $r^2=0.422$, linear regression). The PO coverage varied over a long time; it is unknown whether the whales remained present in the southern sector, but given the northerly movement this seems unlikely.

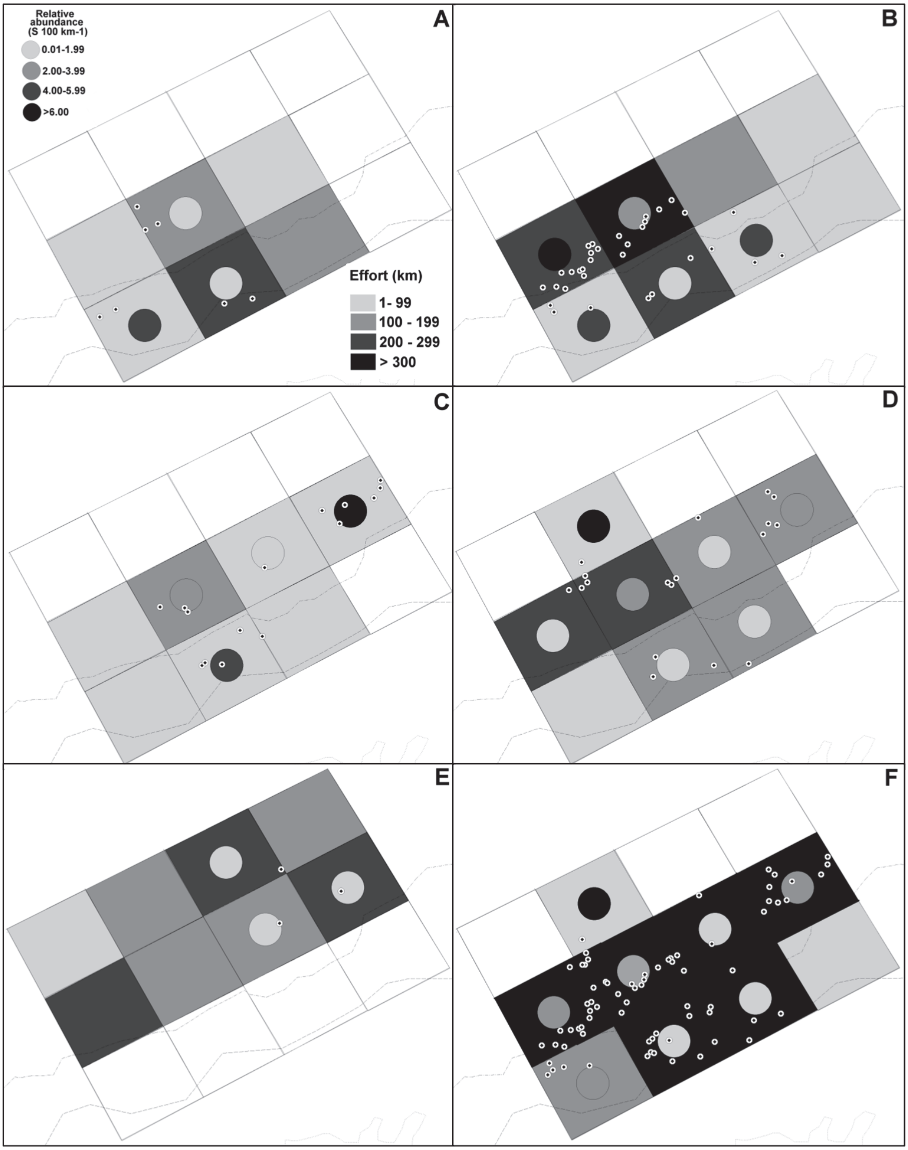


Figure 4.4 *Distribution of effort (km) and spatial distribution of relative abundance (sightings 100 km^{-1}) of minke whales from all vessels during (A) Week 5, (B) Week 6, (C) Week 7, (D) Week 8, (E) Weeks 9 and 10 (PO only), and (F) Weeks 5 to 8 (PO + LT). Effort is indicated by shaded blocks; relative abundance is indicated by shaded circles; and sightings are plotted as open dots. Depth contours: 50 m (dash-dot line) and 40 m (dashed line)*

4.5 DISCUSSION

4.5.1 MINKE WHALE

The estimated minke whale density in April–May was 0.029 whales km^{-2} (95% CI: 0.012 to 0.070, 0.51 CV), which is higher than the SCANS densities reported in July (SCANS-I, 1994, Block G: south-central North Sea 0.0088 whales km^{-2}, 0.70 CV; SCANS-II, 2005 Block U: south-central North Sea 0.022 whales km^{-2}, CV 0.69) and corresponds to the density in Block V in July 2005 (SCANS-II, north-central North Sea 0.028 whales km^{-2}, CV 0.45; Hammond et al., 2002; SCANS-II, 2008). Other studies report on comparable densities between 0.002 and 0.078 whales km^{-2} in the northeast Atlantic (Skaug et al., 2004), whereas densities off Alaska (0.002 to 0.017 whales km^{-2}; Zerbini et al., 2006) and California (0.00072 whales km^{-2}; Barlow and Forney, 2007) were lower.

The group size of minke whales (2.7: LT) was high compared to SCANS (Block G: 1.33; Block U: 1.0; Block V: 1.05; Hammond et al., 2002; SCANS-II 2008). The SCANS relative abundances for minke whales (Block G: 0.33 whales 100 km^{-1}; Block U: 0.58; Hammond et al., 1995; and Block V: 0.69; SCANS-II, 2008) are lower than the LT survey (1.52 whales 100 km^{-1}, 0.21 CV) whereas the PO survey revealed a corresponding abundance (0.56 whales 100 km^{-1}) compared to Block U, although during the ‘peak’ period this was much higher (Weeks 5 to 8: 1.77 whales 100 km^{-1}).

The PO coverage of the study area varied over time, and whale movements may have impacted the observed relative abundances. High local relative abundances for minke whales have been reported off Mull, Scotland (2.1 whales 100 km^{-1} in spring; Macleod et al., 2004) and off the Moray Firth (0.7 to 3.9 whales 100 km^{-1} in summer; Robinson et al., 2007), suggesting that minke whales may temporarily congregate on favoured feeding grounds.

4.5.2 POTENTIAL SOURCES OF BIAS

The lack of a correction factor for $g(0)$ probably causes substantial bias in minke whale densities (e.g. Schweder et al., 1999; Skaug et al., 2004). Skaug and Schweder (1999) estimated that 56 to 68% of minke whales were missed during surveys in the north Atlantic. SCANS implemented methods that allow for the estimation of a correction factor (SCANS-I: $g(0)=0.82$ to 1.0; Hammond et al., 1995). The whale density estimated here must be regarded as a minimum because correction factors could not be calculated. Furthermore, LT surveys generally have 2 observers on watch whilst this survey used 1. The effect of excluding the covariate for sea state resulted in a negative bias of 17.8% in the density estimate, and similar patterns have been shown in other studies (Schweder et al.,1999; Skaug et al., 2004; Palka, 2005). It was not possible to assess the effect of relatively slow survey speed or the problems of replicating transect lines. However, this may have caused a positive bias in the density estimate. The differences in whale density may be a result of timing (summer versus spring). Minke whale surfacing rates in western Scotland have been shown to vary as a result of different foraging strategies for different prey, with slightly higher rates measured in May compared to those in June and July (Stockin et al., 2001). It is likely that foraging minke whales have short surfacing intervals, which may cause a positive bias (Stockin et al., 2001).

4.5.3 OFFSHORE BANK

The present study area lies along the slopes of the Dogger Bank and includes a delicate transition zone between tidally mixed and stratified waters characterised by relatively high primary production values during summer (Riegman and Colijn, 1991) and in May (Van Haren and Joordens, 1990). The latter is the result of a front that causes a subtidal current predominantly directed along the isobath and enhanced vertical mixing (Van Haren and Joordens, 1990). Other frontal zones in the region are the Spurn and Flamborough Head fronts (Pingree and Griffiths, 1978), which lie to the west. Frontal systems can be regarded as biological 'hot spots' where within short distances significant changes can be observed in the pelagic food web regarding productivity, structure, and diversity (Nielsen Gissel and Munk, 1998).

In May, high numbers of sandeels *Ammodytes sp.* were reported in the study area by Danish fishermen and PO1 crew. Stomach contents studies (Folkow et al., 2000; Olsen and Holst 2001; Pierce et al., 2004) have shown that the lesser sandeel *A. marinus* is a preferred prey for North Sea minke whales. Sandeels are a schooling fish that emerge from the sandy substrata during April–May in which they over-winter. They emerge during daylight to forage on calanoid copepods (Macer, 1966; Winslade, 1974). Highest monthly landings of sandeels were reported in the area in May–June 2001 to 2008 (Boulcott et al., 2006; ICES, 2008a). The study area also boarders onto the Fischer Bank, where the concentration of sandeel larvae peaked near a front in May (Nielsen Gissel and Munk, 1998). A seasonal distribution of minke whales over sandeel habitat was reported off Scotland during June (Macleod et al., 2004). Similar observations of pelagic daytime feeding behaviour on sandeels were found in the northern North Sea (Olsen and Holst, 2001) and along offshore banks in Greenland (Laidre et al., 2009).

The minke whales were associated with the 50 m depth contour (Fig. 4.4). It is hypothesised that the slopes of this offshore bank were acting as a temporary congregation area when considerable primary production over suitable sandy sediments resulted in an increased availability of sandeels to foraging minke whales. From late May the feeding conditions for minke whales were no longer optimal for unknown reasons, although it is likely that this temporary congregation site probably extended beyond the study area. The habitat preferences of minke whales along this offshore bank appeared to be similar to those previously observed in coastal areas, in particular the association with the 50 m isobath, gravel/sand sediments and steep slopes (Macleod et al., 2004; Robinson et al., 2009). This suggests some degree of generality regarding the habitat preferences of minke whales in the north Atlantic.

Early spring plankton at the Dogger Bank is patchily distributed, and sandeels only emerge from the seabed when feeding conditions are optimal (Van der Kooij et al., 2008). Because sandeels depend on such a specific habitat and form clusters of schools, it makes them vulnerable to local depletion (Mackinson, 2007).

4.5.4 CETACEAN DIVERSITY

The species diversity recorded along this offshore bank was high: 6 cetacean (Table 4.2, Fig. 4.5) and 2 seal species. The PO data are potentially influenced by unknown reactions of each species to sound produced during the PO1 operations. The porpoise relative abundance from the PO survey was lower than the LT survey (PO: 0.45 and LT: 1.27 porpoises 100 km^{-1}, April–May), although this was based on low sample size. This was also much lower than measured in the central North Sea in July (Block G: 3.53, Block U: 4.85 porpoises 100 km^{-1}; Hammond et al.,

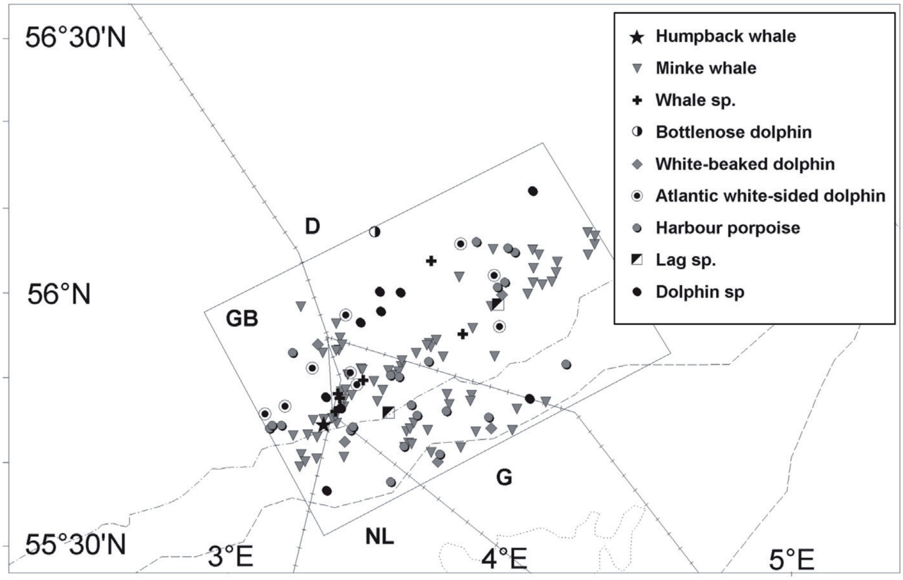


Figure 4.5 The distribution of cetacean species in the study area from all vessels plotted by species. International EEZ waters (Denmark [D], Great Britain [GB], The Netherlands [NL], and Germany [G]) and depth contours are shown: 50 m (dash-dot line), 40 m (dashed line) and 30 m (dotted line)

2002; SCANS-II, 2008) and in May (13.00 porpoises 100 km^{-1}, Gilles et al., 2009). The harbour porpoise is common in the North Sea and occurs year-round in the southern North Sea (Camphuysen, 2004). The porpoise has also been reported at the Dogger Bank in winter (Todd et al., 2009). Although porpoises are notoriously difficult to observe, we expected to see more porpoises, particularly since sandeels may be important prey (Santos et al., 2004).

White-beaked dolphins are common in the central North Sea (Evans et al., 2003; Reid et al., 2003), but Atlantic white-sided dolphins *Lagenorhynchus acutus* dominated north of the 50 m depth contour. Other sightings included a (probable) bottlenose dolphin *Tursiops truncatus* and humpback whale *Megaptera novaeangliae* (3 May). Interestingly, 1 week later a humpback whale was reported off the Dutch coast (10 to 13 May 2007; Camphuysen, 2007).

4.5.5 REDISTRIBUTION OF MINKE WHALES

In the North Sea the timing of various plankton groups do not seem to respond to ocean warming synchronously, resulting in predator-prey mismatches that resonate to higher trophic levels, such as fish, seabirds, and marine mammals (Edwards and Richardson, 2004). SCANS-I showed that minke whales were more abundant in the northwest North Sea (north of 55° N and west of 4° E; Hammond et al., 2002), and the SCANS-II density surface models predicted highest concentrations of animals in the central North Sea (west of the study area), off Norway, northeastern Scotland, southwestern England, and southern Ireland (SCANS-II, 2008). Minke whales were also concentrating further south in summer than previously recorded in the northwest North Sea (54 to 58° 30'N, 2° E; Camphuysen et al., 2006). The results presented here corroborate the other observations of minke whale redistribution within the North Sea. The observed southward change in minke whale distribution is yet unexplained, but may be related to environmental factors such as a decline in prey availability, most likely that of sandeels, elsewhere in the North Sea (ICES, 2008b).

4.5.6 PO VERSUS LT SURVEY

PO vessels provide a low-cost tool for cetacean research and provide opportunities to survey otherwise inaccessible offshore habitats. The combination of different methodologies to solve problems associated with the choice of a single method has proven to be effective, e.g. aerial and boat-based surveys, acoustic and visual surveys, and aerial and PO surveys (Hammond et al., 2002; Certain et al., 2008; SCANS-II, 2008). Unique for this study was the combination of both PO and LT vessels, which provided data suitable for density estimation. The longer time-span increased the probability of detecting all cetacean species and can be contrasted to large-scale surveys in which an area the size of the present study area is covered far less extensively, both in time and space. The timing of the LT survey unexpectedly supplied a ‘peak’ density for minke whales, whilst the PO datasets showed the temporal variability of the whales. The longer temporal coverage highlighted the problem of timing a dedicated survey properly and showed that PO vessels can successfully be used to identify areas and periods of high density to improve designs for future line-transect surveys.

4.6 CONCLUSIONS

Finding temporary congregation sites in offshore waters and identifying concentrations of animals requires a prolonged presence of observers, which is not easily achieved during standard surveys. To overcome the difficulties in detecting trends (e.g. expensive LT surveys) it will be important for future monitoring to apply a consistent methodology using suitable PO vessels. The present study showed the advantages of surveys at a finer spatial scale with longer temporal coverage and, as such, provided ecological information regarding foraging minke whales along an offshore bank in May.

At present there are some threats to minke whales in these waters, and an increased understanding of this species ecology is needed. Parts of the Dogger Bank have been proposed as SACs (sandbank habitat; Diesing et al., 2009). Our observations suggest that the slopes of the Dogger Bank support a high species diversity and offer a predictable foraging site for minke whales and other predators, particularly during spring when they exploit local sandeel aggregations. The habitat preferences of minke whales along this offshore bank appeared to be similar to those previously observed in coastal areas, and this suggests some degree of generality regarding the habitat preferences of minke whales in the north Atlantic. This offshore bank is currently the last extensive sandeel fishing ground in the North Sea, and concern has been raised regarding the effects of local sandeel depletion at the bank on their predators and the North Sea ecosystem as a whole (Mackinson, 2007). Especially when prey becomes less abundant elsewhere, these offshore banks may become increasingly important to marine predators within the North Sea. It is necessary to further study the environmental variables in the area in order to predict the importance of these offshore banks as spring feeding habitats for minke whales and other top predators.

4.7 ACKNOWLEDGEMENTS

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CHAPTER 5

PHOTO-IDENTIFICATION METHODS REVEAL SEASONAL AND LONG-TERM SITE-FIDELITY OF RISSO'S DOLPHINS (*GRAMPUS GRISEUS*) IN SHALLOW WATERS (CARDIGAN BAY, WALES)

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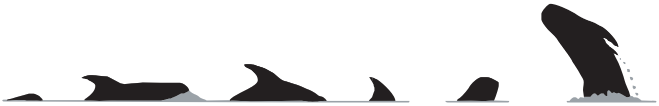
Risso's dolphin



5.1 ABSTRACT

A photo-identification study on Risso’s dolphins was carried out off Bardsey Island in Wales (July to September, 1997-2007). Their local abundance was estimated using two different analytical techniques: (1) mark–recapture of well-marked dolphins using a ‘closed-population’ model; and (2) a census technique based on the total number of identified individual dolphins sighted over the study period. The mark-recapture estimates of 121 (left sides; 64-178 95% CI; CV=0.24) and 145 dolphins (right sides; 78-213 95% CI; CV=0.24) closely matched the census technique estimates (population size of 90-151). It was found that the dolphins showed a degree of long-term and seasonal site-fidelity. A first long-distance match was made for Risso’s dolphins (319 km) between Bardsey Island and Cornwall, confirming they can be wide-ranging animals. This study demonstrates that the combination of systematic and opportunistic photo-ID studies has complementary value as a population assessment tool in generating the first local abundance estimate for Risso’s dolphins in UK waters. From the conservation perspective, these studies confirm the regular presence of Risso's dolphins in these waters and the presence of calves shows breeding. Bardsey Island may be part of a network of localities that are important habitats to this species where it may take advantage of prey abundance in shallow waters. As such, results of this study may provide assistance to include the Risso’s dolphin in future regional conservation strategies including the envisaged marine protected areas.

5.2 INTRODUCTION

The present status of Risso’s dolphins (*Grampus griseus*) in European waters is largely unknown (Wharam and Simmonds, 2008). For NW Europe, sightings data concerning this species mainly consist of opportunistic records although some effort-related data are also available (e.g. Evans et al., 2003; Reid et al., 2003). The only abundance estimates available for other European waters (based on line-transect methods) are for the Mediterranean Sea (Gannier and Gannier, 1994; Gómez de Segura et al., 2006; Bearzi et al., 2010). The picture is not different on a global scale, and only a few abundance estimates exist for waters outside Europe (e.g. Bearzi et al., 2010). Some large-scale studies in the eastern Atlantic such as the NASS (North Atlantic Sightings Survey), SCANS (Small Cetacean Abundance in the European Atlantic and North Sea), CODA (Cetacean Offshore Distribution and Abundance in the European Atlantic) have been carried out and provided some additional information regarding Risso's dolphin distribution within Europe (e.g. SCANS-II, 2008; Bearzi et al., 2010). However, the yield of sightings data was not enough to allow the calculation of abundance estimates, suggesting a relatively low density for this species (e.g. SCANS-II, 2008; Weir et al., 2001).

Mark-recapture techniques are widely used to estimate population-size where animals can be identified individually through photographs (e.g. Hammond, 2010). Risso's dolphins typically exhibit long-lasting identifiable natural marks, which include distinctive nicks in their dorsal fins, patterns of scarring and variations in dorsal fin shape. Therefore, photo-identification (photo-ID) techniques can be used to study association patterns and social structure for this species (Hartman et al., 2008). Mark-recapture techniques have yielded one preliminary abundance estimate for Risso's dolphins in the Mediterranean Sea (Airoldi et al., 2005).

Risso's dolphins have an apparent preference for deep offshore waters and continental slopes but also inhabit coastal areas around oceanic islands and narrow continental shelves (e.g. Bearzi et al., 2010). In UK waters, they are recorded most frequently, and year-round, off the Western Isles. They are also present around Orkney and Shetland (close to the species' known northern limit of distribution), in the Irish Sea, western and southern Ireland, and western English Channel, but they are rare in the North Sea (Weir et al., 2001; Evans et al., 2003; Reid et al., 2003). Both opportunistic and dedicated studies reported most sightings between May and October (De Boer et al., 2002; Reid et al., 2003; Bearzi et al., 2010). Risso's dolphins have been regularly seen in Welsh waters (e.g. De Boer et al., 2002) and incidental sightings made from Bardsey Island (1976-2005) indicate that this species occurs here primarily during the months of July to October with additional sightings recorded in April (De Boer, 2005). Apart from studies off the West coast of Scotland (1992-1997; Atkinson et al., 1997), hardly any dedicated research has been reported from UK waters on this species.

The study was conducted off Bardsey Island between 1997 and 2007 and the main objective was to estimate the local summer population size of Risso's dolphins. Secondly, site fidelity and ranging patterns were examined. Thirdly, an evaluation was made of the utility of small-scale, opportunistic and relatively low-cost studies for studying a relatively scarce species.

5.3 MATERIAL AND METHODS

Boat-based surveys were carried out in July (1997), August (2001, 2002, 2004, 2007) and September (2000, 2005-2006). Risso's dolphins were approached and photographed under license from the Countryside Council for Wales (CCW) adhering to local guidelines to minimise disturbance. The different boats used had an eye-level height of 2-3 m and included both outboard powered vessels (sailing vessel under motor, rigid-hulled inflatable boat) and 5-8 m inboard powered vessels such as the Bardsey ferry, a dory (small fishing boat) and a local wildlife-watching boat. Whenever conditions allowed, the boat surveys were carried out following line-transect survey protocols (De Boer et al., 2002).

5.3.1 STUDY LOCATION

Bardsey Island is situated in the northern parts of Cardigan Bay, Wales, a large shallow embayment on the east side of the St. George's Channel entrance to the semi-enclosed Irish Sea Basin. The northern shores of the Bay are formed by the Lleyn

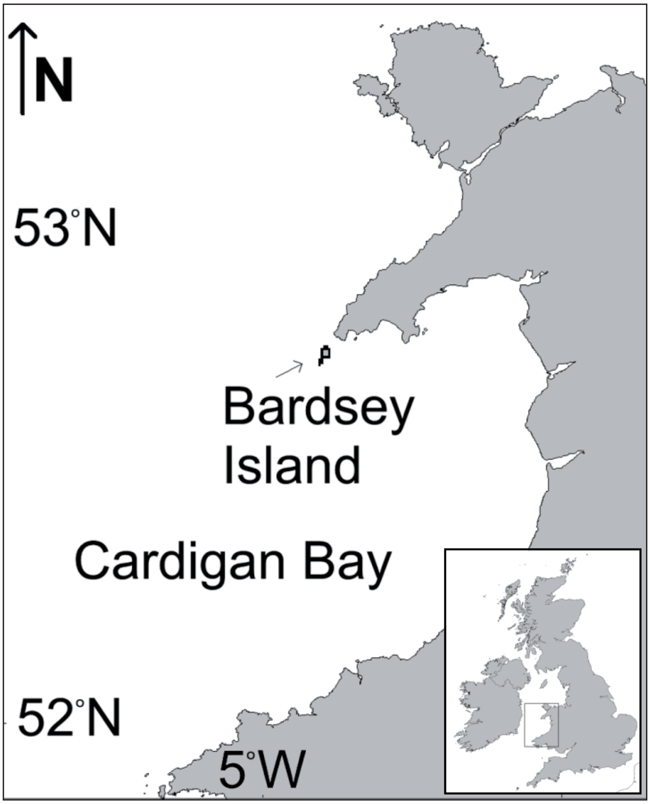


Figure 5.1
Cardigan Bay and Bardsey Island located off the Lleyn Peninsula (inset: UK).

Peninsula, which is orientated NE/SW and extends 40 km, ending in a headland adjacent to deeper water. Bardsey Island (with approximate dimensions of 3 km by 1 km) is situated off the tip of Lleyn Peninsula at 52° 45.36'N and 004° 47.17'W and is separated by Bardsey Sound (approximately 3 km wide) from the mainland (Fig. 5.1).

5.3.2 PHOTOGRAPHIC SURVEY DESIGN

Photographs of Risso's dolphins were collected both during systematic line-transect surveys to the east and west off Bardsey (Fig. 5.2) and opportunistic boat surveys. Opportunistic boat-surveys were launched when the dolphins were seen during dedicated land-based observations which were carried out from one to four look-out points on the Island (De Boer et al., 2012). In addition, Risso's dolphins were also photographed on four occasions from land when they came close to the shore (September 2005 and 2006).

During line-transect surveys, dedicated watches were conducted during calm seas (Beaufort sea states 0-3) and good visibility (>1 nmile). Two experienced observers were on watch covering a combined arch of 180°. Scanning was done with the naked eye and with occasional scans using 7 x 50 reticule binoculars (NIKON 7 x 50).

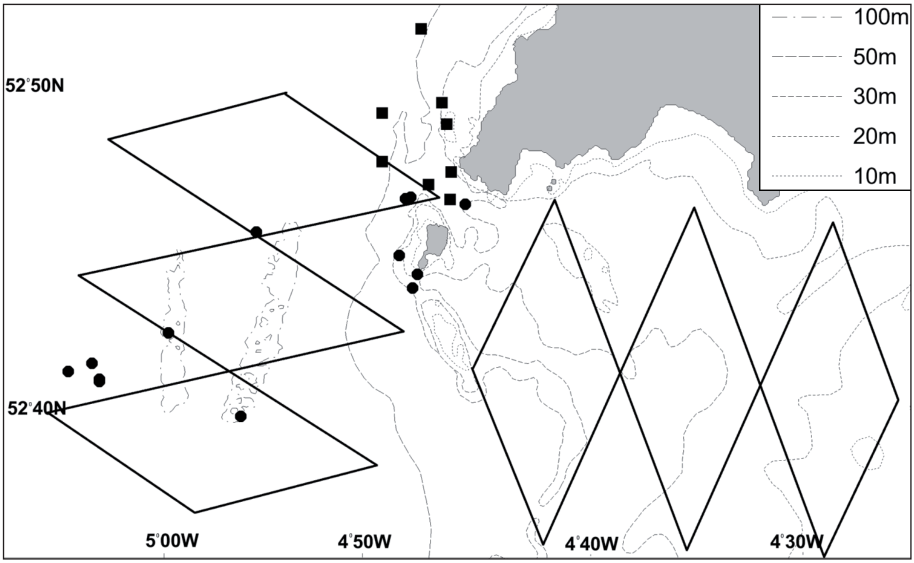


Figure 5.2 Estimated sighting positions of Risso's dolphins from both systematic (line-transect; dots) and opportunistic photo-ID boat-surveys (blocks) together with the dedicated line-transect survey design.

When a sighting was made, the survey went ‘off-effort’ in order to approach the animals and obtain photographs. Photographs were taken using 35-mm slide film (1997-2004) or digital SLRs (2005-2007).

Upon completing the Photo-ID work, the line-transect survey was then restarted from the point where ‘off-effort had commenced’. If a dolphin group was spotted from land, it was either observed from there or subsequently approached by boat for opportunistic studies. Dolphins were followed for 30 minutes to up to 2 hours, to allow time for all individuals to be photographed. Group-size was assessed in the field and later confirmed through the examination of photographs.

5.3.3 INDIVIDUAL RECOGNITION

Dorsal fin photographs from both sides were taken of individuals irrespective of their natural marks to enable an unbiased estimation of the proportion of well-marked animals (those with distinctive and permanent marks on the dorsal fins). For each sighting, the group size and presence of adults, sub-adults and calves were noted. Adults were defined as individuals with moderate to high scarification or white body coloration and mature body size (Hartman et al., 2008). Sub-adults were defined as dark brown individuals with limited scarification. Calves were identified when being less than 75% of the size of adults and accompanied by adults (Hartman et al., 2008), newborn calves were identified by the presence of foetal folds and by their erratic surfacing behaviour.

5.3.4 PHOTO PROCESSING

The photographs were analysed by three independent assessors who studied markings such as scars, nicks and shape of dorsal fin. In addition, scars or wounds found elsewhere on the body were also noted. Images were graded as good, moderate and poor based on the angle of the dorsal fin, contrast and focus. Poor photographs were excluded from analysis. Individuals were classed into well-marked, subtle-marked or unmarked dolphins. The selected photographs were used – as described in the following two sections – in two different techniques to estimate dolphin abundance.

5.3.5 MARK-RECAPTURE APPLICATION AND MODEL SELECTION

To comply with the assumptions for mark-loss, only those dolphins with well-marked dorsal fins were used in the mark-recapture analysis. Subtle marks were included in the mark-recapture analysis as long as these were distinctive and the scarification grade (based on the ratio of dark skin to white scars on the dorsal fin) of animals showing these subtle marks exceeded 10% (Hartman et al., 2008).

Calves were excluded from the mark-capture analyses because their probability of capture was not exclusive from that of their mothers.

Photo-identification data from eight summers (1997-2007) were then pooled per field season and considered as sampling units and recaptures in different survey years were taken into account. The program CAPTURE (Rexstad and Burnham, 1991) was used on capture histories of well-marked animals.

To prevent errors arising from mismatching left and right sides, we estimated abundance using the left and right sides independently (Wilson et al., 1999). Mark-recapture methods rely on a number of fundamental assumptions (e.g. Hammond, 2010), including (1) that a marked animal will be recognized with certainty if recaptured and failure to do so will bias estimates upward; (2) that marks do not change to the extent that they affect subsequent recognition; (3) that marked animals do not demonstrate behavioural responses that affect the probability of their recapture, and (4) that all individuals have the same probability of capture within a sampling session. Furthermore, a population may be regarded as a 'closed' or 'open' population. A closed population model assumes that the population is closed to births, deaths, immigration and emigration, i.e. it does not change over the period of study (e.g. Hammond, 2010). Even though births and possibly deaths occurred during the study periods, the population may be considered geographically closed if the same population units recurrently visited the Bardsey Island waters over time. We applied mark-recapture closed-models (Otis et al., 1987) to estimate the total abundance of well-marked dolphins. The model selection procedure (based on goodness-of-fit tests and discriminant function analysis) was performed to indicate the relative fit of competing models. A score of 1.00 indicates a high probability that the model chosen is more appropriate for the data set than any of the other models (Pollock et al., 1990).

The models for mark–recapture analysis for a closed population include, amongst others: M_0 (assumes that all individuals have an equal chance of being captured and that capture probabilities do not change over time); M_t (allows capture probabilities to vary by time), M_h (accounting for heterogeneity of probability of capture) and M_{th} (allows capture probabilities to vary by time and by individual animal).To calculate the proportion of unmarked individuals (including calves) in the population for each season, the total number of unmarked individuals was divided by the total number of individual dolphins identified. The estimate of well-marked animals in the population that was derived from CAPTURE was then expanded to incorporate the proportion of unmarked individuals to give a total population estimate ($\tilde{N}_{Tot;}$; Williams et al., 1993). The variance and confidence intervals for $\tilde{N}_{Tot}$ were calculated as by Wilson et al. (1999).

5.3.6 CENSUS BASED TECHNIQUE

The census method was used to calculate the minimum local population size as the number of recognisable (marked) individuals recorded. For this analysis, all recognizable dolphins were included in the analysis (i.e. dolphins with dorsal fins that were subtle-marked or well-marked, and dolphins with distinct recognizable marks elsewhere on body), comprising adults, sub-adults and calves. We also included both moderate-quality images showing highly distinctive animals and high-quality images showing relatively poorly-marked animals for this type of analysis. This enabled us to calculate the minimum number of identified respectively recognizable dolphins, bearing features either on the left- or the right-side or both, in Bardsey waters each summer.

5.3.7 DATA ANALYSIS

The local summer population size of Risso's dolphins was estimated using the above mentioned two different analyses techniques. Furthermore, sighting rates and group-size of dolphins encountered during systematic line-transect boat surveys were calculated. The term population here describes the local population of Risso's dolphins frequenting the Bardsey study area in summer rather than having genetic or absolute abundance implications.

5.4 RESULTS

5.4.1 PHOTOGRAPHIC SURVEY

Risso's dolphins were photographed during 24 encounters (Table 5.1) mostly in shallow waters (<50 m; Fig. 5.2). The group-size encountered during photo-ID surveys ranged from 1 to 12, but generally was between 1 and 6 dolphins (mean 5.43; SD 4.25, $n=12$); hence, photographing all dolphins in a group was usually readily achievable although not always on both sides of all dolphins. A wide variety of natural markings were observed including (1) white and dark teeth rake scars; (2) epidermal lesions; (3) linear, parallel and/or crossed marks; (4) circular, irregular well-shaped, or smoothed depigmentation patterns; (5) nicks; and (6) healed wounds (Fig. 5.3).

Figure 5.3 Natural markings of Risso's dolphins, including nicks; different shapes of dorsal fins; healed scars from wounds; and teeth rake scars. A photograph of a newborn calf (with foetal folds) is also shown (photographs © WDC)

Table 5.1 Information on Photo-ID encounters, Sightings (S), Individuals (IND) and dedicated (line-transect) boat days.

			Boat-based survey	
Year	**Month**	**Photo-ID encounter**	**Number of Survey days**	**S (IND)**
1997	July	1 (20 July)	1	1 (10)
1999	Aug	0	3 (11-12, 18 Aug)	0 (0)
2000	Sept	5 (3-9 Sept)	5 (3-5, 8-9 Sep)	5 (16)
2001	Aug-Sept	1 (29 Aug)	2 (2, 11 Sept)	1 (15)
2002	Aug	1 (19 Aug)	3 (15, 16, 28 Aug)	1 (15)
2003	July	0	2 (16, 17 July)	1 (1)
2004	Aug – Sept	3 (31 Aug)	2 (31 Aug, 5 Sept)	3 (22)
2005	Sept	3 (1-12 Sept)	2 (12, 14 Sept)	3 (28)
2006	Sept	7 (11-17 Sept)	1 (16 Sept)	7 (67)
2007	Aug – Sept	3 (24 Aug)	2 (24 Aug, 22 Sept)	3 (16)
Total	**July – Sept**	**24**	**23**	**25 (190)**

Table 5.2 Mark-recapture estimates of Risso's dolphin abundance during the summer months off Bardsey Island based on dorsal fin photographs showing left sides (LSD) and right sides (RSD). $\tilde{N}_{Tot}$ *, total abundance; WM, well-marked individuals; p, probability of capture;* θ *, proportion well-marked individuals; CV, coefficient of variation; se, standard error; CI, upper and lower bounds of the 95% confidence interval;* M_h*-model type*

	Animal captures	***p***	**Criteria value for M_h**	**$\tilde{N}$ (*WM*)**	**CV**	**95% CI**	**θ (*WM*)**	**$\tilde{N}_{Tot}$**	**95% CI $\tilde{N}_{Tot}$**	**se $\tilde{N}_{Tot}$**	**CV $\tilde{N}_{Tot}$**
LSD	33	0.07	1	58	0.21	43–91	0.48	121	64– 178	29.01	0.24
RSD	34	0.06	0.81	76	0.21	54–117	0.52	145	78–213	34.33	0.24

5.4.2 MARK-RECAPTURE BASED ABUNDANCE ESTIMATE

Forty-six dolphins had distinct permanent scars (well-marked) on their dorsal fins (27 left sides and 29 right sides). We adopted a 'closed' population model using data for the whole survey period (1997-2007). The best model was the closed jackknife estimator M_h. Other models that tolerate behavioural and innate differences in capture probabilities were also explored but did not yield high criteria values.

Using CAPTURE and taking into account the proportion of well-marked *vs* unmarked dolphins in the population, we produced abundance estimates for left and right sides separately. We estimate that a total of 121 dolphins (left sides; 64-

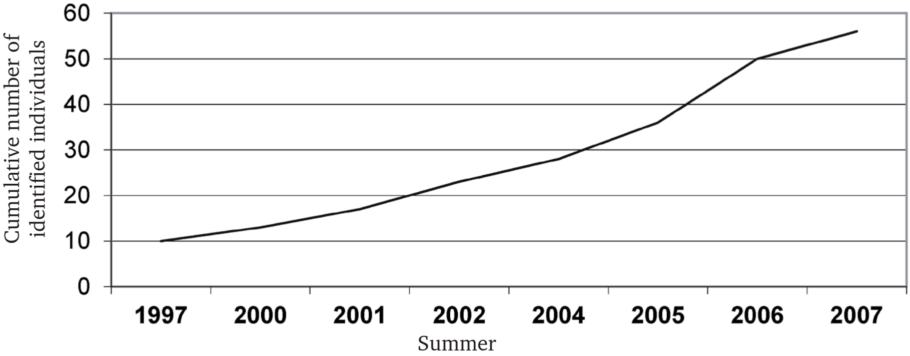


Figure 5.4 Discovery curve of the cumulative number of well-marked Risso's dolphins per summer (1997-2007) in the waters around Bardsey Island.

178 95% CI; CV=0.24) and 145 dolphins (right sides; 78-213 95% CI; CV=0.24) occur in these waters in late summer (Table 5.2). The estimate for left sides had a criteria value equal to one and was therefore regarded as the best estimate (Table 5.2). The rate at which new (well-marked) dolphins were identified throughout the study period is shown as the discovery curve which has a steady increase over time (Fig. 5.4). The dolphin sightings were expressed by field-season (summer) and 25% of the total dolphins had been identified after the third year and 86% had been identified by the end of the seventh year (Fig. 5.4).

5.4.3 CENSUS TECHNIQUE BASED ABUNDANCE ESTIMATE

A total of 59 well-marked and 124 subtle-marked dolphins were identified. Some duplication may have occurred because during the long study-period some of the subtle-marked animals may have changed in appearance. The minimum annual total numbers of individuals seen in Bardsey waters based on marked individuals alone ranged from 4 to 28 animals (Table 5.3). In 2005 and 2006 these numbers were the highest (Table 5.3). There was no positive correlation between the number of photo-ID surveys carried out and the minimum number of animals identified in each year (Spearman's rank order correlation: $r_s=0.586$, $n=8$, $p=0.127$). In total, 103 recognizable individuals were photographed of which 24 were photographed on both sides, 66 on left and 61 on right sides (Table 5.3). This means that an estimated minimum of 90 (assuming all 61 right sides correspond to the 66 left sides) and a maximum of 151 (supposing that all left and right sides are from different animals) dolphins occur off Bardsey in the late-summer months. A total of 11 different calves were photographed representing 10.7% of photographed individuals.

Table 5.3 Total population size using the number of marked dolphins for each survey year. The total minimum is calculated as the highest number of either left or right sides (under-lined) together with the total number of dolphins photographed on both sides. The total maximum is estimated supposing that all left and right sides are from different animals.

Survey year	**Left sides**	**Right sides**	**Both sides**	**Total minimum**	**Total maximum**
1997	3	7	0	7	10
2000	4	3	0	4	7
2001	2	4	0	4	6
2002	4	4	2	6	10
2004	5	9	2	11	16
2005	14	15	13	28	42
2006	25	11	3	28	39
2007	9	8	4	13	21
Total	**66**	**61**	**24**	**90**	**151**

5.4.4 SITE FIDELITY AND ASSOCIATIONS

Throughout the study, 11 individuals were re-sighted at least once and thus the re-sighting rate represented 18.6% of the total number of well-marked animals. Intervals of time between sighting and re-sighting ranged from 347 to 3,345 days (9.16 yrs), and the distance separating the sightings ranged from 2.39-17.24 km. Two adult dolphins seen together in 1997 were again seen together in 2006. A mother and calf identified in 2005 were subsequently seen in 2006. Two adults within a group seen in 2001 were again seen in 2006, although not as part of the same group.

5.4.5 RANGE

Photographs were received from colleagues working elsewhere within Cardigan Bay. These images were matched against the Bardsey Island photo-catalogue and a total of eight matches were made. One dolphin was photographed in 2004 (by J. Baxter), then in 2005 (this study) and finally again in 2009 (by R. Crossen). The distances between the re-sighting locations were 124.6 and 132.23 km respectively from Bardsey Island. The time periods between re-sightings were 454 to 1,476 days. Another dolphin photographed off Bardsey Island in 2006 and 2007 was subsequently photographed (by H. Jones) 319 km further south (off Cornwall, SW England), 995 days later in 2009.

5.4.6 BOAT-BASED SURVEY - SIGHTING RATE AND GROUP-SIZE

Line-transect boat effort was carried out over 630.5 km (49.13 hours) during which the waters around Bardsey Island were systematically covered every year between 1999-2007, except for 2006 (Fig. 5.2).

A total of 12 Risso's dolphin sightings were made, totalling 51 dolphins. The estimated sighting positions were plotted using the radial sightings distance and bearing (Fig. 5.2). The abundance using standard line-transect (distance) techniques could not be estimated due to low sample size. The sighting rate was 0.081 dolphins km^{-1} and the group size averaged 5.42 individuals (SD 4.25, n=12, range 1-12).

5.5 DISCUSSION

Due to inclement weather conditions most photo-ID surveys were opportunistic, i.e. not conducted whilst doing line-transect surveys, and were carried out to complement the dedicated surveys by enhancing our chances of photo-identifying the dolphins when they were close to the island. The opportunistic photo-ID surveys were typically launched when Risso's dolphins were spotted from one of the four look-out points on the Island. It also proved useful to leave a small group of observers behind on the island who would continue to scan the waters around the island when the opportunistic boat surveys were carried out. Those land-based observers were then able to give directions as to where other pods of dolphins were present within the area. In that way we could ensure that all (sub)pods of dolphins were approached for photo-ID purposes.

5.5.1 ABUNDANCE ESTIMATES

Dolphin abundance was estimated using two different analytical methods. The census based technique indicated that the minimum population size of the dolphins occurring in these waters was 90-151 individuals.

Using the mark-recapture based technique, we estimated that during the late summer months at least 121 dolphins occur in these waters. The relatively close agreement between the left (121) and right side (145; both with a CV of 0.24) estimates supports the reliability of this estimate. This estimate matches the estimate calculated with the census based technique. We are of the view that the census based estimate provides the least biased estimate. This is based on the uncertainty about the extent to which the assumptions for an appropriate application of the mark-recapture technique were met as will be elaborated upon in the following section.

We aimed to ensure that our mark-recapture techniques met the appropriate assumptions for the estimates generated to be valid. Most of our boat surveys were opportunistic bringing along an irregular photo-ID survey effort. There was no correlation between the number of surveys conducted and the number of individuals identified and this indicates that the likelihood of recapture was not affected by irregular survey effort. The assumption that all individuals have the same probability of capture within a sampling session was difficult to assess as dolphins may have different preferences for particular areas which varies between individuals. Such differences in capture probabilities can negatively bias the estimates. However, the jackknife model used takes this into account as it assumes that each individual has its own probability of capture and that over time these probabilities do not change (Otis et al., 1978). This model accounts for variations of heterogeneity such as age or sex of an individual as well as the preferences of particular animals for certain areas and/or individual boat attraction or avoidance. The jackknife estimation procedure (Burnham and Overton, 1978) is most commonly used for estimating animal abundance and is regarded as fairly robust (Otis et al., 1978; Williams et al., 2002). However, negative bias will still occur if some members of the population are uncatchable (Otis et al., 1978). A violation in the assumption that well-marked animals do not demonstrate behavioural responses affecting the probability of their recapture can lead to under- or overestimates. Such violations seemed unlikely in this relatively non-invasive photo-identification study where no physical interaction occurred (avoiding ‘trap-shy’ scenarios). We aimed to photograph all individuals within groups in order to avoid over-estimating capture probability and as a consequence under-estimating abundance (Evans and Hammond, 2004). We used photographs of dolphins with distinct marks on the dorsal fin only, so we could assume that the well-marked animal was recognised with certainty during ‘recapture’ and avoid missing matches which leads to over estimations (Pollock et al., 1990). The assumption that marks do not change to the extent that they affect subsequent recognition was likely not to be violated because photo-ID techniques have been shown to be a good tool for individual identification of Risso’s dolphins (Hartman et al., 2008). We aimed to meet the assumption that population changes through births, deaths and movements were minimal. ‘Closure’ is therefore only a reasonable assumption when studies are of relatively short duration. In the present study, sufficient data were only available to allow the use of ‘closed-population’ models. The fact that the two different analytical techniques using different data sets produced similar population estimates, corroborates our use of the closed-population model.

Adults have heavier body scarring and may therefore be overrepresented in the group of well-marked individuals. Calves and sub-adults with little scarring were also encountered and the apparent increase in the discovery curve (Fig. 5.4) can be explained by recruitment of (scarring) sub-adults into the well-marked population. The discovery curve (Fig. 5.4) should be interpreted with care as the curve was still on an incline with seven new individuals added to the catalogue in the final season (2007) and indicates that more effort is required. Despite the limitations discussed above, the research successfully added new insights to the status of Risso's dolphin in UK waters.

Whilst large-scale line-transect cetacean studies in the western Atlantic have resulted in Risso's dolphins abundance estimations, this has not been hitherto possible for eastern Atlantic waters due to low sighting numbers. A preliminary mark-recapture abundance estimate was calculated for Risso's dolphins in the Ligurian Sea (Mediterranean) of 242 dolphins (right-sides) and 267 dolphins (left-sides) for a large study area (24,000 km^2; Airoldi et al., 2005). The only abundance estimates in European waters based on aerial line-transect methods refers to the waters east of Spain (32,270 km^2; 493 dolphins; CV=0.61) with a minimum density of 0.015 dolphins km^{-2} (Gómez de Segura et al., 2006). Another survey reports a line-transect abundance estimate for Risso's dolphins in the northwestern Mediterranean (143,000 km^2) of 2,360 dolphins with a minimum density estimate of 0.018 dolphins km^{-2} (Gannier and Gannier, 1994). In the present study, Risso's dolphins were encountered within a relatively small area (795 km^2; Fig. 5.2). With the present abundance estimate of 121 dolphins, the density of the present study is 0.15 dolphins km^{-2}. This is ten-fold higher when comparing this to the line-transect survey estimates of (Gannier and Gannier, 1994; Gómez de Segura et al., 2006) but it should be noted that the area used in the present study was relatively small. Nevertheless, compared to these studies, the estimated numbers of dolphins in our study area indicate that this area can be considered an important habitat for Risso's dolphins.

The line-transect boat-surveys alone did not achieve high enough sample size to allow for dolphin abundance to be estimated using distance-sampling techniques. The dolphins were seen foraging in localised shallow hotspots (De Boer et al., 2012) and this may have impacted the chances of detection during the line-transect surveys.

5.5.2 SITE-FIDELITY AND ASSOCIATIONS

Site-fidelity of Risso's dolphins, expressed in re-sighting rates, was measured in our study at 18.6%. This is comparable to studies in the northwestern Mediterranean where 9.2-15.7% has been found (David and Di Méglio, 1999). In other areas higher re-sighting rates were observed: 63% in the Azores (Hartman et al., 2008) and in the Ligurian Sea (Airoldi et al., 2000), and 37% off Scotland (Atkinson et al., 1997). Individuals have been re-sighted up to 5 years in the Mediterranean (e.g. Cañadas and Sagarminaga, 1997; David and Di Méglio, 1999). In the present study, one pair of dolphins was re-sighted nine years later. Preliminary studies in the Mediterranean and off the Canaries report strong associations of Risso's dolphins over a period of 3-4 years (e.g. Cañadas and Sagarminaga, 1997) and similar findings were reported off the Azores (Hartman et al., 2008).

5.5.3 LONG-DISTANCE MATCH

One long-distance re-sighting was made in the present study (319 km). In the Mediterranean Sea, Risso's have also been re-sighted over quite long distances (164 km; David and Di Méglio, 1999). One Risso's dolphin which stranded in the Gulf of Mexico was subsequently released and satellite-tagged and traveled over 3,300 km in 23 days (Wells et al., 2009). Considering their seasonal occurrence and comparatively low re-sighting rates around Bardsey, it is to be expected that 'Welsh' Risso's dolphins travel over large distances.

5.6 CONCLUSIONS

The Risso's dolphin is a relatively difficult species to study: difficult to approach and, in our experience, are relatively shy and as deep divers often disappear underwater for long periods of time. In addition, the number of days that could be spent in the field was limited because of the local conditions. The Welsh name for Bardsey translates as 'island of the tides' and the waters around the island are notorious for fast water movements that make even transport to and from the island difficult. Difficult working conditions in the field, an elusive focal species and sometimes a limited budget will not be unique to this study area, so the question is opportune as to whether data gained in this study are still of value as a demonstration of its applicability to obtain information on marine mammals in other remote areas or less well studied species.

As pointed out by Evans and Hammond (2004), opportunistic photo-ID data sets need to be viewed with caution in order to produce data appropriate for robust population assessment. The main limitations identified in the present dataset were (1) the discovery curve indicating that the population had not yet been sufficiently sampled after 11 years of study; whilst (2) the longevity of the study period (1997-2007) did not fully justify the application of mark-recapture methods based on a 'closed population' model. An 'open population' model may be more appropriate to the study of these animals, given the apparently transient nature of the Risso's dolphins that appear annually in the study area and the obvious births and presumed deaths occurring during the study years. However, that approach would also require a great deal more data from each year, as it would effectively require a 'closed population' estimate to be generated from each summer and we strongly recommend this for future studies with a similar set-up. On the other hand, continuing the photo-ID work on Risso's dolphins will increase sample size and allow studying estimates of survival, recruitment and population trends using 'open' population models. Comparisons of photo-ID catalogues from other hotspots may add valuable information and allow us to work out where these Risso's dolphins reside in other seasons. This would also add to our understanding of the wide-scale movements of Risso's dolphins throughout the region and possible connections between different parts of the meta-population. Furthermore, comparisons to other such catalogues may add valuable information, for example, by providing information on individuals that have disappeared from other study sites, on animals that have changed appearance, or on new calves.

This study emphasises the benefits of (small-scale) opportunistic photo-ID studies in yielding important information for conservation management purposes (i.e. assessments of population status and trends). The study also highlights the practical difficulties of studying such irregular but seasonal aggregations of a relatively scarce species and explores alternative methods of analysing sparse opportunistic data.

We conclude that this dataset provided new information regarding the minimum number of dolphins that frequent these coastal waters during the summer months, and that the opportunistic boat surveys complemented the dedicated line-transect surveys by increasing the sample-size of the number of identified dolphins. In addition, the outcome of the mark-recapture based technique could be further improved by focusing on (1) a shorter temporal periodicity; (2) a higher sample effort per year; and (3) applying subsequently a 'closed-population' analysis.

From the conservation perspective, these studies confirm the presence of Risso's dolphins in these waters on a regular basis. The indications so far are that the population is relatively small, but the regular presence of calves shows breeding. There is a variety of conservation initiatives being progressed in Cardigan Bay and the North Wales area, particularly regarding the designation of various marine protected areas. However, none at this point specifically take the Risso's dolphins into account. Our study shows the Bay to be important for the elusive and little known Risso's dolphin, which should provide additional incentive for regional conservation strategies.

We estimated that during the late summer months at least 121 dolphins occur in these waters. The relatively close agreement between the left (121) and right side estimates (145; both with a CV of 0.24) supports the reliability of this estimate and closely matched the census technique estimates (population size of 90-151).The study furthermore revealed that Risso's dolphins show regular seasonal occupancy in these waters with some dolphins showing site-fidelity comparable to but also differing with results measured in other studies on this species. Movement to and from the study area is evident and at least part of the population of dolphins returns to these waters. The long distance match of 319 km shows that Risso's dolphins can range widely. The waters around Bardsey Island may be part of a network of localities that are important to this species where it may take advantage of prey abundance in shallow waters. The existence of such localities has important implications in the design of conservation actions (Hoyt, 2011) and requires a more dynamic species conservation approach.

5.7 ACKNOWLEDGEMENTS

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CHAPTER 6

THE INFLUENCE OF TOPOGRAPHIC AND DYNAMIC CYCLIC VARIABLES ON THE DISTRIBUTION OF SMALL CETACEANS IN A SHALLOW COASTAL SYSTEM

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Harbour porpoise

6.1 ABSTRACT

The influence of topographic and temporal variables on cetacean distribution at a fine-scale is still poorly understood. To study the spatial and temporal distribution of harbour porpoise *Phocoena phocoena* and the poorly known Risso's dolphin *Grampus griseus* we carried out land-based observations from Bardsey Island (Wales, UK) in summer 2001-2007. Using Kernel analysis and Generalized Additive Models it was shown that porpoises and Risso's appeared to be linked to topographic and dynamic cyclic variables with both species using different core areas (dolphins to the West and porpoises to the East off Bardsey). Depth, slope and aspect and a low variation in current speed (for Risso's) were important in explaining the patchy distributions for both species. The prime temporal conditions in these shallow coastal systems were related to the tidal cycle (Low Water Slack and the flood phase), lunar cycle (a few days following the neap tidal phase), diel cycle (afternoons) and seasonal cycle (peaking in August) but differed between species on a temporary but predictable basis. The measure of tidal stratification was shown to be important. Coastal waters generally show a stronger stratification particularly during neap tides upon which the phytoplankton biomass at the surface rises reaching its maximum about 2-3 days after neap tide. It appeared that porpoises occurred in those areas where stratification is maximised and Risso's preferred more mixed waters. This fine-scale study provided a temporal insight into spatial distribution of two species that single studies conducted over broader scales (tens or hundreds of kilometers) do not achieve. Understanding which topographic and cyclic variables drive the patchy distribution of porpoises and Risso's in a Headland/Island system may form the initial basis for identifying potentially critical habitats for these species.

6.2 INTRODUCTION

Due to the elusive nature of most small cetacean species, understanding their habitat selection can be challenging. This has led to the development of more indirect methods, where the heterogeneity in distribution is quantified as a function of habitat variables, such as water depth, sea surface temperature, primary productivity, bottom type, tidal currents and frontal systems (e.g. Mendes et al., 2002; Macleod et al., 2004; Hastie et al., 2005; Panigada et al., 2008). Such habitat models play a key role in improving the understanding of the ecological processes underlying cetacean distributions (Redfern et al., 2006; Matthiopoulos and Aarts, 2010).

Most cetaceans tend to be wide-ranging and their abundance is typically studied using large-scale line-transect surveys that provide a single large-scale 'snapshot' of the distribution (e.g. Hammond et al., 2013). Such studies are not designed to study the fine-scale heterogeneity in high-density areas and they do not provide detailed information regarding temporal drivers that might influence the distribution of cetaceans. Studies that focus on the habitat selection of a cetacean species therefore do this at a much smaller scale (0.5 x 0.5 – 4 x 4 km^2) using either a dedicated research vessel or Platform of Opportunity (e.g. Mendes et al., 2002; Macleod et al., 2004; MacLeod and Zuur, 2005; Johnston et al., 2005a; Bailey and Thompson, 2010).

Several cetacean species are often encountered close to islands and headlands where temporal drivers, such as strong tidal currents can play a dominate role (e.g. Johnston et al., 2005a). Such locations may provide an excellent opportunity to install low-cost observation platforms to carry out dedicated (effort-corrected) surveys. An appealing aspect of such land-based surveys is that they can capture the variations in occurrence of cetaceans in both space and time at a reduced cost compared to boat-based studies. The objective of this study is to provide a temporal insight into the fine-scale spatial distribution that studies conducted over broader geographic scales do not achieve. We focus here on the harbour porpoise *Phocoena phocoena* and Risso's dolphin *Grampus griseus*, which both occur in Welsh waters, and are regularly sighted from Bardsey Island in North Wales (United Kingdom; De Boer et al., 2002). Opportunistic records of Risso's dolphins made from Bardsey Island (1976 – 2005) indicate that this species primarily occurs here during the months of July to October with additional sightings recorded in April (De Boer, 2005). The harbour porpoise is sighted here year round and only occasional sightings are made of other cetacean species (Hope Jones and Okines, 1990; De Boer et al., 2002). The cetacean community off Bardsey Island is therefore best described as dominated by porpoises and Risso's dolphins.

Like any other headland/island system, Bardsey Island acts as a flow obstacle which leads to the formation of residual eddies on either side of the island during flood and ebb (Elliott et al., 1995; Neil et al., 2007). At fine spatial scales, small-scale eddies and fronts appear to enhance the primary productivity and it is recognised that such features may concentrate prey (e.g. Simard et al., 2002; Zamon, 2003). Prey aggregations within headland and island wakes are believed to result from complex secondary flows which concentrate plankton near the surface at convergences and at the edges of eddies (e.g. Mann and Lazier, 1996). There have been few studies of cetaceans foraging in island/headland wakes. Johnston et al. (2005a,b) reported on fin whales *Balaenoptera physalus,* minke whales *Balaenoptera acutorostrata* and harbour porpoises that exploited a tidally driven island system in the Bay of Fundy. In the Moray Firth (Scotland), bottlenose dolphins *Tursiops truncatus* showed fine-scale foraging movements within a narrow channel (Bailey and Thompson, 2010). In Alaska the abundance of humpback whales *Megaptera novaeangliae* appeared to be related to tidal influences near headland wake systems (Chenoweth et al., 2011). Pierpoint (2008) and Isojunno et al., (2012) reported on porpoises in a headland/island system in South Wales.

The area that includes Bardsey Island and its surrounding waters is located in the northern part of Cardigan Bay and has been designated as a Special Area of Conservation (SAC), meeting the requirements of the EU Habitats and Species Directive (JNCC, 2013). This regional SAC, also called 'Pen Llŷn a'r Sarnau' was designated for a number of features including estuaries, coastal lagoons and reefs and also the grey seal *Halichoerus grypus* and bottlenose dolphin. Risso's dolphins are listed under Annex IV of the EU Habitats and Species Directive. Annex IV species, which include all cetaceans, are afforded 'strict protection' whereby the deliberate capture, killing and disturbance of these species are strictly prohibited (Council Directive 92/43/EEC). Harbour porpoise and bottlenose dolphin are the only two species of cetaceans listed under Annex II which are afforded the designation of SACs whereby 'the viability, population size and range of a species' should be maintained in the long term (Council Directive 92/43/EEC). However, no SACs have been designated for harbour porpoise in the UK, although sites have been designated in other parts of Europe. A better understanding of how the distributions of small cetacean species are changing in space and time, at different scales, will ultimately aid the selection of protected areas.

In this study, we investigated whether localised areas afford temporary but predictable areas for harbour porpoises and Risso's dolphins. We use long-term data from fixed viewing points located on Bardsey Island. By constructing habitat selection models we explore whether these localised areas (or hotspots) are influenced by dynamic cyclic variables (e.g. tidal and lunar cycles) and topographic variables. As such, the study provides a temporal insight into the fine-scale spatial distribution of two species beyond the resolution of most studies and management considerations.

6.3 MATERIALS AND METHODS

6.3.1 SURVEY AREA

Cardigan Bay is a large shallow embayment on the East side of the St. George's Channel entrance to the semi-enclosed Irish Sea Basin. Within the Cardigan Bay,

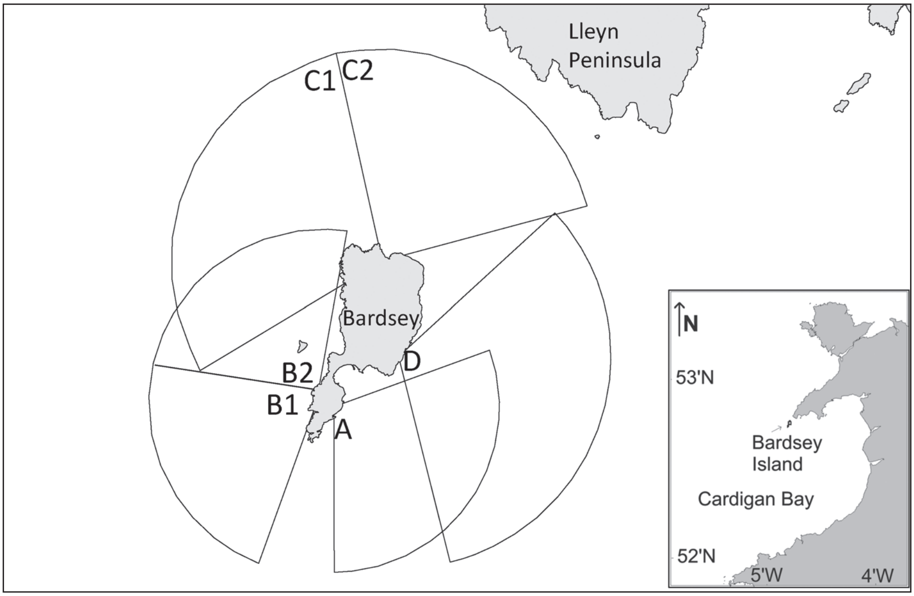

Figure 6.1 The location of Bardsey Island within Cardigan Bay (Wales). The four different viewing points (A-D) and corresponding survey sectors are also shown.

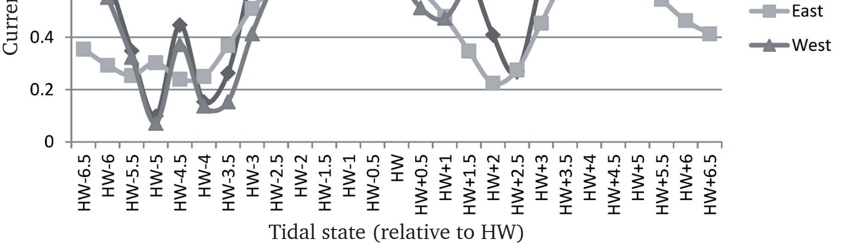

Figure 6.2 The current speeds (m/s) for different areas to the West, East and to the North (Bardsey Sound) of Bardsey Island are shown.

lies the Lleyn peninsula (Wales), which is orientated Northeast/Southwest and is some 40 km in length, ending in a headland adjacent to deeper water. Bardsey Island (with dimensions of 2.6 km by 1 km) is situated off the tip of the Lleyn Peninsula in the northern part of Cardigan Bay at 52°45.36'N and 004°47.17'W and is separated by Bardsey Sound (approximately 3 km wide; Fig. 6.1). Bardsey Island is owned and managed by the Bardsey Island Trust. The tides along the coast of the Lleyn Peninsula are extremely rectilinear and mainly semi-diurnal in character (Elliott et al., 1995). There are strong tidal currents that exist in the waters surrounding Bardsey Island which have currents of up to 3 m s^{-1} (6 knots; Elliott et al., 1995). Water is driven through Bardsey Sound by the tidal current as it enters and exits the Irish Sea during the semi-diurnal tidal regime. The tidal flow through the survey area is mainly Northwest (i.e. flowing through the Sound) during flood and is Southeast for the remainder of the tidal cycle. Interestingly, during HW the mean current speed is still at its highest. Low Water Slack tide (LWS) occurs on the West and North side of the Island between HW-5.0 and HW-3.5 hrs. The High Water Slack tide (HWS) to the West occurs between HW+0.5 and HW+1.5hrs but to the North this occurs later (between HW+2 and HW+3). To the East of the Island, LWS and HWS occur between HW-5 to HW-4hrs and between HW+1.5 to HW+2.5hrs respectively (Fig. 6.2). Bardsey Island constitutes an obstacle to these tidal streams and an island 'wake' is formed behind it, causing eddies and overfalls, especially on high tides. The race on the flood tide sets rapidly after LWS to the West (Fig. 6.2). According to Pingree and Griffiths, (1978) the waters to the West are mixed and to the East are transitional, with a frontal system that exists in the shallow Cardigan Bay area in summer which is highly susceptible to wind mixing.

6.3.2 LAND-BASED SURVEY DESIGN

A standardised method ('scan sampling') was used that was sensitive to short-term changes in the number of cetaceans. No permits were required for the described study, which complied with all relevant regulations. Observations were carried out during the summer months between 2001 and 2006. A study area (sighting angle up to 90° - 115°) was slowly scanned using 7 x 50 Nikon binoculars for a period of 10 minutes (e.g. Pierpoint, 2008). Whenever possible, simultaneous observations were carried out from four observation points which varied in height and survey area (Fig. 6.1). We produced a series of 10-minute 'snapshots' for each sampling segment, detailing the location of cetaceans sighted. To account for tidal amplitude (±5m at spring tide), the height of the observation point above sea level was calculated using tidal height corrected for Bardsey Island (WXTide32 version 4.7). Points A and B (both at 17 m height at LW) were situated at the southern tip of the Island. Point B overlooked waters with exposure to prevailing south-westerly wind and wave action and containing complex bathymetric features, whereas point A overlooked a leeward habitat. The higher points (C-D) were situated at heights of 38 m and 60 m at LW respectively and were located on the northern part of the Island. Point C covered two survey areas of which one overlooked the waters in Bardsey Sound with strong tidal streams and the other area overlooked the western part of the Island which partly overlapped with an area covered from point B. Point D overlooked the eastern part of the Sound but also partly overlapped with the leeward habitat covered from point A. Because points B and C were wide-viewing points, two different survey sectors were covered, totalling the number of similar-sized survey sectors surrounding the Island to six (Fig. 6.1).

Observers switched scanning every 10 minutes and also changed platforms every 2 – 4 hrs to prevent observer exhaustion and to address any observer bias. The following information was collected with each sighting: radial distance (using reticule binoculars), bearing (using the built-in compass in the binoculars – these were frequently checked and calibrated), surfacing direction, group-size, presence of calves and juveniles. Surfacing speed was described as either: ‘slow’—a lethargic-type roll; ‘moderate’—a typical porpoise surface roll with back and upper flanks visible; or ‘fast’—exposing much of the head and flanks and creating some spray. Distinctive behaviours were noted separately. For each 10-minute scan various environmental details were noted, including the Beaufort sea state (0 - 4) and visibility (poor, moderate, good, excellent). Optolyth telescopes (x 30) were used to aid group-size estimation and to distinguish juveniles and calves.

6.3.3 DATA ANALYSIS

We estimated the position of each sighting using the location of the viewing platform (X and Y coordinates), the bearing, radial distance (using the GEOFUNC Software with spherical trigonometry functions; NOAA, 2013) and observation height (taken into account the tidal amplitude according to WXTide32 version 4.7; set-location Bardsey Island). These were imported into ArcGIS version 10 with the following coordinate system (from now on referred to as Bardsey Projection): Transverse_Mercator; Central_Meridian: -4.785; Latitude of Origin: 52.75543; Linear Unit: Meter; Geographic Coordinate System: GCS_WGS_1984.

6.3.4 DETECTABILITY & PRECISION OF MEASUREMENTS

It is extremely unlikely to expect all animals within a surveyed area will be sighted and both habitat preferences and distance can influence the detection function. The ability of the observer to sight the animal is negatively affected by increasing distance between the animal and the observer.

When studying the habitat preferences of cetacean species, it is assumed that spatial variations in sighting rate are the result of differences in habitat use rather than any potentially confounding variables, such as the distance from the observer. However, it is known that the ability to detect cetaceans decreases with distance from the observer. Estimating the distance related detection probability would be possible by using data collected by two-independent land-based observers (Buckland et al., 2001), however such data were not collected in the present study. Instead, to control for this effect, we took a more conservative estimate and removed all locations outside a given radius around each of the observer platforms which defined the point at which distance from the observer starts to influence the likelihood of detection rather than habitat preferences. In order to estimate this radius, we studied the effect of distance on the detectability of sightings by plotting an accumulation curve which shows the proportion of total number of sightings up to a given distance. This allowed us to estimate the 'inflection point', which is the point marking the distance at which there is a change from constant to declining detection rate with distance (the point where the increase changes from linear increase to a curvilinear increase). Since small cetaceans are notoriously difficult to observe with high sea states, a similar comparison was made in order to determine which sea states followed a similar accumulation curve (for each survey site) and could be pooled for analysis (i.e. which of the higher sea states needed to be excluded to reduce bias in the ability of detection).

We assessed the precision of measurements by looking at the level of error from rounding to the closest 0.5 reticles on the binoculars.

6.3.5 IDENTIFYING AREAS OF HIGH DENSITY

The kernel estimated probability of an animal using the habitat at a specified location is a smoothed function of all sighting locations within a specified range (neighbourhood/bandwidth) around that location (Silverman, 1986; Powell, 2000). This method is therefore less affected by errors on the exact locations of an animal's position than some other space-use estimators (Millspaugh et al., 2006). The kernel density estimator is extremely sensitive to the choice of smoothing parameter (bandwidth) and it is recommended that a smoothing bandwidth that is at least equal to the uncertainty in the location is used (Powell, 2000).

To identify key habitats for harbour porpoises and Risso's dolphins, kernel density estimation grids were produced in ArcMap V10 using the fixed kernel density estimator ('kde' commands) by means of Geospatial Modelling Environment (SpatialEcology.com). The Gaussian (bivariate normal) kernel was used where the optimized bandwidth matrix was estimated via smoothed cross validation (SCV) and set to an output cell size of 50 x 50 m. This was found to best relate to the resolution of the habitat variables and our fine-scale analysis. The selected value of 50 m also was appropriate considering the error on the majority of sighting position estimates.

The relative size and form of the kernel density estimate is dependent on the total number of locations and their distribution. More survey effort and increased sightability generally leads to more sightings. Therefore, we treated the data from each observation point separately (due to differences in height and effort), and, to compensate for differences in the amount of survey effort in each of the survey areas we randomly selected those periods when effort was conducted from all four observation points resulting in the same number of scans for all survey sectors (*n*=600). Each sighting falling in overlapping areas received a weight of 0.5 to adjust for double-effort in these areas. We then carried out kernel analysis for each species in order to identify the areas of highest density of sightings for each sampling area. In those areas that overlapped we expected to identify the same areas of high density which helped confirming the findings from any one site.

By determining the smallest possible area containing user-specified percentages of the locations, the kernel grid was divided into percentage volume contours for 95%, 75%, 60% and 50% intervals. This means that the area within the 50% contour represents areas with highest density and the 95% contour almost the entire range. The kernel density estimation tool does not give the possibility of excluding land.

6.3.6 ENVIRONMENTAL VARIABLES USED TO STUDY THE HABITAT PREFERENCES

Acoustic Doppler Current Profiler data (ADCP) were obtained from the University of Bangor at a 300 m x 300 m resolution over complete tidal cycles (Elliott et al., 1995). This data included tidal current measurements in Bardsey Sound and around Bardsey Island and were collected during a survey using a ship-borne ADCP combined with direct reading and moored current meters (Elliott et al., 1995). The ADCP observations were normalized by the tidal range and then scaled to high spring conditions for the nearest Port Liverpool. From the ADCP data maps of surface currents at the different tidal states in respect to HW at Liverpool were derived from 6 hrs prior to 6 hr after HW, at 30 minute intervals (see Elliott et al., 1995 and references therein).

Tidal current data were manually interpolated with respect to HW at Bardsey Island as follows. Every ten minutes the tidal state (hrs after high water) and tidal height (meters above extreme low tide) was obtained from the tidal prediction programme (WXTide32 version 4.7; set-location Bardsey Island).

A range of environmental variables were available for inclusion in the analysis including temporal/tidal variables and topographic variables: *The X and Y coordinates* (Bardsey grid projection) were included using the estimated sighting positions. *Depth values* were obtained as an ASCII grid (50 m x 50 m resolution) from the offshore digital dataset (United Kingdom Hydrographic Office/Marine DigiMap; ©Crown Copyright / SeaZone Solutions Ltd 2008). From which grids of *distance to coast*, *seabed slope* (0 to 90°), standard deviation *(SD) of slope* (used as a measure of spatial variation in bottom topography and this was calculated for each cell and the 5 surrounding cells in Arcview GIS 10.0) and *aspect* (i.e. the azimuthal direction in which a tangent plane faces, 0 to 360) were calculated using Spatial Analysis tool functions in ArcGIS (version 10). Temporal variables such as *day of year, hour of day* and *year* were included. Temporally varying tidal variables were also included, such as *tidal state* (the time in the tidal cycle relative to High Water) and *lunar cycle* (the number of days before (i.e. negative values) or after (i.e. positive values) neap tide) and spatially varying tidal variables were also used, such as *tidal current speeds* and *current directions* and *tidal stratification*. These tidal variables were calculated for each tidal state (i.e. from 6 hrs prior to 6 hrs after HW, at 30 minute increments). *Spatial variation of current speed* was estimated as follows: based on sines and cosines rules, current speed in North-South (Y) and East-West (X) direction was calculated using the available data on current speed (m/s) and direction (degrees). The spatial variation in each of the two current directions (i.e. SD_X and SD_Y) was calculated for each grid cell by estimating the standard deviation of that cell and the 5 surrounding cells. Finally, the *average spatial variation in speed* was estimated by applying the Pythagorean equation on SD_X and SD_Y.

In shallow seas (<200 m) the tendency of a water column to thermally stratify can be quantified by the ratio between the total depth (h) and the cube of a measure of the tidal current amplitude (U), h/U^3 (Simpson and Hunter, 1974; Pingree and Griffiths, 1978). Tidal stratification, $log10(h/U^3)$, was found to be the best indicator of the probability of presence and abundance of individual marine apex predators (including harbour porpoise; Scott et al., 2010). *Tidal stratification* values were calculated over the whole study area using the depth data (resolution 50 m, see above) and the tidal velocities from the ADCP data (resolution 300 m). The *mean stratification* was also computed using the mean tidal velocities calculated from the ADCP data over one complete tidal cycle (Scott et al., 2010).

6.3.7 STATISTICAL MODELLING

The distribution of harbour porpoises and Risso's dolphins was modelled as a spatiotemporal Inhomogeneous Poisson Point process (IPP; Warton and Shepherd, 2010; Aarts et al., 2012). Under an IPP, the individual animals are treated as point observations in space and time. To quantify variations in density, these observations were contrasted with where and when animals could have been observed, taking into account the variations in effort. This was achieved by sampling uniform random within the survey area (up to the distance of the inflection point) at times when survey effort took place at the observation platform in question. Next, an infinitely weighted logistic regression (IWLR; Fithian and Hastie, in press) was fitted to the data. Here, the animal observations were treated as response of 1, and the contrasting availability points were treated as a response of 0. The variations in the response were modelled as a function of environmental variables. All potential explanatory variables were screened using histograms, dot plots (univariate) and scatter plots (bivariate) to determine distributions, detect outliers and identify co-linearity between variables. Where 2 variables were strongly collinear ($r \geq 0.8$), one was excluded from further analysis (Scott et al., 2010). Initial exploration of co-linearity between the proposed model covariates found high correlation ($r \geq 0.8$) between distance-from-coast and mean-stratification, radial-distance and mean-stratification, and also between tidal-stratification and current-speed. The predictor variables distance-from-coast, radial-distance and current speed were removed (as tidal-stratification and mean-stratification were considered to be the more biologically relevant variables; Scott et al., 2010; Embling et al., 2012).

The potential environmental covariates used in the model were a thin plate smooth (Wood, 2006) of mean- stratification, tidal stratification, day of year, hour of day, year, depth, slope, spatial variation in slope and spatial variation in current speed. The variables lunar cycle, tidal state, aspect and current direction are circular covariates, and therefore were included as cyclic cubic regression splines (type “cc” in the R-package mgcv). At the data extremes the estimated smooth function is identical up to the 2nd order derivate (Wood, 2006). Therefore the data points located around both extremes (e.g. for aspect 0 and 360 degrees) contribute to the estimation of the smooth function on either side. Here, we made the implicit assumption that each point in space is a unique habitat and we therefore included a tensor product smooth of X and Y coordinates (Bardsey Projection) in the model. Although, X and Y cannot have a direct causal relationship with the underlying process of habitat selection, they may correlate spatially with environmental variables that do. This tensor product smooth can therefore absorb large-scale residual spatial effects in the distribution of sightings that cannot be explained by the environmental variables included in the model. Furthermore, the inclusion of X and Y will also deal with any issues regarding unbalanced sampling effort although the IPP process also accounts for any differences in effort between the various observation points. Finally, sea state and viewing point were included as a factor variable because it was expected that these would affect the distribution of sightings.

Forward model selection was carried out using likelihood-based k-fold cross-validation (e.g. Matthiopoulos, 2003; Horne and Garton, 2006). All animal and control observations were grouped by day, and a model was fitted using all data, except for one day (i.e. the left-out data). Next the resulting model was used to predict for the left-out day and to estimate the corresponding likelihood. This was repeated for all *k* days and all variables. The model with the lowest overall cross-validation likelihood was retained for further analysis.

6.4 RESULTS

6.4.1 DETECTABILITY AND PRECISION OF MEASUREMENTS

We studied the effect of distance on the number of Risso's dolphin and harbour porpoise sightings by plotting accumulation curves which showed the proportion of total number of sightings within a given distance (Supplementary materials 6.S1 and 6.S2). It was also found that the accumulation curves for either Risso's dolphins or porpoises differed for observation platform C (C1 *vs* C2) and it was decided to treat these two survey sectors separately because of their different inflection points (Fig. 6.S1). The accumulation curves for both sectors (B1 and B2) covered from observation platform B were comparable and we concluded that data could be pooled. We then explored how the sea state was affecting the accumulation curve for both species (Fig. 6.S2). On the basis of the outcome of these investigations, we were able determine the distance (based on the defined inflection points) to which we assume that the number of sightings remained constant at each different sea state(Table 6.S1) for each of the different survey sectors (A, B, C-1, C-2 and D) and for both species.

The step-wise appearance of the accumulation curves and concentric circles in the distribution of Risso's (and to a lesser extend porpoise) sightings is most likely caused by the inaccuracy of the inclination and the angle measurements made using the reticule binoculars and the built-in compass (where rounding occurred to the nearest half reticule and the nearest degree). This step-wise appearance is to some extend reduced when accounting for the tidal amplitude which affects the observation height of platform and thereby the estimated radial distances to sightings. The distance measurements per 0.5 reticules are shown in Fig. 6.S3. It is evident that for larger distances the difference between two subsequent 0.5 reticule steps is large, however, within 1.5 km the difference is <100 m and within 1 km this is <50 m (Fig. 6.S3). Overall, the error was small for porpoises as the fast majority of sightings occurred at distances <1500 m (91% of all sightings) or <1100 m (70.3%). On average the location error was higher for dolphins, because the dolphins were typically sighted at greater distances (with 58% of dolphin sightings occurring at a distance > 1500 m).

6.4.2 EFFORT AND SIGHTING RATES

We used sea states 0-2 for any data analysis regarding dolphins and sea state 0-1 for porpoises and only included those porpoise observations made during sea state 2 up to the corresponding inflection points (Supplements). After filtering for sea state and taking into account the different inflection points, a total of 791 porpoise and 238 Risso's dolphin sightings were included in the data analysis with a total effort of 8262 scans of 10 minutes each (Table 6.1). Most effort was conducted from point D, not only because this site offered the most sheltered study area but also because this was the only look-out manned during those periods when only two people were stationed on the island. As such, this observation point collected the most data during July, whilst the other observation points had the majority of effort carried out in August and September (Table 6.1).

Table 6.1 Overview of different survey sites regarding height, sector coverage (size) and summary of systematic effort (number of 10-min scans) during sea states 0-2 with number of harbour porpoise and Risso's dolphin sightings relative to corresponding inflection points.

Survey site	**Site specifics Height (Size)**	**Effort (scans)**	**Harbour porpoise Sightings (animals)**	**Risso's dolphin Sightings (animals)**	**Effort July (Scans)**	**Effort August (Scans)**	**Effort September (Scans)**
A	17 m (110°)	900	62 (104)	0	155	531	214
B	17 m (2 x 90°)	887	16 (28)	33 (57)	107	475	305
C-1	37.5 m (110°)	805	28 (63)	174 (242)	124	300	381
C-2	37.5 m (90°)	1486	180 (371	22 (68)	262	601	623
D	60 m (115°)	4183	505 (856)	9 (33)	1227	2037	919
TOTAL		8261	791 (1422)	238 (400)	1875	3944	2442

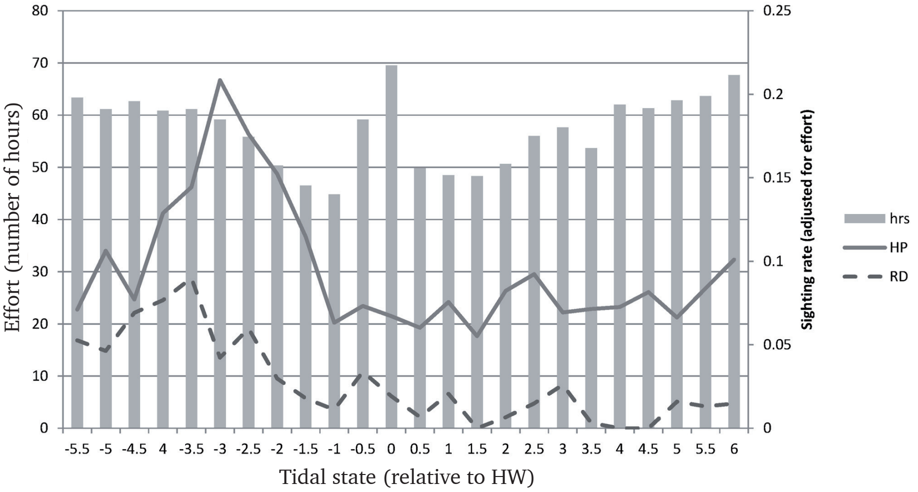

Figure 6.3 Hours of effort and sighting rates for different tidal states. HP = Harbour porpoise; RD = Risso's dolphin.

6.4.3 TIDAL CYCLE

For each tidal state more than 45 hrs of effort was carried out. The sighting rates for dolphins and porpoises (adjusted for effort) showed a peak at HW-3.5 and HW-3 respectively (Fig. 6.3). This is approximately one hour after Low Water Slack when the currents change direction from SE to NW. A smaller peak in sighting rate for porpoise is evident during the next slack water period (HWS: HW+1.5 until HW+2.5).

6.4.4 IDENTIFYING AREAS OF HIGH DENSITY

Kernel methods were used to analyse spatial clustering in the sightings data and the resulting 50 % density isopleth was selected to define the core-areas. From the kernel density percent volume contours it is evident that the survey area is not evenly utilised by both species (Fig. 6.4). The Risso's dolphins use a core-habitat to the West of the island, and this area is used both in August and September (Fig. 6.4). An area to the North of the Island (within Bardsey Sound) is also used in September (Fig. 6.4C). Harbour porpoises use a different area to that of Risso's dolphins, although there is a noticeable overlap where both species occur within the sound in September. The areas to the East of the Island, and also an area within the Sound, are identified as core-areas where porpoises regularly occur (Fig. 6.4D). In August, the majority of porpoises occur to the East of the Island (Fig. 6.4F). The area within the Sound is more pronounced in September but is located slightly closer to the shore (Fig. 6.4G). In addition, there is more porpoise activity in September to the West of the Island overlapping with the area where Risso's mainly occur. The 50 % kernel volume contour for porpoises to the East of the Island involved an area of 2.8 km^2 and in the Sound this was 0.9 km^2. For Risso's dolphins the core area involved an area of 2.6 km^2. These represent 19%, 6% and 8% respectively of the full survey area of 34.31 km^2 (for dolphins) and 14.6 km^2 (for porpoises).

Using the kernel density plots we checked to see if the occurrence of harbour porpoise and Risso's were correlated and found no evidence for this ($R^2 = -0.2309$), suggesting that the two species use the local spatial area in different ways. A Mann-Whitney U test also confirmed that the kernel density data were significantly different between the two species ($p<0.0001$).

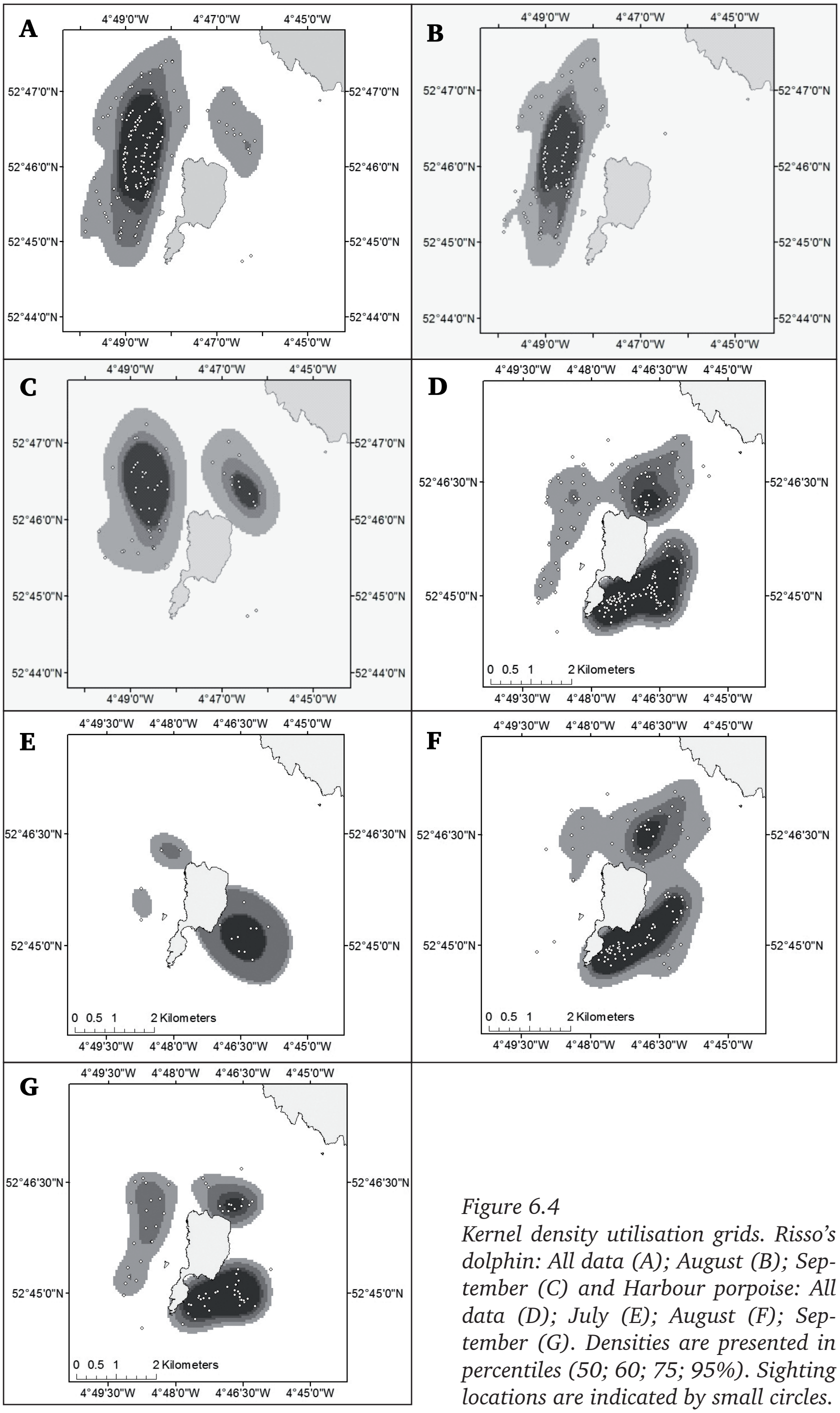

Figure 6.4
Kernel density utilisation grids. Risso's dolphin: All data (A); August (B); September (C) and Harbour porpoise: All data (D); July (E); August (F); September (G). Densities are presented in percentiles (50; 60; 75; 95%). Sighting locations are indicated by small circles.

6.4.5 HABITAT MODELLING

The final habitat model for harbour porpoises, selected through forward stepwise model selection, contained sea state, a spatial smooth of x- and y-coordinates, the observation site, lunar cycle, mean stratification, day of year, depth, aspect, tidal state and slope (Table 6.2). The model explained only 7.5% of the deviance in the observed variation in the response variable (Table 6.S2). Sea state was the most important variable and was retained first (table 6.S2). The parameter estimates for sea state 1 and 2 (relative to sea state 0), were -0.58 and -1.69, respectively (see Table 6.S2). This implies that the sighting rate under these conditions was 0.56 (i.e. $e^{-0.58}$) and 0.18 (i.e. $e^{-1.69}$) lower, compared to sea state 0. The spatial smooth of x and y coordinates was the second most important covariate to be retained, explaining more of the variation than any other spatial or temporal variable. The smooth of x and y coordinates absorbs any residual large scale spatial pattern in marine mammal sightings that cannot be explained by the environmental variables included in the model. The apparent significance of this covariate (based on model

Table 6.2 Forward variable selection based on models fitted to harbour porpoise data, based on the cross-validation log-Likelihood (CVLL). ΔCVLL is the change in CVLL by adding a (smooth of the) covariate. Sea state and Site entered the model as factor variables. "te(X,Y)" represents a tensor product smooth of X and Y coordinates (Bardsey projection). "s" represents a thin plate regression spline smoother (or cubic regression spline for cyclic smoothers, i.e. for the covariates Lunar cycle, aspect and tidal state). The best model contains all variables up to slope.

Covariate	**CVLL**	**ΔCVLL**
Sea State	-9645.54	
te(X,Y)	-9524.84	120.70
Site	-9421.26	103.58
s(Lunar cycle)	-9336.61	84.65
s(Mean stratification)	-9305.75	30.86
s(Day of year)	-9285.25	20.50
s(Depth)	-9267.39	17.85
s(Aspect)	-9252.76	14.64
s(Tidal state)	-9241.04	11.72
s(Slope)	**-9240.30**	**0.74**
s(Year)	-9241.38	-1.08
s(Hour of day)	-9249.61	-8.23

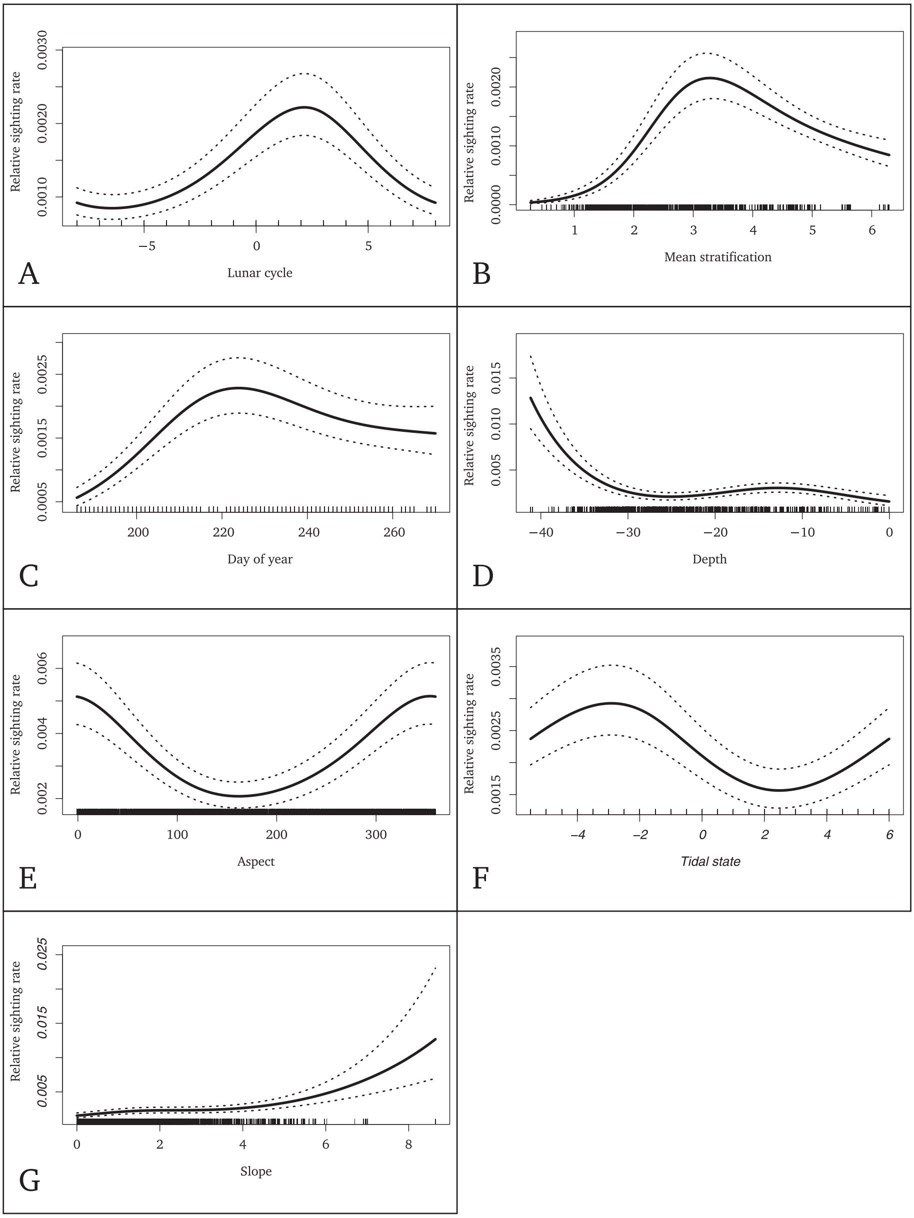

Figure 6.5 The estimated effect of environmental covariates on the observed harbour porpoise sighting rate. Predictions are made by varying the variable of interest (e.g. Lunar cycle in the first figure), but keeping the other values fixed at median values at which they occur in the model data.

selection), suggests that a biologically important variable that drives the porpoise distribution was not included this study.

The final selected model also indicated that porpoises were more frequently seen 2-3 days following neap tide (Fig. 6.5a), in areas with a relatively high stratification (3.3 $m^{-2}s^{3}$; Fig. 6.5b), and mostly in August (Fig. 6c). Depth was the 7th most influential variable, suggesting that the highest sighting rate occurred in areas of approximately ~14 m depth or depths exceeding 30 m (Fig. 6.5d). The perceived preference for increasing depths is mostly driven by a number of sightings in the deeper main channel. Finally, sighting rate was higher on NW facing slopes (Fig. 6.5e), around approximately 3 hrs before HW (Fig. 6.5f) and steeper slopes (Fig. 6.5g).

The final habitat model for Risso's dolphins, selected through forward stepwise model selection, contained observation site, sea state, spatial variation of current speed, hour of day, slope, depth, tidal stratification and aspect (Table 6.3). The model explained 19.7% of the deviance in the observed variation in the response variable (Table 6.S3). Observation site was the most important variable and was retained first (Table 6.S3). The parameter estimates for points B, C1 and C2 relative to sites where no dolphin sightings were made, were 2.3, 3.6 and 2.2, respectively (see Table 6.S3). This implies that the sighting rate from these observation sites was 9.99 (i.e. $e^{2.3}$), 36.6 (i.e. $e^{3.6}$) and 9.02 (i.e. $e^{2.2}$) higher, compared to sites where no sightings were made (e.g. Point A). The sea state was the second most important covariate to be retained. The parameter estimates for sea state 1 and 2 (relative to sea state 0), were 0.65 and -0.67, respectively (see Table 6.S3).

Table 6.3 Forward variable selection based on models fitted to Risso's Dolphin data. The best model contains all variables up to Aspect. For more details, see Table 6.2.

Covariate	CVLL	ΔCVLL
Site	-3036.86	
Sea State	-2953.44	83.42
s(SD of current speed)	-2906.52	46.92
s(Hour of day)	-2872.70	33.82
s(Slope)	-2855.48	17.22
s(Depth)	-2843.52	11.96
s(Tidal stratification)	-2834.70	8.83
s(Aspect)	**-2824.53**	**10.16**
s(SD of sloop)	-2840.46	-15.92
s(Current direction)	-2861.82	-21.36
s(Mean stratification)	-2892.66	-30.84
s(Tidal state)	-2927.68	-35.02

This implies that the sighting rate for sea state 1 and 2 was 1.91 (i.e. $e^{0.65}$) and 0.51 (i.e. $e^{-0.67}$) times the sighting rate during sea state 0.

This selected model indicated that Risso's dolphins were more frequently seen in areas with a low spatial variation of current speed (Fig. 6.6a). The dolphins were most frequently seen in the afternoon (2pm; Fig. 6.6b), in areas with a relatively steep slope (Fig. 6.6c). Depth was the 4th most influential variable, suggesting that the highest sighting rate occurred in areas of approximately ~25 m depth (Fig. 6.6e). The sighting rate for dolphins occurred in areas with a tidal stratification of ~2.7 m^{-2} s^3 (Fig. 6.6f) and on south-facing slopes (Fig. 6.6g). For illustrative purposes, Figure 6.S4 shows a visualisation of the predicted relative sighting rate for porpoises and dolphins.

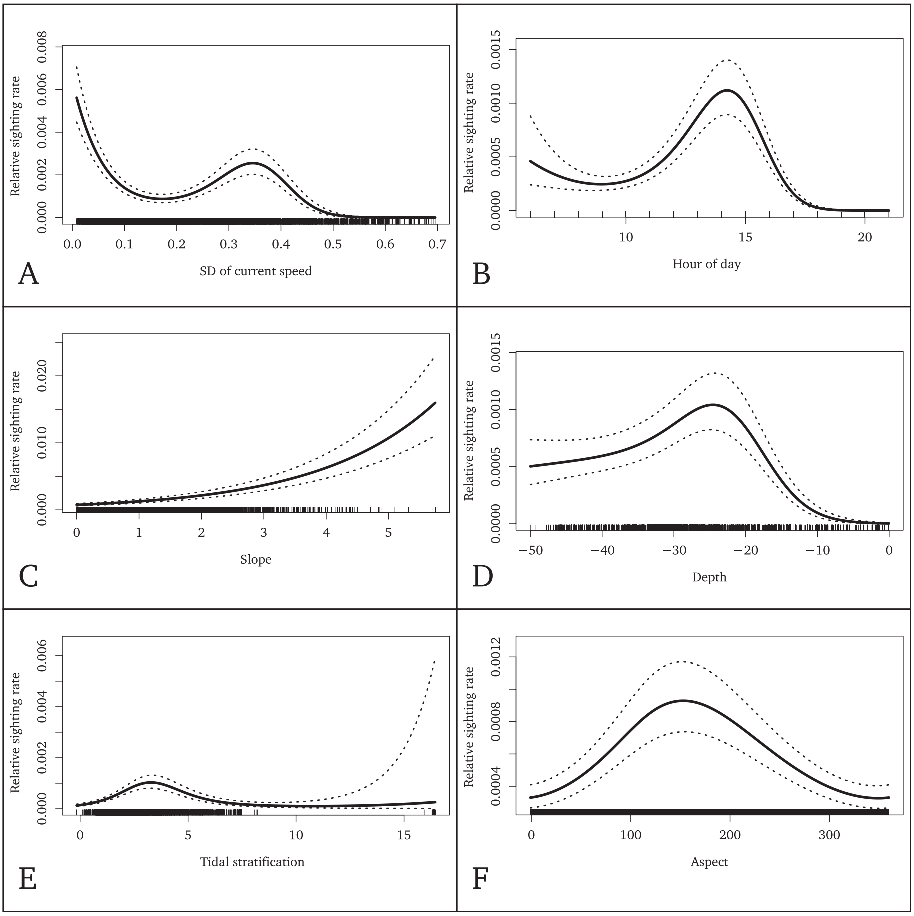

Figure 6.6 The estimated effect of environmental covariates on the observed Risso's dolphins sighting rate. See Figure 6.5 for more details.

6.5 DISCUSSION

This study showed that the Risso's dolphins and harbour porpoises in the waters surrounding Bardsey Island had different distributions and habitat-use patterns. We first used kernel density grids to determine the core areas for both species, an approach previously used to define important areas for cetaceans using satellite telemetry data (e.g. Johnston et al., 2005; Sveegard et al., 2011), boat-based data (e.g. Fury et al.,2012) and land-based data (Jones, 2012). The kernel grids showed that the two species use the local spatial area in different ways with Risso's dolphins mainly using a core-area to the West and porpoises mainly using a core-area to the East of the Island (Fig. 4). In addition, there is an area within the Sound where both species overlap in September. Secondly, we used GAMs to analyse the distribution of each species in relation to both dynamic cyclic and topographic variables. Dynamic cyclic variables (seasonal, diel/diurnal, tidal and lunar cycles) were clearly identified as important features that influence the fine-scale distribution of these species. Each species showed different preferences and these are discussed below.

6.5.1 HARBOUR PORPOISE

For the harbour porpoise, sea state explained most variability in sighting rate. Although there may a biological mechanism underlying this, it is most likely the consequence of sea state dependent detection probability. This effect seems relative substantial, with a 5 times lower probability of detecting porpoises during a sea state of 2 compared to 0. The fact that the porpoise presence was affected by sea state is consistent with other surveys (e.g. Evans and Hammond, 2004; Embling 2007, Marubini et al., 2009). The second most important variable was a smooth interaction between X and Y coordinates. Although a large number of spatial covariates were included in this study, this result implies that some process that drives the porpoise distribution is not included and that the other (physical) covariates are insufficient surrogates for this process. It is generally assumed that most relationships with such variables are indirect and are mediated through the habitat preferences of preferred prey species (e.g. Macleod et al., 2004). However, the direct relationship between predator distribution and its preferred prey may not necessarily be straight forward as might be anticipated for some species (MacLeod et al., 2013). Nevertheless, some direct links were recently shown in the Baltic Sea between porpoise distribution and their prey (Sveegaard et al., 2012a,b) but such data are difficult to collect at a fine-scale or temporal level.

The present study showed a relationship between topographic variables and porpoise distribution, involving depths with the highest sighting rate occurring in areas of approximately 14 m or > 30 m depth, and those areas with North-facing and steep slopes. In UK waters, cetacean-habitat relationships have been explored for porpoises, and depth has been successfully used to explain distribution patterns (e.g. Embling, 2007; MacLeod et al., 2007; Maribuni et al., 2009; Booth et al., 2013). Seabed slope has also been found to influence porpoise distribution (Bailey and Thompson, 2010; Embling et al., 2010; Isojunno et al., 2012). Porpoises in other studies showed a low preference for shallow (<20 m) waters (Northridge et al., 1995; Evans et al., 2003; Reid et al., 2003; Marubini et al., 2009; Embling et al., 2010; Isojunno et al., 2012) which is not consistent with our findings. The bottom topography in the area to the East of the Island demonstrates a small 'gully', with depths varying between 10 m and 20 m (Fig. 6.S6). Such areas probably act as a restricted channel and interrupt the water flow and therefore may create areas where zooplankton accumulates and where fish may shelter from strong currents (Gaskin and Watson, 1985). Similar observations were made of off Angelsey where an area of the flood race demonstrated particularly high relief with gullies with depths varying between 10 m and 30 m, and where porpoise presence was higher during flood (Calderan, 2003). Such areas may also form a natural trap where fish possibly get caught between the different dominating currents and this may be intensified by irregular bottom topography. For example, at HW-4.5 hrs the direction of the currents through the Sound is still SE. Because the Island is obstructing the general flow, some of the water passing south of the island rotates northward before decreasing in speed when LWS is reached. Such parallel 'streams of water' flowing in opposite direction were visible during the observations and in particular to the East and North of the Island and intensified until LWS.

Recently, studies that were carried out at a finer spatial scale, showed that tidal variables, such as tidal state, tidal speed or tidal height, also have an important influence on both the distribution (Marubini et al., 2009; Embling et al., 2010; Jones, 2012) and behaviour (Calderan, 2003; Johnston et al., 2005; Pierpoint, 2008) of porpoises. However, the preferred tidal phase or speed appears to vary across areas (Calderan, 2003; Johnston et al., 2005; Pierpoint, 2008; Marubini et al., 2009; Embling et al., 2010; Isojunno et al., 2012; Jones, 2012). For example, porpoises off West Scotland preferred areas with high current speeds and generally prefer high tide (e.g. Marubini et al., 2009), those occurring off Land's End (Cornwall) preferred strong ebbing tidal flows (Jones, 2012), off Skomer Island (South Wales) they preferred conditions when the tide started to ebb (Isojunno et al., 2012) and those in Ramsey Sound (South Wales) preferred the entire ebb tidal phase (Pierpoint, 2008). The porpoises presence in our study peaked at HW-3, which reflects the period just after LWS (during which the currents changed direction from SE to NW) at the onset of the flood cycle. These tidal currents rapidly build up in strength and ultimately may become too strong for porpoises to maintain a favourable foraging position. The porpoises however also appeared to take benefit of these strong currents and were frequently observed 'hitch-hiking the current' (traveling with fast speed following the tidal flow through the Sound).

Porpoise presence off West Scotland was found to be highest during slack phases of the tidal cycle (Embling et al., 2010) and off Anglesey (North Wales) at HW-3 (Calderan, 2003) which match our findings. The porpoises were probably moving between foraging areas during different tidal states on either side of the Sound. Land-based observations carried out from the Lleyn Peninsula showed that porpoises were foraging off the most westerly headland (M. de Boer, pers. obs.) but this is too great a distance to observe from Bardsey Island. In South Wales, porpoises have also been shown to move from either side of a channel during different tidal states (Pierpoint, 2008).

The majority of the porpoise calves were sighted to the East of the Island and mainly from point D (70% of all calves) whereas calves were less often encountered to the West (1% from points B and C-1; 15% from point C-2) and to the Southeast (14%). The waters to the East were more sheltered, areas of upwelling were visible and tidal races were not as pronounced compared to the West. From the ADCP data it is evident that this area has overall weaker currents (Fig. 6.2). Similar findings were reported off Ramsey in South Wales where female porpoises with dependent calves also preferred areas characterised by weaker currents (Pierpoint, 2008). Females may avoid areas where tidal currents are strongest because of a risk of separation from calves that might experience difficulty swimming against the tidal stream (Pierpoint, 2008). Indeed, the speed at which porpoises surfaced was mainly fast within Bardsey Sound where faster currents persisted whilst to the East of the Island porpoises were surfacing mainly slow.

The porpoises were more frequently seen at 2-3 days following neap tide. In order to reduce the number of covariates, we did not account for the fact that there are two neap tides and two spring tides within a single month and that these are different in terms of tidal ranges. As for tidal cycles, it seems that lunar phase preference also appears to vary across areas with higher densities of harbour porpoises predicted during spring tides off West Scotland (Embling et al., 2010) and off Vancouver Island (Canada; Hall et al., 2011) but no preferences for either spring or neap tides were apparent using acoustic data off Angelsey (Calderan, 2003).

The Irish Sea is generally mixed in winter, but in spring and summer a complex patchwork of mixed and stratified areas develops (Simpson and Bowers, 1981). As in most areas of the Irish Sea the tides are sufficiently energetic to mix and create a vertically homogeneous water column (Sharples, 2008). Areas where stratification occurs are those where increased water depths and weak tidal streaming prevent the generation of sufficient turbulent energy to maintain vertical mixing against the surface buoyancy flux in summer (Pingree and Griffiths, 1978). The fronts which mark the boundaries between mixed and stratified waters in summer are zones of enhanced primary production and they influence the distribution of plankton and zooplankton (Gowen et al., 2003), and may create preferred foraging sites for marine mammals (Scott et al., 2010). A tidal frontal system exists in the shallow Cardigan Bay area in summer although this is influenced by wind mixing (Pingree and Griffiths, 1978). Within stratifying regions, a tidal stratification value of 2.75 m^{-2} s^3 has been shown to represent the locations of fronts, separating permanently-mixed water from seasonally-stratified regions (Sharples, 2008). Values between 2.3 and 2.75 m^{-2} s^3 indicate regions that can switch between being mixed and stratified, depending on the phase of biweekly tidal currents; values between 2.75 and 3.5 m^{-2} s^3 are regions likely to see spring-neap impacts on sub-surface primary production within the thermocline and represent areas that always remain stratified in summer (Sharples, 2008). Although, the waters around Bardsey are expected to be unstratified due to the presence of strong tidal currents, it appears that in some areas the waters are stratified. Our findings indicated that porpoises were more frequently seen in areas with a stratification value of 3.3 m^{-2} s^3 which is similar to the findings reported for porpoises in a shallow area in the North Sea (3.56 m^{-2} s^3; Scott et al., 2012). Most notably, the porpoises showed a peak in sighting rate at 2-3 days following a neap tide. Coastal waters generally show a stronger stratification particularly during neap tides upon which the phytoplankton biomass at the surface rises (with the developing stratification) reaching its maximum about 2-3 days after neap tide (Sharples, 2008). It therefore appears that porpoises occur in those areas where stratification is maximized. As recently suggested by Scott et al. (2012) marine top predators are more likely to forage in different locations, defined to some extent by the level of stratification. *Log10* (h/U^3) is an inverse measure of tidal mixing normalised by the water depth (which explains some of the extreme values caused by current speeds that were equal to zero.

The porpoises in the present study were more frequently seen in August (Fig. 6.6c). Seasonal variation in harbour porpoise habitat preference and distribution within European waters are poorly understood. Peaks in sightings during the summer may be indicative of better survey conditions in those months, although significant variations in seasonal distributions have been observed in the southern North Sea, indicating that animals aggregate seasonally in ‘hot spots’ within their range (Gilles et al., 2011). Within the UK, August and September have been proposed as the months with peak numbers of porpoise encounters (e.g. Evans et al., 2003) which matches our findings. Seasonal migrations in this species have also been documented in other geographical areas such as the German Baltic Sea with increased use of coastal areas during the summer months (Siebert et al., 2006; Verfuß et al., 2007). Considering that habitat preferences are strongly linked to prey availability some changes might be related to the seasonal variations in diet (Santos et al., 2004).

6.5.2 RISSO'S DOLPHIN

The Risso's dolphins mostly preferred areas with relatively low spatial variation in current speed. The ADCP data revealed flow structures at slack water that were consistent with the formation of tidal eddies to the West of the Island during the flood cycle and to the East of the island during the ebb cycle (Elliott et al., 1995; Neil, 2008). This eddy overlaps with the core area for Risso's dolphins (Fig. 6.S5). It was expected that the presence of eddies and frontal areas would result in a preference of dolphins for areas with a high spatial variation in current speed but the opposite was found. This may be because the spatial and temporal resolution of the sightings or ADCP current sampling was insufficient. The kernel density plots showed that dolphins favoured the Sound during ebb (data not shown). Large areas with upwelling (slick domes of water on the surface) were frequently observed there. A higher sighting rate for dolphins occurred in areas with a tidal stratification of ~2.7 m^{-2} s^{3} which has been shown to represent the locations of tidal fronts, separating permanently-mixed water from seasonally-stratified regions (Sharples, 2008). At fine spatial scales, tidal frontal systems appear to enhance the primary productivity and it is recognised that these features may provide predictable concentrations of prey (e.g. Simard et al., 2002; Zamon, 2003).

The diet of Risso's dolphins consists primarily of cephalopods (e.g. Kruse et al., 1999). The lesser octopus *Eledone cirrhosa* has been predominantly found in the stomachs of Risso's stranded in Wales, Scotland and southern England (e.g. Clarke and Pasco, 1985; Atkinson and Gill, 1996). The lesser octopus has been recorded in waters depths of up to 700 m, but is most common in water depths between 50 and 300 m with peaks in occurrence between early summer to autumn (June – October), especially in inshore waters (Boyle, 1986). The region in the direct vicinity of Bardsey is relative shallow (0-50 m), and this would be at the upper range of the lesser octopus distribution. Risso's indeed avoid the very shallow regions (<20 m, see Fig. 6.6). It is interesting to note that the lesser octopus is a normal and regular predator of large crustaceans caught in commercial traps (Boyle, 1986). This might explain the multiple observations of Risso's dolphins foraging in the vicinity of lobster pots set off the NW point off Bardsey. Sports fishermen fishing within the Risso's core-area whilst dolphins were present, also reported catching octopus (pers obs). However, MacLeod et al., (2013) did not find a relationship between Risso's dolphin occurrence and a model-based estimate of the distribution of the lesser octopus, but the spatial resolution of the study may have been insufficient. Risso's may exploit very small patches (< ~10 m in size) of suitable prey habitat which is beyond the resolution of most studies (including MacLeod et al., 2013).

This study shows that Risso's were more often observed in the late afternoon. Currently, little is known about the Risso's diel activity patterns and descriptions of their seasonal and inter-annual movement patterns in UK Waters. Cetacean studies off California indicated that Risso's dolphins show variable behavioral states during the day and probably forage at night (Shane, 1995). A significant diel pattern was also shown in the echolocation activity of Risso's dolphins in the Southern California Bight (Soldevilla et al., 2010) and Risso's dolphins off the Azores were mainly resting in the morning and in the afternoon (Visser et al., 2011). The Risso's dolphins in the present study were often seen spread out over a wider area with single or pairs of animals conducting long dives, which is indicative of foraging.

Risso's dolphin sightings indicate possible year-round residency off NW Scotland. However, sightings are more frequent in this region over the summer and autumn months (Atkinson and Gill, 1996) but it is likely that the available datasets are biased by much greater survey effort in summer. Off Southern California, the seasonal and inter-annual variabilities in Risso's dolphin occurrence were high with a peak occurrence in autumn of most years (Soldevilla et al., 2010). Year-round residency and inshore or offshore movements in response to warm and cold waters has been reported for this species off California (Dohl et al., 1981). In the present study no Risso's dolphin sightings were made in July but seasonality was not selected as an influential variable in the model. A possible explanation for this is the relative low coverage of the C-1 and B study areas during July (largely due to unfavourable sighting conditions; Table 6.1). Risso's dolphins may have been present but were actually not observed. Incidental boat-based records do exist for Risso's dolphins off Bardsey in the month of July but generally more sightings are recorded in August and September (De Boer et al., 2013).

The highest sighting rate occurred in areas of approximately ~25m depth but the dolphins were also observed in waters as shallow as 7 m. Similar observations with Risso's occurring in shallow waters were reported off NW Scotland (<30 m; Gill et al., 1997). Risso's dolphins are usually found in deeper waters (1000 m; e.g. Cañadas et al., 2002; Bearzi et al., 2010) and in less deep waters of the continental slope (Praca and Gannier, 2007). Risso's dolphins off the Azores are more frequently sighted in waters of 600 m (Pereira, 2008), whilst most dolphin sightings off Scotland occurred in <200 m depth (Weir et al., 2001). In this study, the dolphins preferred areas with steep South-facing slopes. Other studies (Mediterranean and Azores) also confirm the preference for steep slopes (e.g. Cañadas et al., 2002; Praca and Gannier, 2007; Bearzi et al., 2010).

6.6 CONCLUSIONS

Knowledge about the habitat selection of cetaceans and the biological and physical variables that underpin this selection is important to interpret their distribution patterns. Such information is relevant for designing measures to reduce impacts of present and future anthropogenic activities including the creation and management of protected areas (Hoyt, 2011). An importance aspect of habitat models involves the identification of important habitat variables, the prediction of a species' distribution patterns and areas that show high levels of usage. This has been used for different cetacean species in areas which were surveyed at a larger scale (e.g. Panigada et al., 2008; Hammond et al., 2013). Preference for short-lived, yet predictable, oceanographic features may go unnoticed in large-scale surveys that visit a given area only briefly. It is therefore also essential to model their habitat selection based on more continuous data and if possible include multiple years/ seasons in order to understand the fine-scale temporal patterns that drive the distribution of a species. The key drivers in the habitat selection, however, remain unclear for most cetaceans, as the fine-scale changes in their habitat use have not been examined. In some cases, line-transect surveys have been carried out over a smaller area and over a number of years or seasons and this already provides more information regarding the relations between cetaceans and tidal variables (e.g. Johnston et al., 2005a,b; Skov and Thomsen, 2008; Marubini et al., 2009; Embling, 2010). Recently, Isojunno et al. (2012) explored the use of temporally intensive data derived from Platforms of Opportunity in order to achieve a better fine-scale precision to study porpoises. Only a few studies have used land-based data on cetaceans in order to investigate their habitat-use (Mendes et al., 2002) and using GLMs (Hastie et al.,2005) or GAMs (Jones, PhD-thesis). The present study used a fine-scale repeated/continuous land-based survey design and GAMs to provide a temporal insight into the importance of dynamic cyclic patterns on the fine-scale spatial distribution of two different cetacean species.

Our findings show that porpoises and Risso's dolphins appeared to be integrally linked to dynamic cyclic variables with both species using different core areas on a temporary but predictable basis. Other studies have also found that different cetacean species, e.g. minke whale and harbour porpoise, may use the same fine-scale 'island wake' feature, but with both species using different aspects of that feature (Johnston et al., 2005a,b). The measure of tidal stratification was shown to be important with porpoises occurring in areas when stratification is maximized and dolphins using a different habitat which was less stratified. The prime conditions for foraging in these tidal stratified systems appeared to be related to the flood cycle (LWS and the onset of the flood phase). The number of porpoises furthermore peaked following a few days after the neap tidal phase (first and third quarter moon). This temporal variability implies that porpoises move between the Bardsey Island region and other areas. Single large scale surveys may not capture such spatiotemporal patterns.

Our conclusion is that by using a fine-scale repeated survey design together with ADCP data, we identified patterns that drive the patchy distribution of porpoises and Risso's dolphins in a shallow Island system. The links between harbour porpoise and Risso's dolphin distribution and topographic and dynamic cyclic variables has not been previously documented. In particular involving the variety of variables included in the present model, and beyond the resolution of most studies. Such dynamic patterns may form the initial basis for identifying potentially critical habitats for these species within relatively shallow coastal systems. The information provided on how environmental characteristics determine a critical habit serve as a blueprint for studies carrying out Environmental Impact Assessment studies related to planned anthropogenic activities in areas where cetaceans occur. Particularly, the expansion of marine renewable-energy developments, such as wind turbines, wave-power devices and tidal turbines, may negatively affect cetaceans in a variety of ways and often operate at a fine-spatial scale (e.g. Simmonds and Brown, 2010).

6.7 ACKNOWLEDGEMENTS

This work would not have been possible without the help of all the volunteers and the Whale and Dolphin Conservation (WDC) staff. Special thanks go to Jo and Trevor Clark, Pine Eisfeld, Simon Keith, Lucy Molleson, Nicola Hodgins, Rob Lott and Joanna Wharam. Many thanks also to Steve Stansfield (Bardsey Island Bird Observatory) and Megan Morgan-Jenks (Friends of Cardigan Bay). We thank Colin MacLeod for analytical advice on the kernel analysis.

6.8 SUPPLEMENTARY MATERIAL

6.8.S1 SINGLE SPECIES APPROACH

We studied the effect of distance on the number of Risso's dolphin sightings by plotting the accumulation curve which showed the proportion of total number of sightings within a given distance for the lower observation points (A+B) and compared these to the higher points (C+D). As expected, the inflection point for the higher platforms differed (2.8 km) to that for the lower ones (2.2 km; Fig. 6.S1). It was also found that the accumulation curves for Risso's differed for point C (C1 *vs* C2) and it was decided to treat these two survey sectors separate because of their different inflection points (Fig. 6.S1). The accumulation curves for both sectors (B1 and B2) covered from point B were comparable and we concluded that data could be pooled (figures not shown). Similar results were found for porpoises (Fig. 6.S1).

We then explored how the sea state was affecting the accumulation curve for both species. It is evident that for dolphins the sea states 0-2 followed a similar accumulation curve but that this differed for sea state 3 (Fig. 6.S2). We therefore only include sea states 0-2 for any further data analysis regarding dolphins. One might argue that the accumulation curve for sea state 2 for porpoises does not quite follow a similar curve compared to lower sea states however for sea state 3 this is more pronounced (Fig. 6.S2). For the higher points (C+D), we concluded to pool all porpoise sightings made during sea states 0-1 up to the defined inflection point but only to include those observations made during sea state 2 up to the corresponding inflection point. The distance (based on the defined inflection points) to which we assume that the number of sightings remained constant are listed in Table 6.S1 for each of the different survey sectors and for both species.

6.8.S2 INTER-SPECIES COMPARISONS

For point C1 and C2 we noticed a different accumulation curve (Fig. 6.S1) and this indicated that the two sectors potentially differ in physical habitat. It seems likely that the relatively narrow and deep channel (Bardsey Sound) is responsible for this difference as the inflection point for both Risso's dolphins and porpoises is noticeably shorter for C2. There is also a difference in detection between both species for point D, with a much higher inflection point measured for Risso's dolphins compared to porpoises, however, however, this is based on a low sample size of dolphins (data not shown).

Table 6.S1. Inflection points defined for different sea states (SS) for Risso's dolphins (RD) and harbour porpoises (HP).

Species	Survey-site	SS 0	SS 1	SS 2	SS 3	SS 0-2
RD	A	n/a	n/a	n/a	n/a	2.167[a]
HP	A	n/a	1.092	1.053	n/a	1.053
RD	B(B1+B2)	n/a	2.216	2.167	n/a	2.167
HP	B(B1+B2)	2.253	1.552	1.318	0.982	1.318
RD	C1	2.765	2.772	2.725	0.847	2.765
HP	C1	2.052	2.052	2.052	n/a	2.052
RD	C2	n/a	2.33	2.237	n/a	2.33
HP	C2	2.382	2.382	1.323	0.815	2.382 (SS 0-1); 1.323 (SS 2)
RD	D	n/a	2.054	n/a	n/a	2.765[b]
HP	D	1.817	1.478	1.329	1.053	1.478 (SS 0-1); 1.329 (SS 2)

[a] due to low sample size this is based on point B; [b] due to low sample size this is based on point C.

Table 6.S2 Model summary harbour porpoise habitat selection model.

Parametric coefficients				
	Estimate	**Std. Error**	**Z value**	**Pr(>|z|)**
(Intercept)	-7.05852	0.15813	-44.636	< 2e-16 ***
factor(SEA)1	-0.58310	0.07978	-7.309	2.69e-13 ***
factor(SEA)2	-1.68900	0.09211	-18.337	< 2e-16 ***
factor(SITE.NAME)A	-0.15776	0.21456	-0.735	0.46216
factor(SITE.NAME)B	-1.64830	0.60852	-2.709	0.00675 **
factor(SITE.NAME)C_1	0.99233	0.50384	1.970	0.04889 *
factor(SITE.NAME)C_2	3.10403	0.31498	9.855	< 2e-16 ***
Approximate significance of smooth terms				
	Edf	**Ref.df**	**Chi.sq**	**p-value**
te(xuk,yuk)	13.546	14.322	285.84	< 2e-16 ***
s(LUNAR)	1.958	1.999	137.13	< 2e-16 ***
s(mean_stratification)	2.964	2.999	67.93	1.18e-14 ***
s(yday)	2.900	2.992	63.46	1.06e-13 ***
s(depth)	2.919	2.994	50.72	5.57e-11 ***
s(aspect)	1.966	1.998	53.72	2.16e-12 ***
s(HW.TIDAL)	1.943	1.998	57.31	3.58e-13 ***
s(slope)	2.706	2.940	19.25	0.000226 ***

R-sq.(adj)= -0.353; Deviance explained = 7.51%; UBRE score = 0.20401;Scale est. =1; n = 17305 (Wood, 2006)
*[*]Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

Table 6.S3 Model summary Risso’s dolphin habitat selection model.

Parametric coefficients				
	Estimate	**Std. Error**	**Z value**	**Pr(>|z|)**
(Intercept)	-11.1936	0.3045	-36.766	< 2e-16 ***
factor(SITE.NAME)B	2.2585	0.2471	9.141	< 2e-16 ***
factor(SITE.NAME)C_1	3.6032	0.2207	16.327	< 2e-16 ***
factor(SITE.NAME)C_2	2.1870	0.2257	9.691	< 2e-16 ***
factor(SEA)1	0.6553	0.2421	2.707	0.00679 **
factor(SEA)2	-0.6697	0.2588	-2.588	0.00966 **
Approximate significance of smooth terms				
	edf	**Ref.df**	**Chi.sq**	**p-value**
s(sd_speed)	2.973	3.000	70.58	3.20e-15 ***
s(hour)	2.973	2.999	117.61	< 2e-16 ***
s(slope)	1.000	1.001	76.71	< 2e-16 ***
s(depth)	2.935	2.996	34.17	1.82e-07 ***
s(tidal_stratification)	2.891	2.993	38.69	2.00e-08 ***
s(aspect)	1.911	1.996	28.83	5.45e-07 ***

R-sq.(adj) = -0.456; Deviance explained = 19.7%; UBRE score = -0.6;Scale est. =1; n = 14876

*Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

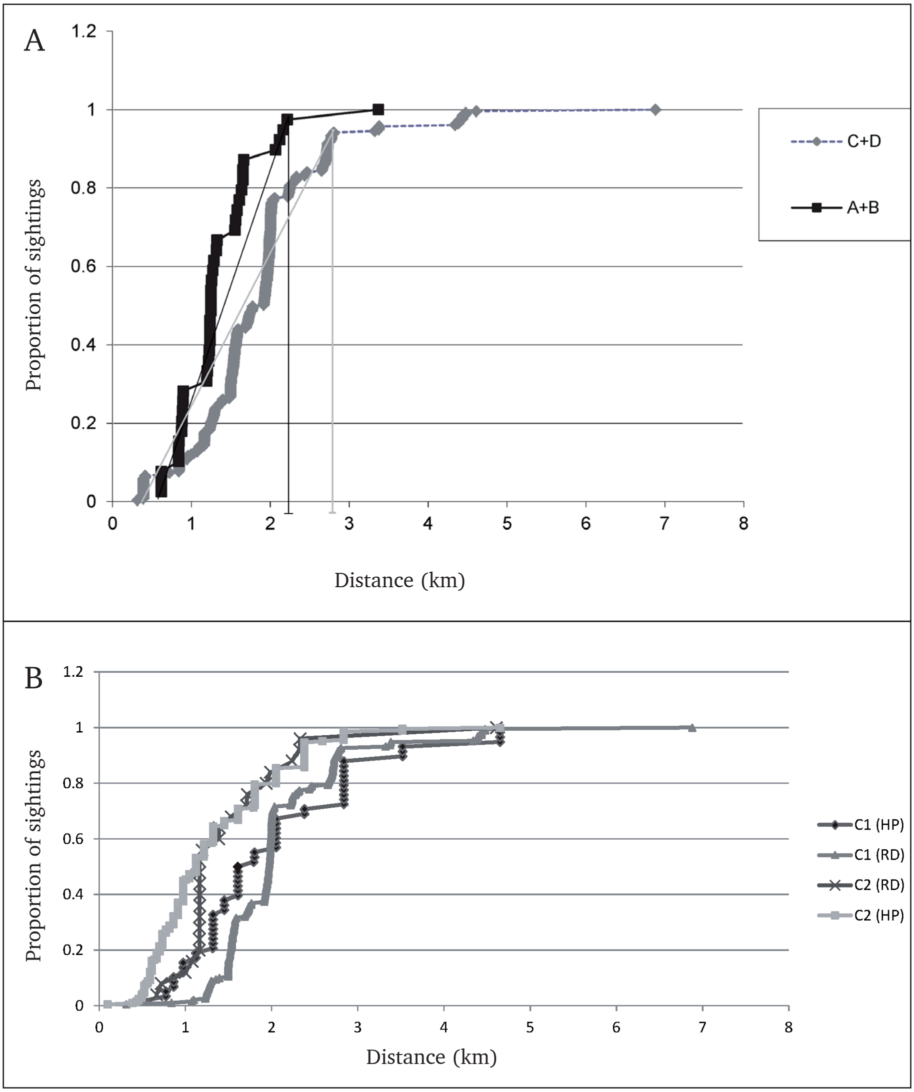

Figure 6.S1 Accumulation curves plotted using different sightings data. Sightings data for Risso's dolphins pooled for lower (black) vs higher points (grey) is shown at the top with parallel lines showing an indication of corresponding inflection points. The bottom plot shows the differences in curves between the two sectors surveyed from point C (C1 vs C2) for harbour porpoise (HP) or Risso's dolphin (RD).

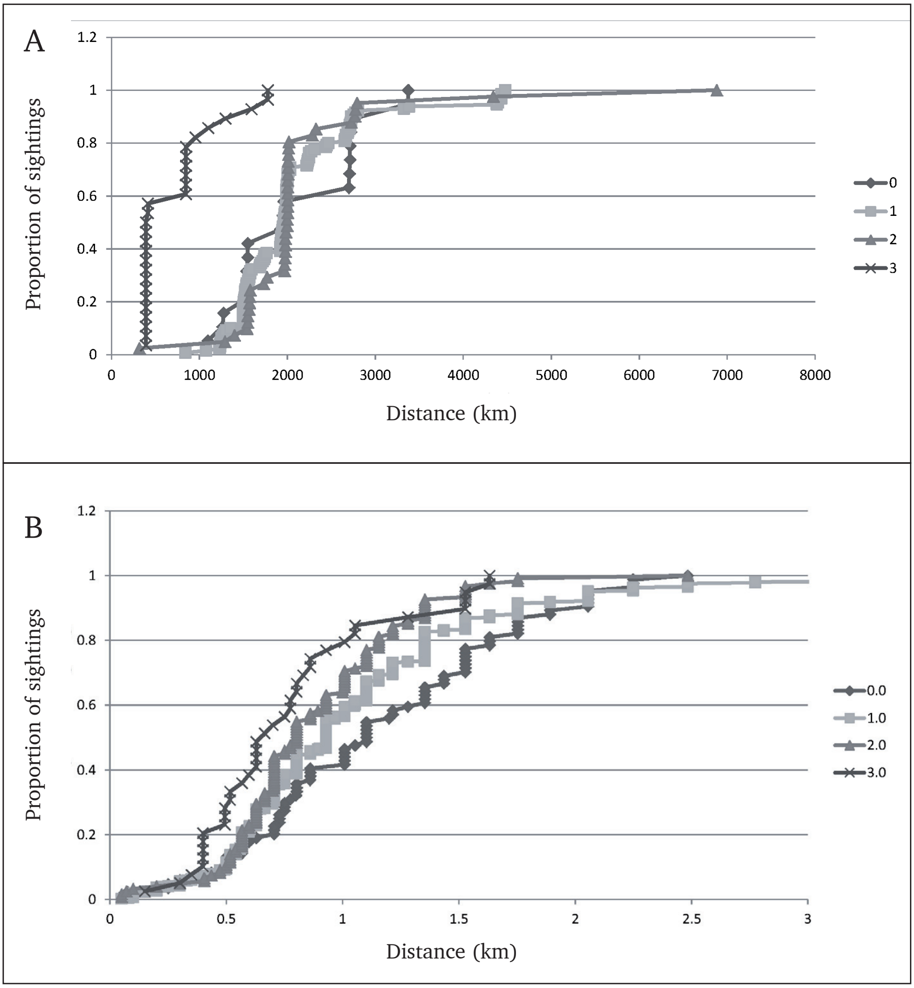

Figure 6.S2 *Examples of accumulation curves plotted using sightings data collected during different sea states (ranging from 0 to 3). Sightings data for Risso's dolphins for point C1 (A) and harbour porpoises for point D (B).*

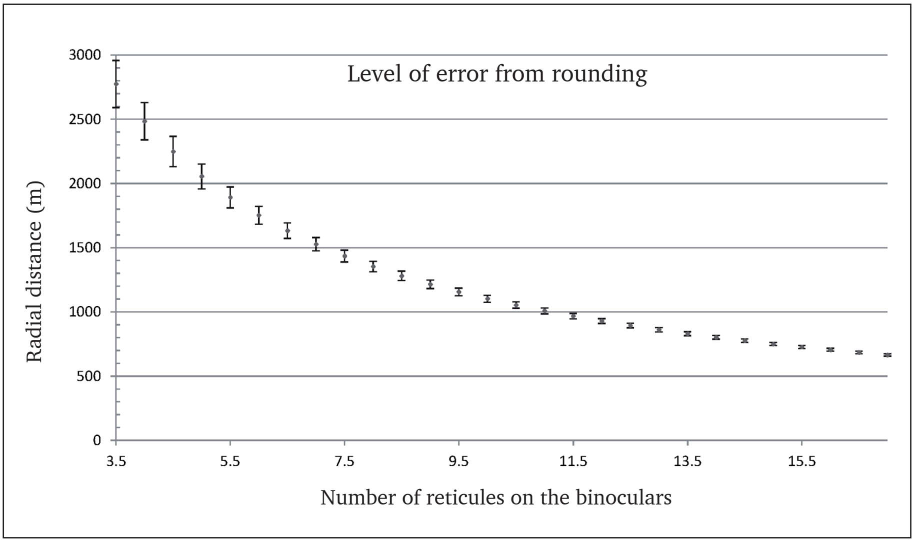

Figure 6.S3 The level of error from rounding to the closest half reticle as measured with the binoculars shown for a radial distance of up to 2800 m (the inflection point for the C-1 study area) .

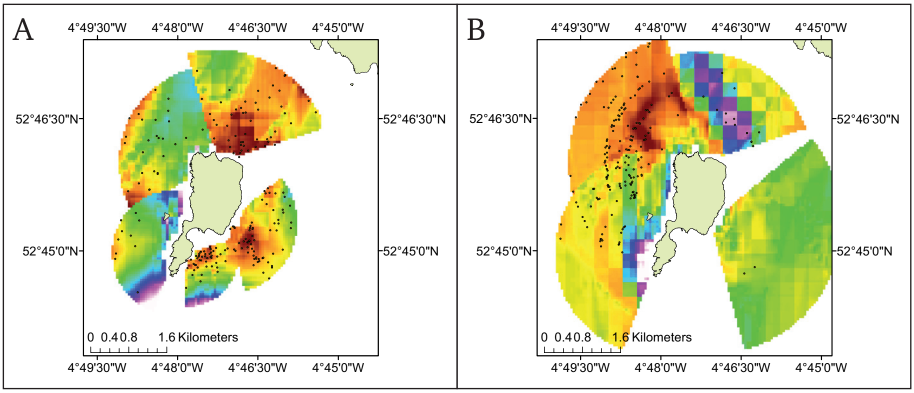

Figure 6.S4 Visualisation of the predicted relative sighting rate per unit area and time for the harbour porpoise (A) and Risso's dolphins (B). Model predictions are based on the best model fitted to all data (see also table 6.S2 and 6.S3). The values range from high to low, respectively red, yellow, green, cyan, blue, magenta.

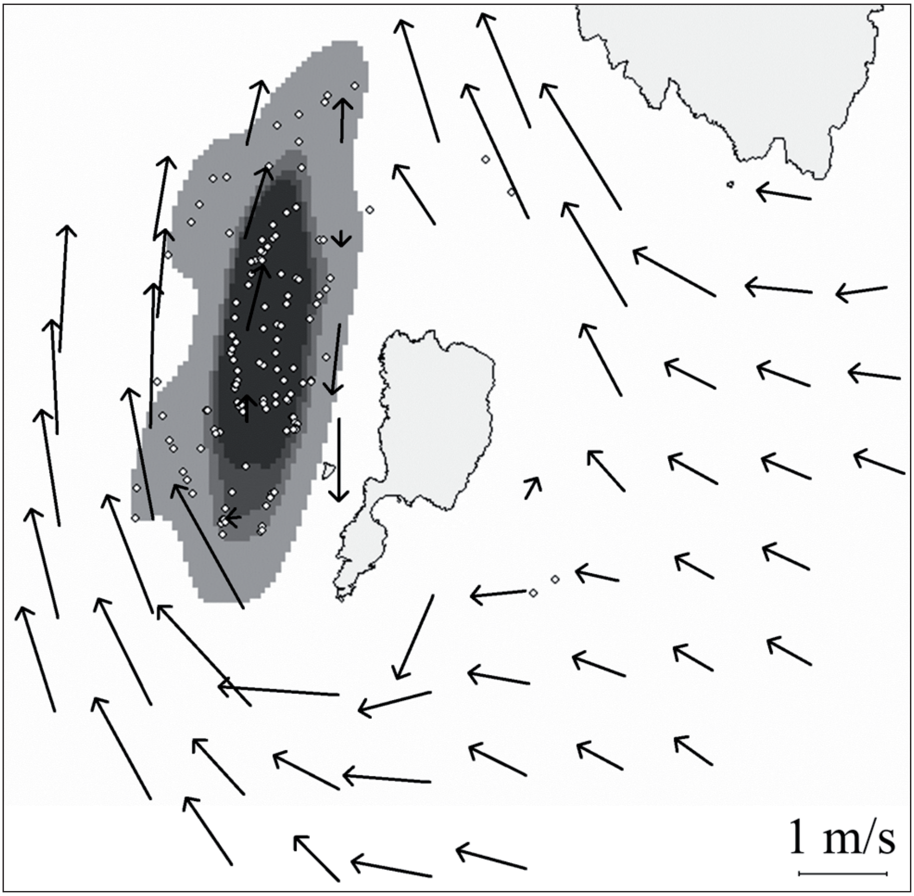

Figure 6.S5 Kernel density utilisation grid for Risso's dolphin during flood and sighting positions (circles) in relation to a simulated tidal eddie during flood, indicate the direction and strength of the currents, darkest shade of grey shows the 50% kernel core-area. Information regarding currents and eddies were derived from Neil (2008).

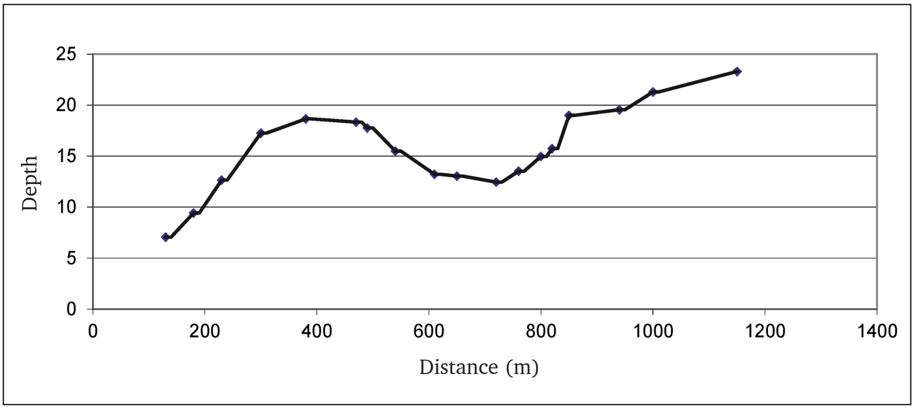

Figure 6.S6 Depth profile to the East of Bardsey showing a small 'dip' or 'gully'.

CHAPTER 7

CETACEAN DISTRIBUTION AND RELATIVE ABUNDANCE IN OFFSHORE GABONESE WATERS

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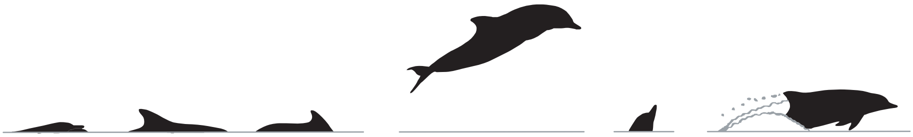
Atlantic spotted dolphin



7.1 ABSTRACT

Information on cetaceans off Gabon in tropical West Africa is summarised from boat-based surveys carried out between 7 March and 7 August 2009. Thirteen cetacean species were positively identified comprising two baleen whale species, one sperm whale species (*Physeter macrocephalus*) and ten species of delphinid. Bryde's whale (*Balaenoptera brydei*) and humpback whale (*Megaptera novaeangliae*) were the most frequently encountered species. Cetaceans were found throughout a range of sea surface temperature between 20.5°C and 27.5°C and a wide range of depths with the majority of effort and sightings occurring seaward of the shelf break. Of particular interest from the study were the following: (1) Gabonese waters have a broad cetacean diversity, especially with a large and diversified delphinid community in the northern part of the study area; (2) the variations in oceanographic conditions within Gabonese waters are likely to result in a temporal variation in species composition; (3) the sightings of Atlantic spotted dolphin (*Stenella frontalis*) are the first at-sea sightings confirmed for these waters, although not unexpected given their distribution and abundant presence in surrounding waters; and (4) the poorly known Clymene dolphin (*Stenella clymene*) was sighted on four occasions in deep oceanic waters and was the most abundant cetacean. These are the first confirmed records of Clymene dolphins in Gabonese waters.

7.2 INTRODUCTION

The West Africa region has a diverse marine mammal fauna (Perrin and Van Waerebeek, 2007; Weir, 2010), however relatively little is known about cetacean ecology in the area extending from the Gulf of Guinea south towards Angola (Jefferson et al., 1997; Hoyt, 2005; Weir, 2010). The Gulf of Guinea and coastal waters of central Africa were a focus of commercial whaling activity (Townsend, 1935) with catches being made in Gabon until 1959 (Budker and Collignon, 1952). A humpback whale research project that began in 2000 has greatly increased the knowledge of cetaceans occurring in the inshore waters (Rosenbaum and Collins, 2004).These surveys indicate that the coastal waters of Gabon represent an important breeding habitat for southern hemisphere humpback whales (Rosenbaum and Collins, 2006; Collins et al., 2008). Published information on the distribution and abundance of other cetacean species occurring off Gabon is however limited, particularly in deep water areas. Findlay et al. (2006) reported the occurrence of seven species of large whales (six mysticetes and the odontocete sperm whale) in Gabonese waters. The occurrence of six cetacean species was recently reported for São Tomé and Príncipe located in the Gulf of Guinea at the same latitude as the northern Gabonese coast (Picanço et al., 2009). In a recent review, Weir (2010) listed a total of 17 species recorded in Gabon with the majority of information compiled from stranded specimens, captures (deliberate and accidental catch in fisheries) and incidental sightings (Jefferson et al., 1997; Perrin and Van Waerebeek, 2007).

The paucity of information on cetaceans in central West African waters suggests a need for research to study the distribution and abundance of cetaceans and also to study their threats (Perrin and Van Waerebeek, 2007). The main purpose of this paper is to contribute information on the distribution and relative abundance of cetaceans sighted during a geophysical survey in Gabonese waters and where possible to relate the occurrence of different species with oceanographic parameters such as sea surface temperature (SST) and depth.

7.3 MATERIALS AND METHODS

Cetacean surveys were carried out in Gabonese waters (0° 33'S-05° 26'S and 07° 02'E-010° 43'E) between 7 March and 7 August 2009. A geophysical seismic survey vessel, the *CGG Venturer* was used to collect data on cetaceans, and as such acted as a Platform of Opportunity. The study area was situated to the southwest of Port Gentil, and consisted of a northern (North of 3° S) and southern sector (South of 3° S; Fig. 7.1). The area extended between 25-130 nmiles off the coast. There were a total of three different survey periods which differ in methodology.

7.3.1 MAIN SURVEY

Dedicated cetacean observations were carried out between 5 May and 12 July 2009 (Table 7.1). An experienced observer searched for marine mammals from the flying bridge deck (12.5 m) or from the monkey island (14.5 m). Periods of dedicated watches for cetaceans were conducted during all daylight hours (12.5 hours) for the duration of the dedicated survey period. Cetacean data were collected in an opportunistic manner, with the distribution of the survey effort determined by the geophysical survey work and where the vessel did not deviate from the track-line when a sighting was made. The observer scanned predominately with the naked eye but used binoculars (7 x 50 and 8 x 43) for searching the horizon, aiding species identification and group-size estimations. Searches included a 180° arc ahead

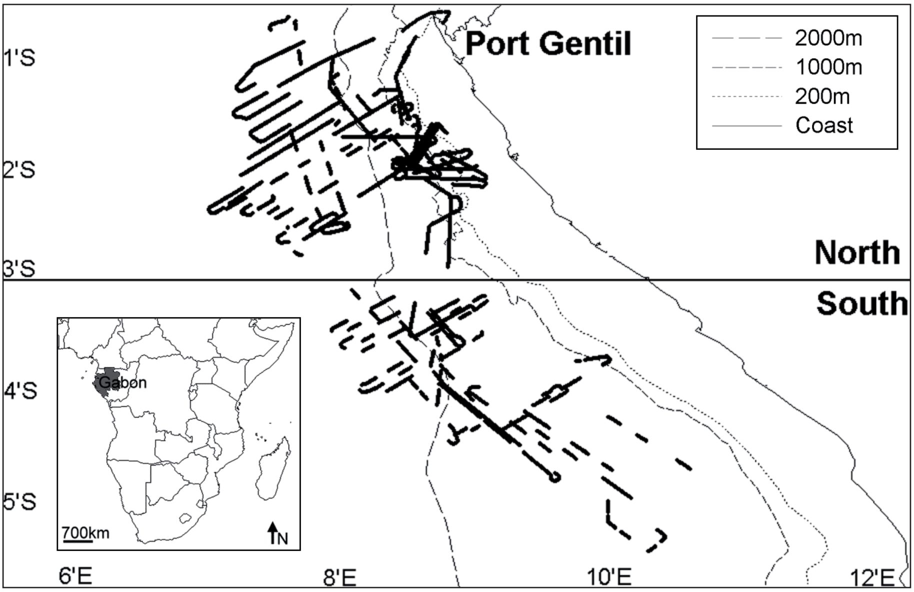


Figure 7.1 Distribution of survey effort (thick black lines) during the main survey (7 May – 12 July 2009)

Table 7.1 Extent of visual survey effort in hours (hr) and minutes (mm) during the main and additional[1] surveys in the northern and southern sectors between 7 March and 7 August 2009.

Survey sector	Survey period	Hours of Effort (hr:mm)	Effort (km)
North	27 May - 28 June	235:55	1878
	4 -12 July	102:05	839
	Total	*338:00*	*2717*
South	7 March – 3 May[1]	294:30	-
	7 - 26 May	108:39	959
	28 June - 3 July	65:15	433
	24 July - 7 August[1]	77:10	-
	Total	*545:34*	*1392*
Total area	27 May -12 July	511:54	4109
	7 March -3 May[1]	295:30	-
	24 July - 7 August[1]	77:10	-
	Total	*884:34*	*4109*

of the vessel with occasional scans of 360°. Once a sighting was made the radial sighting distance to a sighted cetacean was determined using reticule binoculars or person-specific range-sticks. The bearing to the sighted animals and their heading were determined using an angle-board. Sightings data also included the time (GMT), GPS position, water depth, species identification, the presence of calves and/or juveniles, school size (maximum, minimum and best), travel mode (slow, moderate or fast), group composition and behaviour. Environmental data recorded included: wind speed and direction, visibility, swell height, Sea Surface Temperature (SST) and Beaufort sea state (BSS). Ship's position, speed and course were continuously logged.

7.3.2 ADDITIONAL SURVEYS

Two additional cetacean surveys were carried out during which the author was not present (7 March-4 May 2009 and 24 July-7 August 2009) and watches were not maintained as rigorously as those described above. Observers involved during the additional surveys had previous experience of conducting cetacean surveys in tropical waters. The data regarding the ship's position, speed and course were not continuously logged, however, information was provided regarding the hours on watch. Cetacean sightings reported 'off effort' were regarded as incidental.

7.3.3 DATA ANALYSIS

Cetacean sightings reported 'off effort' and with a BSS >4 were regarded as incidental. Identifications included an associated 'degree of certainty' that ranged between definite (100%), probable (75%) and possible (50%). Where possible, animals were photographed to confirm identification using a Sony Single Lens Reflex (SLR) camera and 70-200 mm (f2.8) Sigma zoom lens. The species identification provided by observers was checked and verified using written descriptions and photographs. Animals too distant from the vessel to allow definite identification (>1 km for small dolphins such as *Stenella/Delphinus*) were classed as dolphin species.

7.4 RESULTS AND DISCUSSION

During the main survey, a total of 512 observation hours over 4109 km were carried out in good conditions (BSS 0-4 and visibility >5 km; Table 7.1). A total of 373 observation hours was carried out during the additional surveys. The water depth ranged between approximately 50 m and 4000 m with the vast majority (65%) of searches made in deep waters of ~2500 m. SSTs in the Eastern Gulf of Guinea generally vary between 27°C and 29°C, however they can drop to less than 22°C off the coast between July and September (Findlay et al., 2006). SSTs recorded during this survey were highest during early March (28.5°C) and lowest in July and early August (20.5°C). The vessel was in seismic operation for 61 % of the main survey and data presented here are potentially influenced by unknown reactions of cetaceans to air gun operations.

Table 7.2 (For caption see next page)

Species	**Sightings Main survey**		**Sightings Additional surveys & Incidental sightings**		**Relative Abundance**	**Mean water depth (all sightings)**	**Mean SST (all sightings)**
	S	**I**	**S**	**I**	**(I/100 km)**	**(m)**	**(°C)**
Bryde's whale *Balaenoptera brydei*	9	10	0	0	0.24	1690 (SD 1037) 651-3382	23.4 (SD 2.85) 21.5-27.5
Humpback whale *Megaptera novaeangliae*	7	29	5	7	0.71	1717 (SD 1517) 41-3715	22.6 (SD 0.90) 20.5-23.5
Baleen whale	3	3	1	1	0.07	2404 (SD 525) 1809-3065	24.8 (SD 3.1) 21.5-27.5
Sperm whale *Physeter macrocephalus*	3	10	7	19	0.24	2638 (SD 932) 515-3593	25.2 (SD 2.1) 23.5-27.5
Beaked whale sp.	1	1	1	1	0.02	2062 (SD 336 1825-2300	23.5
Killer whale *Orcinus orca*	0	0	1	4	0.00	879	20.5
Short-finned pilot whale *Globicephala macrorhynchus*	2	11	1	10	0.27	1586 (SD 908) 685-2500	22.5 (SD 2.83) 20.5-24.5
Melon-headed whale *Peponocephala electra*	0	0	1	2	0.00	1426	20.5
Risso's dolphin *Grampus griseus*	1	5	1	200	0.12	826 (SD 851) 224-1428	22 (SD 2.12) 20.5-23.5
Rough-toothed dolphin *Steno bredanensis*	0	0	1	50	0.00	3056	23.5
Bottlenose dolphin *Tursiops truncatus*	1	25	2	100	0.61	1760 (SD 1060) 682-2800	27.5
Pantropical spotted dolphin *Stenella attenuata*	1	60	0	0	1.46	516	21.5
Atlantic spotted dolphin *Stenella frontalis*	3	41	0	0	1.00	1988 (SD 1195) 1159-3357	21.5
Clymene dolphin *Stenella clymene*	3	370	1	60	9.00	2662 (SD 178) 2405-2800	24 (SD 2.08) 21.5-26.5
Common dolphin *Delphinus* sp.	1	20	0	0	0.49	1461	24.5
Delphinus + *Stenella* sp.	1	60	1	150	1.46	1393 (SD 1881) 63-2723	22.5 (SD 1.41) 21.5-23.5
Dolphin sp.	9	207	6	322	5.04	1211 (SD 1057) 109-2823	22.3 (SD 1.22) 20.5-23.5
Whale sp.	5	6	4	4	0.15	2209 (SD 1436) 87-3962	23.6 (SD 2.80) 20.5-27.5
Total – North	**37**	**811**	**16**	**546**	**20.88***	**n/a**	**n/a**
Total – South	**13**	**47**	**17**	**384**	**19.74***	**n/a**	**n/a**
Total	**50**	**858**	**33**	**930**	**1.14***	**n/a**	**n/a**

* *Figures have been recently revised. For details see Annex to this chapter.*

Table 7.2 Overview of sightings (S) and total number of individuals (I) made during the main and additional surveys. The number of individuals 100 km^{-1} seen during the main survey is shown as the relative abundance for each species. In addition, the relative abundance for all species is shown for the different survey sectors. For all sightings (main + additional surveys) the mean water depth (m) and SST (°C) are presented together with the range.

Definite (72%) and probable sightings (22%) comprised the majority of all sightings. A total of 50 sightings of 858 animals involving 13 different cetacean species were made during the dedicated main survey (Table 7.2). In addition, 29 sightings of 679 animals involving eight species were made during the additional surveys. A further four incidental sightings were made whilst off-effort. Many sightings remained unidentified during the surveys (*n*=29, 36%) due to their distance from the vessel and confusion over species identifications, particularly those of *Stenella* sp. and *Balaenoptera* sp.

Bryde's whale (Balaenoptera cf. brydei)

The Bryde's whale was the most frequently encountered baleen whale during the survey with a total of nine sightings at distances <2 km from the vessel. With the exception of one encounter involving two animals, Bryde's whales were encountered singly. The relative abundance (0.24 whales 100 km^{-1}) was low compared to humpback whales (0.71, Table 7.2). Bryde's whales were sighted in deep water with a mean depth of 1690 m and mean SST 23.4°C (Table 7.2). For sightings with Bryde's whales encountered in deep oceanic waters (>2400 m) a higher sea surface temperature was measured (>26.5°C). The majority of sightings were made in the northern sector along the 1,000 m depth contour (Fig. 7.2).

Bryde's whales are notoriously difficult to identify to species level as they are very similar to Sei whales (*Balaenoptera borealis*) in appearance and can also be confused with fin whales (*Balaenoptera physalus*). For this reason an additional four possible Bryde's sightings were logged as 'baleen whales'. Given current uncertainty regarding the taxonomic status of these whales, Best (2007) adopts *B. brydei* for all Bryde's-like whales occurring in southern Africa. A divide in Bryde's whale distribution in distinctly separate habitats (shallow waters of <100 m or deep oceanic waters of >1600 m) was noted off Angola (Weir, 2007) and may reflect distinct 'offshore' and 'inshore' forms of this species (Best, 2001). The Bryde's whales encountered during this study were most likely of the offshore form given that all sightings were in waters exceeding 650 m in depth. The 'offshore' form may make extensive migrations between South Africa (Jan-Feb) and Gabon (May-July; Best, 2001). Bryde's whale sightings during this study occurred in May and July and are consistent with this theory. The majority of Bryde's whales were seen traveling. In July, feeding activity was noted in an area where small fish (likely *Sardinella* sp.) were seen in huge shoals close to the surface.

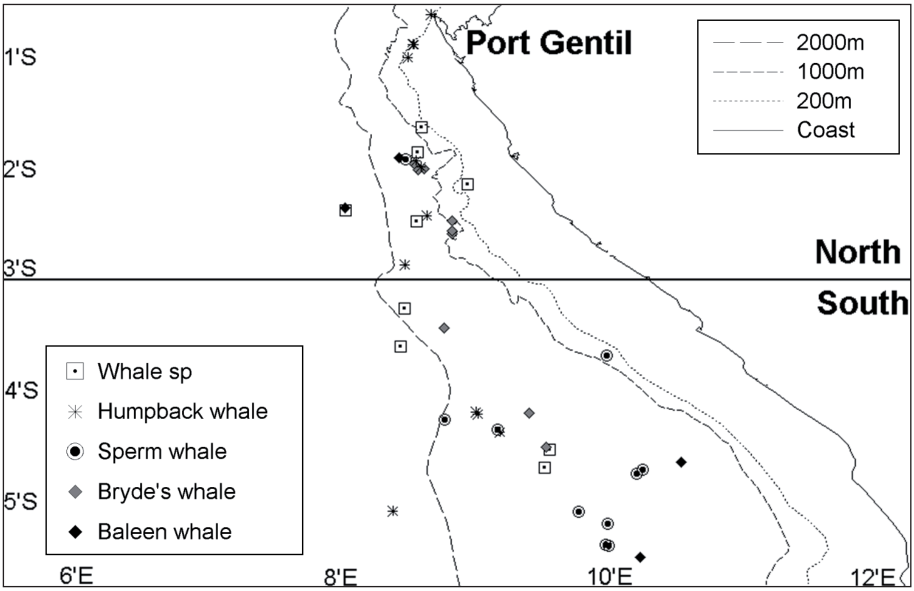


Figure 7.2 Distribution of all whale sightings (humpback whale, Bryde's whale, sperm whale and unidentified whale) made during the main and additional surveys. The 2000, 1000 and 200 m depth contours are also displayed.

Humpback whale (Megaptera novaeangliae)

Humpback whales were less frequently encountered than Bryde's whales but were however the most abundant whales encountered during the study. The first sighting occurred in the southern sector on 30 June after which they were seen more regularly with seven sightings recorded during the main survey and five sightings made during the additional surveys. The majority were seen in the Northern sector (Fig. 7.2) in water depths that ranged between 38 m and 3715 m with a mean temperature of 22.6°C (Table 7.2). The largest group of at least 20 whales was observed on 12 July. This surface-active group of whales was sighted whilst in transit in coastal waters (41 m) and was comprised of five mother/calf pairs (each pair >5 body lengths away from other pairs) and single whales in the vicinity of the pairs. All other encounters made during the present study consisted of single whales or pairs. The majority of sightings made during the main survey were encountered in deeper waters (>1000 m), although four sightings occurred in waters of <150 m. Humpback whales sighted in deep waters were typically traveling and those in shallow waters were surface active. The whales were sighted at distances ranging between 200 and 1200 m. During the additional surveys humpback whales were also sighted at greater distances (*n=2*; 1500 and 2500 m).

The relative abundance was 0.71 whales 100 km^{-1} (Table 7.2) and was expected to be higher due to the reasons outlined below. The coastal waters of Gabon represent an important breeding habitat for humpback whales (Rosenbaum and Collins, 2006). Humpback whales in Gabonese waters are for the majority observed during the months of June through November and include animals from populations that feed in the waters of the southern ocean and the coastal waters of Antarctica (Findlay et al., 2006; Pomilla and Rosenbaum, 2006; Rosenbaum et al., 2009).

Humpback whales in general show a preference for shallow water breeding habitats (<100 m; Clapham, 2000) which has also been noted in the region (Weir, 2007; Picanço et al., 2009). It is therefore likely that these whales were more abundant in shallow waters where less survey effort was carried out. On 1 July, two humpback whales were seen interacting with at least three sperm whales in water depths of 3593 m; both species were frequently breaching and tail slapping was also observed. No direct contact between the two species was observed.

Sperm whale (Physeter macrocephalus)

The majority of sperm whales were sighted during the additional survey in April (*n*=7) with only three sightings made during the main survey in May, June and July. The whales were mainly seen in deep waters (>1600 m) with one encounter in 515 m water depth. All sightings were made seaward of the shelf break (Fig. 7.2). The relative abundance of the whales was low during the main survey (0.24 whales 100 km^{-1}; Table 7.2) compared to Angola waters, where this species was the most abundant whale (Weir, 2007). The mean group-size of sperm whales was 2.9 and six sightings consisted of groups. The sperm whales were mainly encountered in the southern part of the study area (south of 3° S) with one record sighted in the northern sector at latitude of 1° 55'S on 3 June.

Recent work suggests that the occurrence of sperm whales off Angola peakes between January and May (Weir, 2007). Sperm whales were often sighted at long range from the survey vessel (ranging from 100 to 5000 m) and group composition could not be confirmed.

Unidentified beaked whales

Two sightings of unidentified beaked whales (one in each sector) were recorded (Fig. 7.3). Records of beaked whales off the west coast of Africa were summarised by Weir (2006c), with Cuvier’s (*Ziphius cavirostris*), Blainville’s (*Mesoplodon densirostris*) and Gervais’ (*Mesoplodon europaeus*) beaked whales considered the most likely species to occur off Angola.

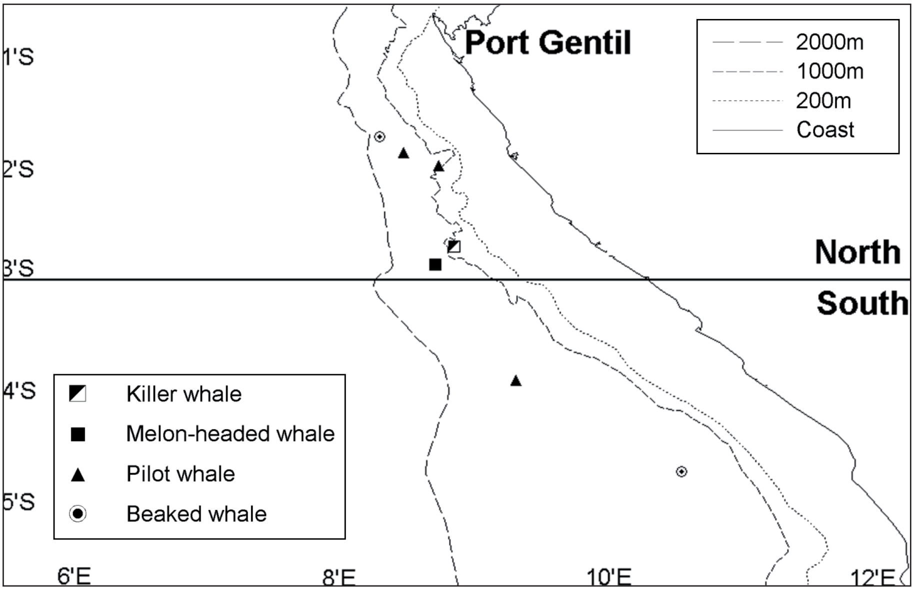


Figure 7.3 Distribution of all sightings of short-finned pilot whale, killer whale, melon-headed whale and unidentified beaked whales made during the main and additional surveys. The 2000, 1000 & 200 m depth contours are also displayed.

Killer whale (Orcinus orca), short-finned pilot whale (Globicephala macrorhynchus) and melon-headed whale (Peponocephala electra)

Pilot whales were seen on three occasions throughout a range of depths (685, 1573 and 2500 m) at distances <750 m from the vessel. Only one sighting was made in the southern sector and the relative abundance during the main survey was low (Table 7.2, Fig. 2.3). A group of eight pilot whales was seen in the northern sector in the vicinity of a solitary sperm whale. The pilot whales seen during the present study were most likely short-finned pilot whales due to their tropical location. However, distant views did not allow a positive identification but this species is believed to occur year-round in these waters (Jefferson et al., 1997; Weir, 2010).

Killer whales were seen on one occasion in the northern sector at a distance of 180 m from the vessel (Fig. 7.3). The group consisted of four animals was sighted in waters of 879 m and 20.5°C (Table 7.2). Killer whale presence has been reported off Gabon (Reeves and Mitchell, 1988; Weir et al., 2010) and off northern Angola with both offshore (>2000 m depth) and inshore sightings (Weir, 2007).

Two melon-headed whales were sighted in deep water in the northern sector (Fig. 7.3). The whales frequently approached the vessel to bow-ride for a period of at least six hours. Melon-headed whales have been recorded off Gabon (Findlay et al., 2006) and Angola (Weir, 2007).

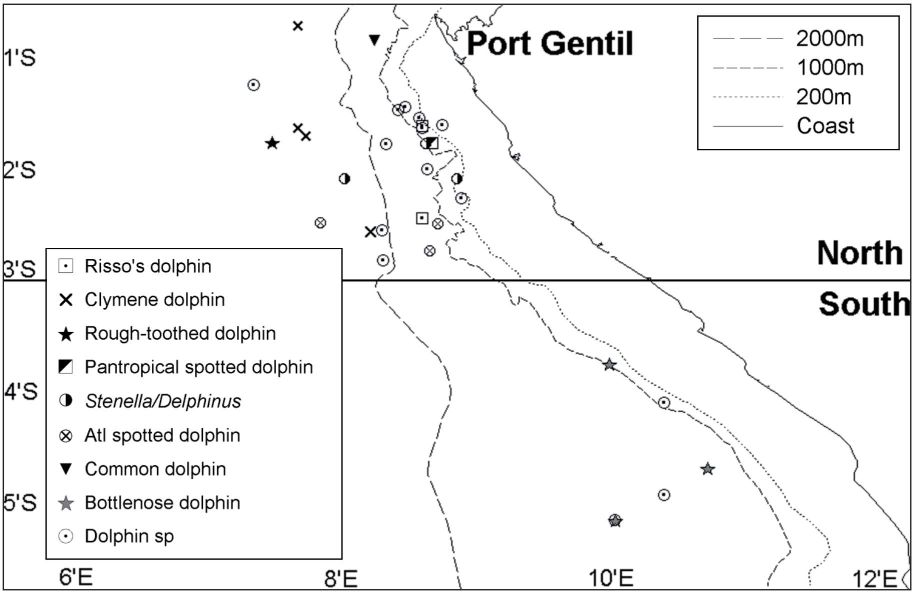


Figure 7.4 Distribution of all dolphin sightings: bottlenose dolphin, rough-toothed dolphin, Clymene dolphin, Atlantic spotted dolphin, Pantropical spotted dolphin, common dolphin (Delphinus sp.), Stenella/Delphinus sp. mixed groups, Risso's dolphin and unidentified dolphin made during the main and additional surveys. The 2000, 1000 & 200 m depth contours are also displayed.

Risso's dolphin (Grampus griseus)

Risso's dolphins were seen on two occasions in the northern sector. During the main survey (in June) a group was seen in 224 m water depth. The group included one juvenile who briefly traveled at the bow of the vessel. The other sighting (28 July) was made during the additional survey and occurred in deep oceanic waters (Fig. 7.4) at a distance of 1200 m.

Risso's dolphins probably occur along the entire West African Coast (Jefferson et al., 1997; Weir, 2010) and have been sighted in both deep waters and in shallower habitats off Gabon and Angola (Findlay et al., 2006; Weir, 2007).

Rough-toothed dolphin (Steno bredanensis)

One incidental sighting was made in June of a group of at least 50 animals including an all-white calf. The dolphins were sighted in the northern sector (depth >3000 m, Fig. 7.4) and a detailed description of this encounter is described elsewhere (De Boer, 2010b).

A stranded dead rough-toothed dolphin was recorded at Gamba, Gabon, during September 2002, (T. Collins, pers comm) providing the first verifiable record of the species in Gabonese waters (Rosenbaum and Collins, 2004). At-sea sightings are rare but have been reported in the region, including three sightings off Angola, one off Gabon (Weir, 2006a) and two off St Helena Island (MacLeod and Bennett, 2006).

Common Bottlenose dolphin (Tursiops truncatus)

A sighting of bow-riding bottlenose dolphins was recorded during the main survey on 11 May in 682 m. Two other sightings were made during the additional surveys at sighting distances of <1750 m. Those sightings occurred in deep waters (1800 and 2800 m) and consisted of groups of traveling dolphins (up to 50 animals). All three sightings were made in the southern sector (Fig. 7.4).

Bottlenose dolphins assumed to be *T. truncatus* are widespread in West Africa and probably inhabit near shore areas along the entire coast (Jefferson et al., 1997). The bottlenose dolphin is a coastal resident off Gabon (Collins et al., 2004; Rosenbaum and Collins, 2004) and sightings off Angola suggest a year-round presence in both coastal and deep offshore waters (Weir, 2010).

Pantropical spotted dolphin (Stenella attenuata) and Atlantic spotted dolphin (Stenella frontalis)

Some of the unidentified dolphins recorded during the surveys were strongly suspected to be either pantropical or Atlantic spotted dolphin. Species identity could not however be firmly resolved and were therefore recorded as *Stenella* sp. One sighting of pantropical spotted dolphins was made during the main survey in the northern sector on 9 July, involving a surface active group seen at a range of 350 m (Fig. 7.4). Some of the dolphins showed the distinct bipartite pigmentation on the flanks unlike the tripartite pigmentation pattern found on Atlantic spotted dolphins. Furthermore, the distinct cape blaze characteristic for Atlantic spotted dolphins was not observed. Some of the dolphins had extensive spotting which obscured the pigmentation patterns. The sighting occurred in waters with a depth of 516 m and an average SST of 21.5°C (Table 7.2) and involved a group of at least 60 dolphins. Pantropical spotted dolphins have been reported in the Gulf of Guinea, off Gabon and off Angola (Perrin et al., 1987; Perrin and Van Waerebeek, 2007; Picanço et al., 2009; Weir, 2010).

Three sightings of Atlantic spotted dolphins were made during the main survey towards the end of June whilst the vessel was in transit in the northern sector (Fig. 7.4). The dolphins were sighted in deep waters with depths of 3357 m, 1447 m and 1159 m and an average SST of 21.5°C (Table 7.2). On two occasions small groups of dolphins (5 to 6 animals) came to bow-ride the survey vessel but a larger group of up to 30 dolphins was seen traveling away from the vessel at a distance of 500 m. Due to the small group size, the relative abundance was not very high (1.00, Table 7.2).

A *Stenella* sp. specimen record (of unknown origin) has been reported in Gabon (Perrin et al., 1987; Weir, 2010). Both Atlantic and Pantropical spotted dolphins have been sighted off Angola (Weir, 2007) and are therefore assumed to also occur off Gabon. Moreover, the Atlantic spotted dolphin is considered to be one of the most numerous dolphin species inhabiting the primarily deep waters off West Africa (Weir, 2010). The sightings of Atlantic spotted dolphin during the present study are the first confirmed at-sea sightings off Gabon.

Clymene dolphin (Stenella clymene)

During the main survey, three sightings of Clymene dolphins were made in May and June and one sighting was made during the additional survey in late July. All sightings occurred in the northern sector (Fig. 7.4) and were sighted at distances of 70, 600, 750 and 800 m from the vessel. Clymene dolphins were encountered in relatively deep oceanic waters (>2400 m) with a mean SST of 24°C (Table 7.2). School sizes were large (best estimates of 150, 120, 100 and 60) making it the most abundant species seen during this study (Table 7.2).

The Clymene dolphin is especially poorly known in the eastern Atlantic off the African coast, although is endemic to the tropical/subtropical Atlantic Ocean (Van Waerebeek, 2007). Only a very few reported sightings at sea have been made (Robineau et al., 1994; Fertl et al., 2003; Jefferson et al., 1997). Recently, Clymene dolphins were reported off Angola (Weir, 2006b) but no confirmed records for this species in Gabonese waters are presently known.

Fertl et al. (2003) emphasize the importance of verifying the identification features of Clymene dolphins due to confusion with other pelagic dolphins of similar size, shape and colouration. The main identification features observed during sightings included: a small (<2 m), robust, streamlined body shape; prominent beak with a dark tip; tri-coloured flank pattern with a darker cape, grey flank and white ventral surface; dark cape with a rounded ‘dip’ below the dorsal fin almost reaching the white ventral surface; slightly enlarged tailstock; and dark slender pointed flippers. The dolphins did not approach the vessel to bow-ride and the distinctive ‘moustache’ marking situated one-third of the way down the dorsal surface of the beak (Perrin and Mead, 1994; Jefferson, 1996; Fertl et al., 2003) was therefore not visible. The dolphins were traveling fast and some spinning behaviour was observed. A minimum of 5 juveniles were sighted amongst the group, but given the distance between the vessel and the group this should be regarded as a minimum.

Common dolphin (Delphinus sp.)

Common dolphins (*Delphinus* sp.) were sighted in the northern sector during the main survey in June (Fig. 7.4, Table 7.2). Two mixed groups including both *Delphinus* and *Stenella* sp. were also encountered. These sightings were made at 300 and 1000 m from the vessel. One such sighting was made in shallow waters (63 m) whilst the other sighting was made during the additional survey in waters of 2723 m depth. A third group of 20 surface-active *Delphinus sp.* was sighted during the main survey in waters of 1461 m depth at a distance of 1000 m from the vessel.

Common dolphins are considered to be the most common offshore dolphin in West Africa (Jefferson et al., 1997). *Delphinus* sp. are regularly reported in the coastal waters of Gabon (Rosenbaum and Collins, 2004) and Van Waerebeek (1997) confirmed that both species of common dolphin (*capensis* and *delphis*) occur off Gabon. Sightings of common dolphins in the present study were not identified to species level as they are difficult to distinguish at sea. Furthermore, the morphology of *Delphinus* off Angola is not fully consistent with either *D. delphis* or *D. capensis* (Weir and Coles, 2007).

7.5 CONCLUSIONS

Thirteen different cetacean species were identified during the surveys reflecting a broad cetacean diversity. These included two baleen whales, one sperm whale species (*P. macrocephalus*) and ten species of delphinid. The observations of this study should be taken cautiously due to low sample sizes, the limited temporal coverage of the 5 month-study (with the main study covering ten weeks) and unknown reactions of cetaceans to seismic operations.

In keeping with the distribution of survey effort the majority of sightings were made seaward of the shelf break at a distance of approximately 100 km from the coast. Risso's dolphins, mixed groups of *Delphinus/Stenella* sp. and humpback whales were sighted in shelf waters although they were also seen in deeper waters. The Bryde's whales sighted were probably all 'offshore' forms as these whales were encountered in waters exceeding 650 m in depth (whereas the inshore form is usually encountered in Angolan waters less than 100 m deep; Weir, 2007). The majority of humpback whale sightings were made in deep waters (>1000 m), although three sightings occurred in shelf waters. All sperm whales were sighted in deep waters seaward of the shelf break. Bottlenose dolphins, Clymene dolphins, rough-toothed dolphins, Atlantic spotted dolphins and a mixed-group of *Stenella/Delphinus* sp. were seen in deep oceanic waters (>2400 m).

Bryde's whales, unidentified baleen whales, sperm whales, Clymene dolphins and bottlenose dolphins were sighted in waters with a SST>25°C, although some of these species were also seen when temperatures were cooler (Table 7.2). Delphinid species such as Atlantic spotted dolphin, pantropical spotted dolphin, rough-toothed dolphin, Risso's dolphin and *Delphinus* spp. were sighted in SST< 25°C. Sightings of pilot whale, killer whale, melon-headed whale and unidentified beaked whale were also made when waters were cooler (20.5°C).

The highest relative abundance for cetaceans (19.7 animals 100 km^{-1})[1] was measured in the Northern sector (Table 7.2) which also measured the highest spe-

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[1] Figures have been recently revised. For details see Annex to this chapter.

cies diversity with nine species identified during the main survey and three species identified during the additional surveys. In the southern sector, only five species were recorded, but survey effort, and thus the opportunity to see animals, was considerably lower here than in the northern sector (1392 km versus 2717 km). However bathymetric features (such as a relatively narrow neritic zone and shelf width) and oceanographic processes (such as upwelling; Roy, 2004), may have increased the productivity of the northern sector, providing improved conditions for a wider diversity of species. Bathymetric features and frontal zones may provide a means of predicting important foraging habitats for marine mammals (e.g. Yen et al., 2004; Johnston et al., 2005b; Panigada et al., 2005; Bost et al., 2009). During seasonal upwellings (July to September) the waters of the Gulf of Guinea cool and SST's reach a minimum, with an average temperature of 22°C (Longhurst, 1962). Such temperature changes appear to be related to an active oceanographic front (Odekunle and Eludoyin, 2008). This pattern was evident during the survey period with water temperatures ranging between 28.5°C (March) and 20.5°C (July/August). The foraging Bryde's whales sighted during this study were probably feeding on *Sardinella sp*. As small fish (likely *Sardinella* sp.) were seen in huge shoals close to the surface. These schooling fish occur year-round in West African waters and large schools of spawning *Sardinella* sp. have been linked with upwelling regimes (Whitehead, 1985). Predation by Bryde's whales on schooling fish elsewhere in the Atlantic has been reported off South Africa (Best, 1977; Best and Rickett, 1984) and off Brazil (Siciliano et al., 2004).

It is important to note that the variations in oceanographic conditions (particularly SST) in Gabonese waters coincide with a temporal variation in species composition. This is apparent in data set with the majority of sperm whales sighted in the southern sector in April (when SSTs are high), humpback whales arriving in the area in June and a higher diversity of delphinid species recorded in June and July (when SSTs are low).

Cetaceans in the region face various threats, particularly that of expanding offshore hydrocarbon extraction activity (Findlay et al., 2006; Weir, 2007). Other threats include the impact of direct fisheries and fisheries bycatch, increased vessel activity and increased coastal development (Maigret, 1981; Maigret, 1994; Jefferson et al., 1997; van Waerebeek et al., 2007; Rosenbaum and Collins, 2006; Perrin and Van Waerebeek, 2007).

The cetacean fauna in tropical West African waters is poorly known and the present survey adds to the limited data available from this region. Further cetacean surveys are clearly needed and the present study should be seen as part of an ongoing effort to both collect data when opportunities arise and to synthesize existing data in order to improve the current understanding of regional cetacean distribution, migration and critical habitat parameters.

7.6 ACKNOWLEDGEMENTS

I thank Ron Spicer and Phil Johnston who both helped with the observations. Of equal importance has been the support and goodwill of the bridge crew of the survey vessel. Thanks also to CGG Veritas DL and the Ministry of Gabon and to all those who encouraged me to write up this interesting data set. The manuscript was reviewed and improved by comments from Tim Collins and Ron Spicer.

ANNEX

Several small amendments are listed here in regards to the published version:

1. During the proofread typographic errors were introduced in Table 7.2. The correct relative abundance figures for *Total – North* is 29.84; for *Total – South* this is 3.34; and for *Total* this should read 20.88.

2. Recently obtained information on the location of maritime boundaries has resulted in the reallocation of five sighting records to the Republic of the Congo (e.g. Weir, 2011). These included sightings of one *Dolphin sp*., one *Beaked whale sp*., two sperm whales and one bottlenose dolphin. A further seven sightings are located in a region classed as 'Gabon/Rep. of the Congo' (e.g. Weir, 2011).

3. At the time of the publication in the *Journal of the Marine Biological Association of the United Kingdom* it was the editor's opinion that there was no need to include photographs of the species encountered. In view of the increasing use of photographic images to proof species records, these are shown here (Plates 1-2).

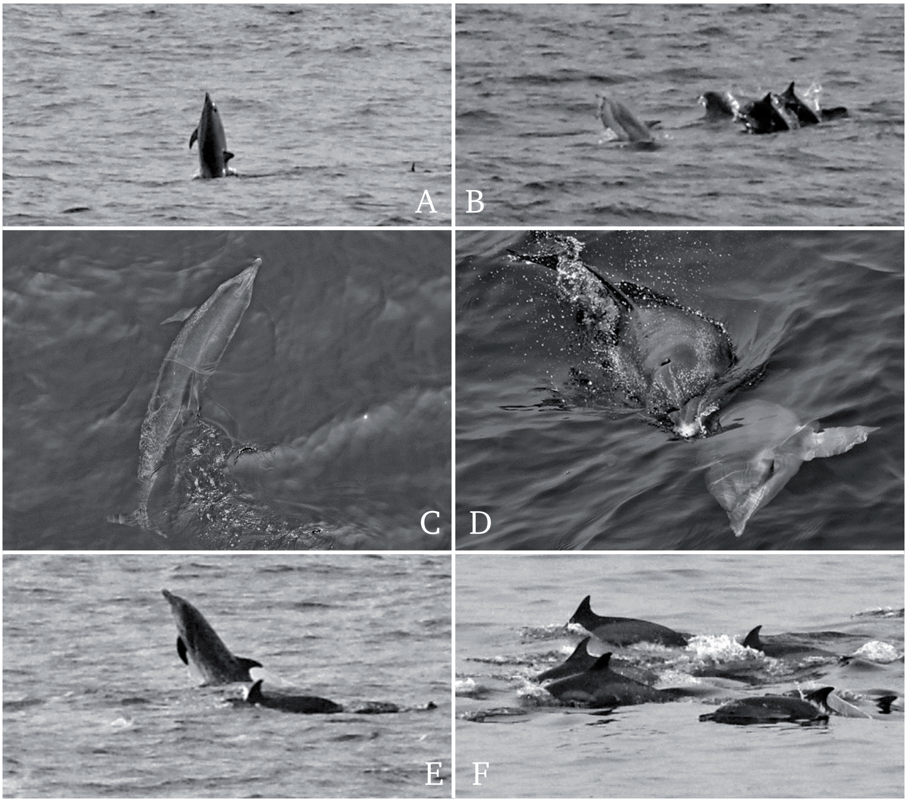

Plate 1: Clymene dolphin (A-B); Atlantic spotted dolphin (C-D); pantropical spotted dolphin (E) and Delphinus spp. (F). Photographs © M. de Boer.

Plate 2: Bryde's whale (A); humpback whale (B); sperm whale (C); short-finned pilot whale (D); melon-headed whale (E); orca (F); rough-toothed dolphin (G) and common bottlenose dolphin (G). Photographs © M. de Boer (A-D, G-H), P. Johnston (C) and R. Spicer (E+F).

CHAPTER 8

FIRST RECORD OF A WHITE ROUGH-TOOTHED DOLPHIN (*STENO BREDANENSIS*) OFF WEST AFRICA, INCLUDING NOTES ON ROUGH-TOOTHED DOLPHIN SURFACE BEHAVIOUR

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Rough-toothed dolphin

8.1 ABSTRACT

In June 2009, a white rough-toothed dolphin (*Steno bredanensis*) calf was photographed in a group of at least 50 dolphins in the southern Gulf of Guinea, 95 nmiles off the Gabon coast (01° 45'S, 07° 29'E), West Africa. Reports of unusually pigmented cetaceans are infrequent and this record represents the first of an all-white rough-toothed dolphin. Furthermore, there is little documentation concerning rough-toothed dolphins and this note contributes to the knowledge of this species in tropical West African waters.

8.2 INTRODUCTION

The rough-toothed dolphin (*Steno bredanensis* Lesson, 1828) is known to be endemic to the offshore waters of tropical, sub-tropical and warm-temperate seas around the world. This species prefers deep waters with a Sea Surface Temperature (SST) of 25°C (Leatherwood and Reeves, 1983; Miyazaki and Perrin, 1994; Jefferson, 2002) although they do occur in waters with lower water temperatures (Ott and Danilewicz, 1996; Ritter, 2002). The rough-toothed dolphin appears grey in colour without obvious pigmentation patterns apart from a distinctively-shaped dark cape and variable areas of mottling with white/pink spotted areas on the latero-ventral region. The literature concerning rough-toothed dolphins indicates that little is known about this species (Miyazaki and Perrin, 1994; Steiner, 1995; Waring et al., 1997; Addink and Smeenk, 2001; Jefferson, 2002; Kuczaj and Yeater, 2007; Baird et al., 2008). In September 2002, a stranded dead rough-toothed dolphin was reported at Gamba (Gabon) and this finding provided the first verifiable record of this species in Gabon waters (Rosenbaum and Colins, 2004). Weir (2006a) reported three at-sea sightings with rough-toothed dolphins off Angola and one off Gabon. The species has also been recorded off Côte d'Ivoire, Ghana, St Helena (Cadenat, 1959, MacLeod and Bennett, 2006; Weir, 2010), in the western Gulf of Guinea (Jefferson et al., 1997; Van Waerebeek and Ofori-Danson, 1999; Ofori-Danson et al., 2003) and off North-west Africa (Jefferson et al., 1997), although published at-sea records are rare. Information concerning the behaviour of rough-toothed dolphins is sparse (Kuczaj and Yeater, 2007) and some notes regarding behavioural observations are included in this note.

8.3 MATERIALS AND METHODS

A dedicated cetacean survey was carried out off Gabon, West Africa between 5 March and 7 August 2009 aboard a geophysical seismic survey vessel, the *CGG Venturer* at 12.5 m eye height. The study area was situated approximately between 25-130 nmiles off the coast. Dedicated watches were carried out by one observer scanning with the naked eye but using binoculars (8 x 43 Leica) aiding species identification and group size estimations. Standard Joint Nature Conservation Committee recording forms were used (JNCC, 2004). The radial sighting distance to animal(s) was determined using a range finding stick (Komdeur et al., 1992). The bearing to animal(s) and their heading were determined by ship's compass. Other sightings data included time (GMT), water depth (depth sounder or electronic sea chart), presence of calf and/or juvenile, school size, group composition and behaviour.

The behaviours of the dolphins were noted in 3-minute samples during focal group follows (Mann, 1999). Behaviour states included travel, foraging, milling, resting, social, interaction with boat, acrobatics and play with object. Behaviour events were recorded continuously (such as spy hop, fluke slap, breach, swimming abreast) using a dictaphone and digital photographs.

The following environmental data were collected: GPS position, speed (knots), course, wind speed and direction, visibility (km), swell height (m), SST (°C) and Beaufort sea state. Photographs were taken with a digital camera (Sony α-700 with a SIGMA 70-200 f2.8 zoom lens).

8.4 RESULTS AND DISCUSSION

On 10 June 2009 12:47 (GMT), at least 50 rough-toothed dolphins were sighted in deep offshore waters off Gabon (01° 49'S – 07° 27'E to 01° 45'S – 07° 29'E, Fig. 8.1). This was the only sighting with rough-toothed dolphins during the total survey period. The encounter with the dolphins lasted 2 hours and 43 minutes during which the vessel was travelling at a slow speed of 2.5 knots, steering a steady course in 3056 m deep waters. The vessel was not in operation at the time and was conducting maintenance on towed equipment. The visibility was excellent (>5 km) with a slight sea state, low swell (1 m) and a SST of 23.5°C. Details regarding other cetaceans are presented elsewhere (De Boer, 2010c).

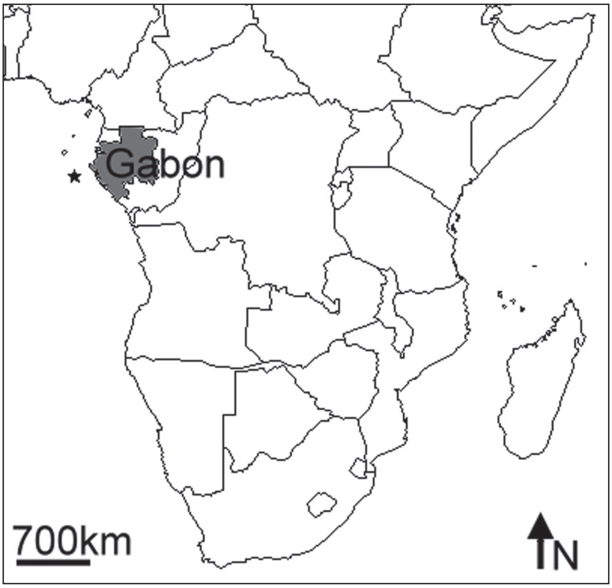

Figure 8.1
Location of Gabon in tropical West Africa and sighting position of the rough-toothed dolphins (marked as an asterix).

8.4.1 SURFACE BEHAVIOUR

The group of 50 dolphins consisted of all age classes, including six juveniles and two calves. Rough-toothed dolphins are usually observed in groups of 10-20 animals, although larger aggregations do occur (e.g. Leatherwood et al., 1982; MacLeod and Bennett, 2006, Baird et al., 2008). The dolphins were 'surface active' (displaying acrobatics) throughout the encounter and were travelling parallel to the vessel (staying on starboard only) or were briefly bow-riding and surfacing ahead of the vessel. The dolphins frequently changed direction with dolphins travelling either ahead of the vessel (up to a distance of 400 m) or travelling in an opposite direction until approaching the stern area. The direction change appeared to be initiated by tail-slapping of one and other (responding) dolphins upon which all the members of the pod would change direction. This behaviour of directional change following tail-slapping (or in some cases inverted tail-slapping) was noted on seven occasions and confirmed by the numerous photographs taken during the encounter. The period between the directional changes varied between 4 and 18 minutes but was no longer observed in the last hour of observations. The sub-group formations (2-8 animals) varied from tight to loose formations (2-5 body lengths). Towards the end of the observation period the dolphins were more widely dispersed with single animals seen more frequently at the surface.

The sub-groups were regularly seen travelling 'line abreast' as described in Neumann and Orams (2003) involving up to eleven individuals. Such synchronous swimming behaviour among tightly spaced sub-groups may characterize this species (Steiner, 1995; Addink and Smeenk, 2001; Pittman and Stinchcomb, 2002; Ritter, 2002; Götz et al., 2005). Social interactions were frequent and were carried out by both adults and juveniles and consisted of touch (pectoral fin rubbing), chasing and belly-flashing. Other active surface events observed included fluking, fluke rise, fluke wave, spy hop, flipper wave, chin slap, backwards leaping, high leaping, side leaping, breaching and spraying water out of the mouth. The dolphins were also seen foraging with animals swimming in circles and diving in a synchronized manner creating lots of splashes ('carousel feeding' in Neumann and Orams, 2003). One dolphin was observed carrying a plastic bag on its beak. The apparent playful nature of rough-toothed dolphins has been reported in other studies and they are known to associate with floating objects but also with other species like turtle (*Caretta caretta*) and puffer fish (*Lagocephalus lagocephalus*; Leatherwood et al., 1982; Watkins et al., 1987; Steiner, 1995; Lodi and Hetzel, 1999; Pitman and Stinchcomb, 2002; Ritter, 2002; Kuczaj and Highfill, 2005; Kuczaj and Yeater, 2007).

On several occasions the dolphins were probably engaged in foraging activities with the dolphins observed circling in apparent coordinated movements as in pursuit of prey. The directional changes and repeated tail-slapping were probably carried out to affectively herd prey and such coordinated movements have been interpreted as co-operative foraging of rough-toothed dolphins (Steiner, 1995; Lodi and Hetzel, 1999; Addink and Smeenk, 2001; Pitman and Stinchcom, 2002).

A large remora (family Echeneididae) was attached to one of the dolphins (right flank) but it was not possible to identify the remora to species as this is difficult without a close inspection (Fertl and Landry, 1999 and 2002). It was also observed that a juvenile dolphin initially had an unidentified remora attached on its left flank but after a series of breaching events the remora appeared to have been dislodged.

8.4.2 SCARRING AND INTERACTIONS WITH FISHING GEAR

The dorsal fins of most animals showed features which allowed individual recognition, mainly nicks and scars, which were used to identify the sub-groups. The majority of the individuals showed extensive body-scarring and blotching and a few dolphins showed fresh pinkish wounds and older scars probably caused by bites from cookie-cutter sharks (*Isistius brasiliensis)*. Such scars are regularly observed on rough-toothed dolphins (e.g. Miyazaki and Perrin, 1994, Addink and Smeenk, 2001). In addition to this, some dolphins showed scars probably caused by entanglement in fishing gear. These lesions included deep incisions around the dorsal fin and lacerations in front of the dorsal fin and are thought to be indicative of interactions with fishing gear (Kuiken et al., 1994). Towards the end of the encounter, the group was widely scattered and moved away from the vessel whilst briefly investigating a Fisheries Aggregating Device (FAD). Such interactions between rough-toothed dolphins and fishing gear, including FADs have been observed off Brazil, Hawaii and Mauritania (Maigret, 1994; Lodi and Hetzel, 1999; Addink and Smeenk, 2001; Baird et al., 2008).

8.4.3 ANOMALOUSLY WHITE PIGMENTATION

One of the calves was uniformly white and possessed a very faint outline of the characteristic caped pigmentation pattern (Fig. 8.2A-C). Examination of photographs indicated the presence of two small darker dots in vicinity of the blowhole but unfortunately the eye colour could not be confirmed. The calf remained in close association with a normally pigmented adult and was seen surfacing on its own on two occasions and appeared to be interacting with other members of the pod. For the majority of the time, however it was swimming in the echelon position and on one occasion the calf appeared to be suckling. The mother/calf pair was generally observed on the outskirts of the dolphin group, furthest from the vessel making a closest approach of approximately 350 m whilst other dolphins, including juveniles with slightly paler pigmentation compared to that of adults (Fig. 8.2D), frequently approached the vessel to bow-ride.

Albinism is differentiated from piebaldism (body pigmentation missing in only some areas) and leucism (dark-eyed anomalously white animals) and pigmentation patterns should not be the only criterion used to define albinism, as some mutant phenotypes (pseudo-albinism) may be due to the action of genes at other loci (Fertl and Rosel, 2002). Anomalously white pigmentations have been recorded in a number of cetacean species (Hain and Leatherwood, 1982; Fertl et al., 1999; Fertl and Rosel, 2002; Fertl et al., 2004; Stockin and Visser, 2005; Nascimento et al., 2007). Fertl et al. (1999) reviewed the occurrence of anomalously white cetaceans for twenty species, listing a sighting made in 1978 of a white rough-toothed dolphin off Cocos Island, Costa Rica. Further investigation of this sighting, however, revealed that the individual was actually a ‘pale’ bottlenose dolphin (*Tursiops sp*, Webber and Fertl, pers. comm.). No other records of anomalously white rough-toothed dolphins have been reported (Fertl et al., 2004). Anomalously pigmented rough-toothed dolphins have been reported from Hawaii (piebaldism; R Baird, pers comm.) and from the Canary Islands (light-grey coloured individuals showing all normal flank patterns, Morganonline, 2007). Little is known about how common anomalously white cetaceans are and about the survivability of those presenting the condition (Fertl and Rosel, 2002).

The present sighting provides the first record of an anomalously white rough-toothed dolphin and furthermore contributes to our knowledge of cetaceans in the relatively under-recorded tropical West African region.

Figure 8.2 Photos of the anomalously white pigmented rough-toothed dolphin calf: (A) swimming with an adult and another calf in front, (B) surfacing on its own and (C) swimming next to adult. Photo of typically pigmented juvenile (D).

8.5 ACKNOWLEDGEMENTS

Thanks to the bridge crew of the survey vessel and to CGG Veritas DL and the Ministry of Gabon and to all those who encouraged me to document this interesting encounter. The manuscript was improved by comments from N. Hodgins and S.A. Kuczaj.

CHAPTER 9

CETACEANS OBSERVED IN SURINAME AND ADJACENT WATERS

Published as: De Boer MN (in press) Cetaceans observed in Suriname and adjacent waters. Latin American Journal of Aquatic Mammals.

Long-beaked common dolphin

9.1 ABSTRACT

Very little information exists about the cetaceans in the Guianas: Suriname and its neighbouring countries Guyana and French Guiana. During a dedicated cetacean survey carried out from a geophysical seismic survey vessel in the offshore waters of Suriname (May-September 2012), the occurrence of 13 cetacean species was documented and of those, 11 were newly documented for this area. The species observed by the author included sperm whale (*Physeter macrocephalus*), Bryde's whale (*Balaenoptera edeni*), false killer whale (*Pseudorca crassidens*), melon-headed whale (*Peponocephala electra*), rough-toothed dolphin (*Steno bredanensis*), long-beaked common dolphin (*Delphinus capensis*), Fraser's dolphin (*Lagenodelphis hosei*), pantropical spotted dolphin (*Stenella attenuata*) and spinner dolphin (*Stenella longirostris*). During transit to the survey area (Trinidad to Suriname) incidental sightings were recorded which included bottlenose dolphin off Trinidad, *Stenella* sp. off Guyana and Guiana dolphin (*Sotalis guianensis*) at the entrance of the Suriname River. Opportunistic records originating from the periods December 2008-March 2009 and August-October 2012 were forwarded to the author. These records included common bottlenose dolphin (*Tursiops truncatus*), Atlantic spotted dolphin (*Stenella frontalis*) and short-finned pilot whale (*Globicephala macrorhynchus*).

There is a growing need to identify critical areas for marine biodiversity conservation, both locally and regionally. This paper describes the general occurrence of the cetacean community encountered in Suriname waters in summer. The study revealed that the offshore cetacean community in Suriname is best described as primarily a tropical community, dominated by odontocetes (dolphins and sperm whales). Although the species diversity was relatively high, the overall cetacean relative abundance index (number of animals per 100 km effort) was low, which is consistent for tropical equatorial offshore waters. Apart from the sperm whale and the Guiana dolphin, all the other species recorded represent new species records for Suriname. It is recommended that more continuous monitoring in different seasons is carried out in order to gain a better understanding of the occurrence, distribution and status of the different cetacean species within the region.

9.2 INTRODUCTION

A total of 31 cetacean species occur within the Wider Caribbean Region (WCR) but there is a marked lack of records in the Guianas (Sub-Region VI of the WCR), which includes the countries of Guyana, Suriname and French Guiana (Ward et al., 2001; Weir et al., 2011; Mannocci et al., 2013). The mammals of Suriname were listed by Husson (1978) and included six cetacean species that were either sighted in Suriname coastal waters or were found stranded. These were sperm whale (*Physeter macrocephalus*), Guiana dolphin (*Sotalia guianensis*), minke whale (recorded as *Balaenoptera bonaerensis* and *Balaenoptera acutorostrata*), fin whale *Balaenoptera physalus*) and sei whale (*Balaenoptera borealis;* Husson, 1978). The cetacean community is also under-recorded in the neighbouring countries (French Guiana - Mannocci et al., 2013 and Guyana; Kalamandeen and Chesney, 2013). Recent aerial surveys reported the presence of cetaceans in French Guiana, including fin whale, sperm whale, Cuvier's beaked whale (*Ziphius cavirostris*), short-finned pilot whale (*Globicephala macrorhynchus*), Risso's dolphin (*Grampus griseus*), common bottlenose dolphin (*Tursiops truncatus*) and Guiana dolphin (Mannocci et al., 2013). In contrast, more detailed records exist for Venezuela in the Southern Caribbean region (Romero, 2001; Bolaños and Villarroel-Marin, 2003; Bermúdez Villapol et al., 2008). Apart from a recent study on the Guiana dolphin (M. Pool, pers. comm.), cetacean research has been lacking for Suriname. The scarcity of cetacean records for Suriname can therefore be attributed to a lack of survey effort rather than an absence of marine mammals.

During the past two decades, awareness of marine mammals and their habitats in the Wider Caribbean Region has increased (Hoyt, 2011). The Specially Protected Areas and Wildlife (SPAW) Protocol, the regional agreement for biodiversity and for the advancement of the conservation and protection of the marine environment in the WCR, became international law in June 2000 (UNEP, 2012). A specific Marine Mammal Action Plan was adopted in 2008 under the framework of the United Nations Environment Programme's (UNEP) Caribbean Environment Programme with the aims to provide training workshops on stranding response and networking, whale- and dolphin-watch training, and implementation of a regional manatee conservation plan (Hoyt, 2011). This has also resulted in an increase in conservation management action in the Guianas and neighbouring countries along northeastern Latin America, ranging from northern Brazil to Venezuela, including Trinidad and Tobago and the "ABC islands" (Aruba, Bonaire, Curaçao) of the Dutch Caribbean (Brichet, 2012).

The objectives of the study were to describe: (1) the occurrence of cetaceans in Suriname offshore waters; (2) their relative abundance; and (3) species diversity. In addition, we present information on anecdotal records for Suriname and adjacent waters. This study provides a list of cetacean species that have been recorded in Suriname waters. These baseline data can be used for future investigations and monitoring as well as for conservation and management of cetaceans in the Guianas.

9.3 MATERIALS AND METHODS

9.3.1 STUDY AREA

Suriname is located on the northeast coast of South America, bordering the Atlantic Ocean, with French Guiana to the east, Guyana to the west and Brazil to the southeast (Fig. 9.1). The Guianas and the Eastern Venezuelan Atlantic Front (also known as the Guiana Shield) are under the influence of the Amazon River. The typical ecosystems include estuaries, mudflats, sandy beaches, and mangrove forests, which extend along most of the largely unexplored coastline (Miloslavich, 2011).

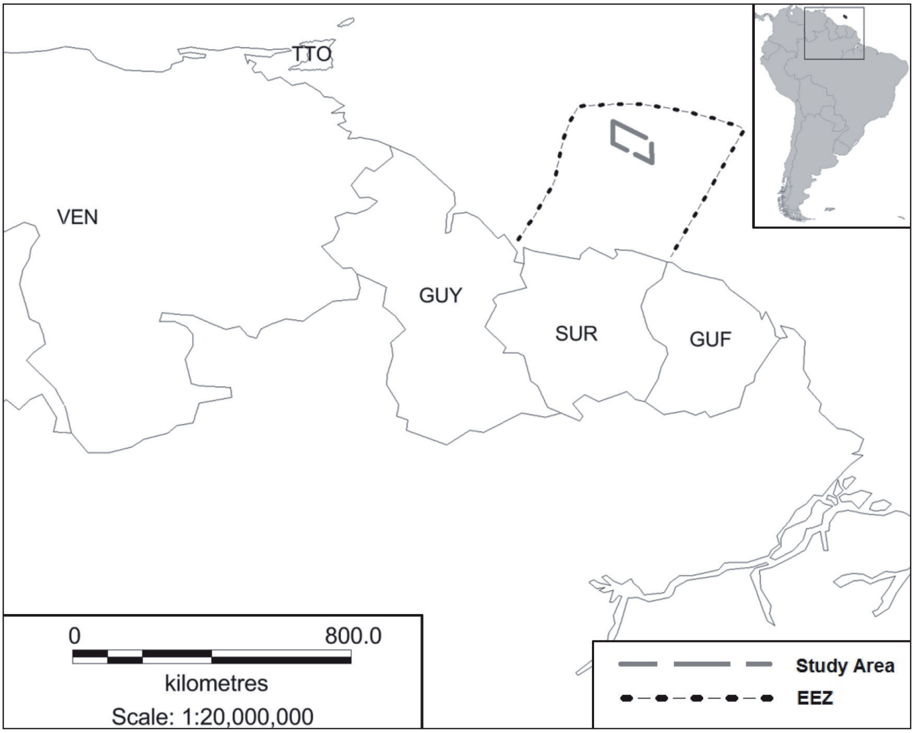

Figure 9.1 The Guianas: Guyana (GUY), Suriname (SUR) and French Guiana (GUF). Venezuela (VEN) with Trinidad and Tobago (TTO), the study area (in grey) and the outline of the Exclusive Economic Zone (EEZ) area also shown (some parts of the EEZ between Guyana and Suriname are disputed).

The tides along the coast of Suriname are semi-diurnal with tidal amplitudes ranging 1.3-2.3 m. Sea surface temperatures (SST) are almost constant throughout the year (27-29°C). Within the Guianas, the Guiana Current is the main current which is composed predominantly of the warm North Brazil Current which flows north along the northeastern coast of South America. Upon reaching French Guiana this current separates from the coast and joins the North Equatorial Counter Current. The rest of the North Brazil Current continues flowing northwestward to form the Guiana Current (Condie, 1991). It is generally accepted that in Suriname's offshore areas the currents mainly flow from the southwest to the northeast quadrant and the highest current speeds are measured in April-May along the edge of the continental shelf (Gyory, 2005).

9.3.2 DEDICATED SURVEY (EFFORT-RELATED)

Dedicated (effort-related) cetacean observations were carried out within Suriname waters (08° 29'N, 54° 041'W) between 17 May and 3 September 2012 during a geophysical seismic survey onboard the *Western Regent*. The 93.2 m long vessel acted as a Platform of Opportunity where the distribution of survey effort was determined by parallel survey transects (n=114) designed for the geophysical activities. The only sightings recorded, and used in this study, were when the vessel did not deviate from the track-line. The vessel left Trinidad on 15 May and transited to the prospect area which extended between 220 and 300 km North of Paramaribo. There were three different survey periods (17 May – 24 June; 25 June-24 July; 25 July-3 September). The main survey area comprised of water depths between 1200-3600 m and covered approximately 3,000 km^2 (Fig. 9.2). The vessel operated with a speed over ground (SOG) of ca. 4 knots. Observations were carried out during all daylight hours (09:00-22:00 UTC). During the survey, teams of 2 observers carried out observations of either 1.5 or 2 hours duration. Observational effort was conducted from the bridge wings and foredeck at 14 m height with one observer monitoring ahead and to the port side of the vessel and the other observer watching ahead and to the starboard side. The observers scanned the sea predominately with the naked eye but used binoculars (8 x 43 and 10 x 42) for searching the horizon, aiding species identification and group-size estimations. Once a sighting was made the radial sighting distance was determined using person-specific range-sticks (Heinemann, 1981). The bearing to the sighted animals and their heading were estimated using the ship's mounted compasses which were positioned on both the starboard and portside bridge wings. Sightings data also included the time (UTC), GPS position, water depth, species identification, group-size and the presence of calves and/or sub-adults. DSLR cameras were used with zoom lenses (e.g. Sony 700alpha with a 200 mm f2.8 lens and a Canon EOS550D with a 100-400 mm f4.5-5.6 lens). Environmental observations were also collected during the survey, such as wind speed and direction (using the ship's wind meter), swell height and visibility (estimated by eye) and Beaufort sea state (BSS) according to the Beaufort scale. Water depth and SST were measured throughout the survey period (Acoustic Doppler Current Profiler data). A Garmin GPS (GPSMAP76CSx) was used to log the ship's position every minute (Fig. 9.2). During the third leg the author was not present; however, the two observers who were present on the first leg were again present during the third leg. All observers had previous experience of conducting cetacean surveys in tropical waters. GPS, speed and course data were not continuously logged during the third leg; however, information on effort was provided as hours on watch.

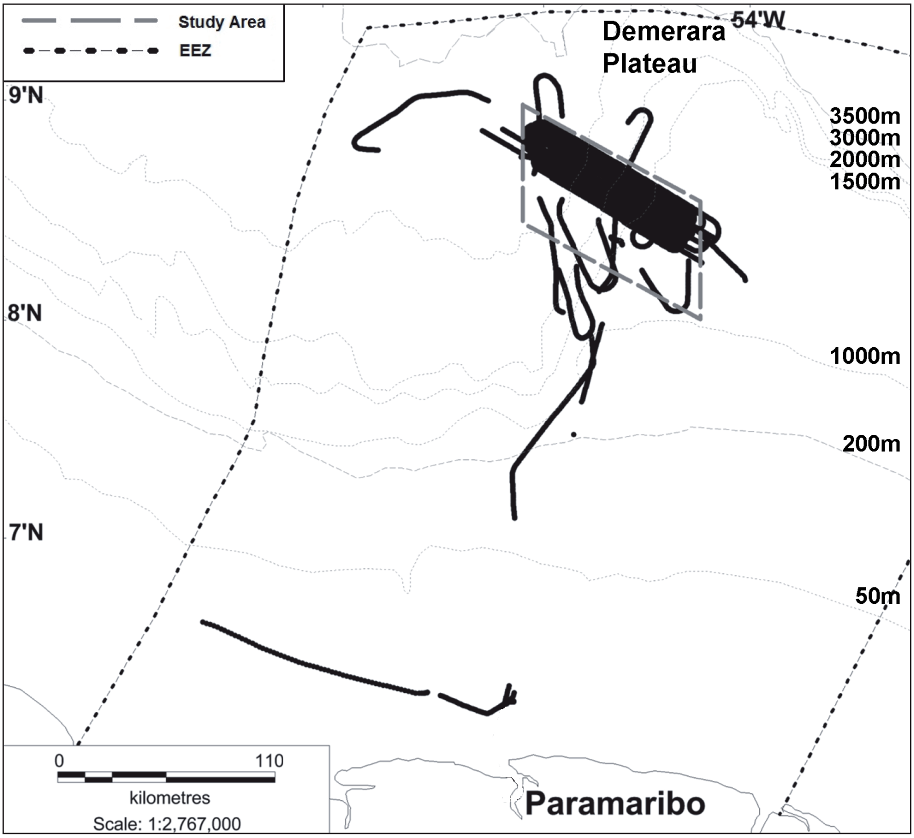

Figure 9.2 The main study area (in grey) where effort-related cetacean observations were carried out from a geophysical seismic survey vessel together with the GPS tracks (in black) within Suriname waters 17 May to 25 July 2012; some parts of the Exclusive Economic Zone between Guyana to the west and Suriname are disputed). No GPS tracks were available from 25 July onwards; however, effort-related observations continued from the survey vessel within the study area until 3 September 2012.

9.3.3 SPECIES CATEGORIES

The tall, falcate dorsal fins of Bryde's whales (*Balaenoptera brydei/edeni*; e.g. Notarbartolo di Sciara, 1983) are easily confused with those of sei whales. Baleen whales too distant from the vessel to allow definite identification (>1 km) were therefore classed as 'balaenopterid' (i.e. large rorqual with vertical blow and well-defined fin; definitely not blue or humpback whale) or 'Bryde's/Sei whale' (i.e. large rorquals with prominent, upright and falcate dorsal fin). Depending on sighting distance and glare intensities, similar looking dolphins were classed as follows: *Stenella/Delphinus* sp. (definitely one of the five *Stenella* species: pantropical spotted, Atlantic spotted, spinner, clymene, striped and/or *Delphinus* species); '*Stenella* sp.' (i.e. definitely a *Stenella* species with a mid-length beak: pantropical spotted, Atlantic spotted, clymene or striped; but definitely not spinner dolphin or long-beaked common dolphin); 'spinner/clymene sp.' (i.e. small active dolphins seen 'spinning' and likely to be one of these two species); or 'small blackfish sp.' (melon-headed whale or pygmy killer whale). All other unidentified animals were classed as 'dolphin sp.' or 'whale sp.'

9.3.4 DATA ANALYSIS (EFFORT-RELATED)

The data in the present study are not suitable to estimate the abundance of species because the survey track-lines fail to provide equal coverage probability (e.g. Buckland et al., 2001). Instead, the relative abundance (or encounter rate) was measured and expressed as the number of individuals per 100 km effort (BSS ≤4, swell ≤4 m, visibility ≥1 km). However, these relative abundances were only calculated for legs 1-2 for which detailed GPS tracks were available.

The bearing and distance to sightings were used to estimate the position of each sighting taking into account the location of the vessel at the time of the sighting and the observation eye-height (using the GEOFUNC Software with spherical trigonometry functions; NOAA, 2013). All GPS records were imported into MapInfo Geographic Information System (v. 11) using the projection WGS84.

To estimate species diversity, the Shannon-Wiener index was calculated. Only sightings which were identified to species level were used (Ricklefs, 2007): $H = -\Sigma P_i * \text{Ln } P_i$, where H is a measure of diversity and P_i is the proportion of individuals belonging to species i.

9.3.5 INCIDENTAL SIGHTINGS (OFF-EFFORT)

Cetacean sightings recorded during transit or those recorded when conditions were poor (i.e BSS >4, swell >4 m and visibility <1 km) were regarded as *incidental* (i.e. 'off-effort'). The species identification was checked and verified using written descriptions and photographs.

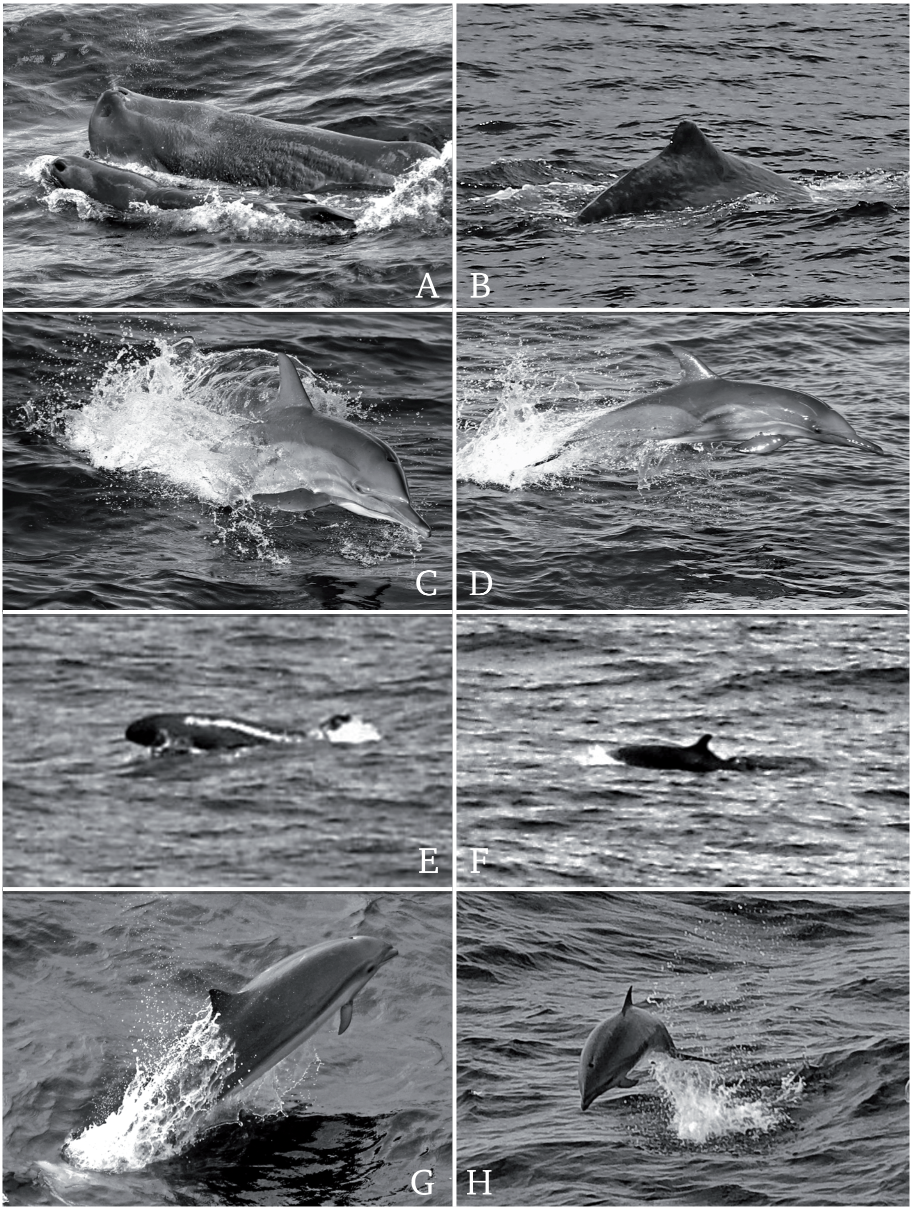

Plate 9.1 Photographs of sperm whale with calf (A), adult sperm whale (B) long-beaked common dolphin (C-D), false killer whale (E-F) and Fraser's dolphin (G-H). Photographs © M. de Boer (A, C-F, H), J. Saulino (B) and A. Williams (G).

9.3.6 OPPORTUNISTIC RECORDS (NOT EFFORT-RELATED)

Oil companies were contacted to request information about observed cetaceans within Suriname waters. These opportunistic records were integrated into the analysis only when verifying information in the form of photographs was available. Specimens of stranded cetaceans were inspected at the National Zoological Collection of Suriname (NZCS) at the University of Paramaribo.

9.4 RESULTS

9.4.1 DEDICATED SURVEY (EFFORT-RELATED)

A total of 1268 hours of observational effort were carried out in fair weather conditions (BSS 0-4, swell ≤4 m and visibility ≥1 km). During Leg 1, a total of 389 hours of effort (2922 km) and during Leg 2 a total of 376 hours of effort (3151 km) were carried out. During the third leg a total of 503 hours of effort were carried out. A total of 68 effort-related sightings and 2,152 animals were recorded. An additional 10 incidental sightings were also recorded (Table 9.1). A total of 44.1% of sightings remained unidentified (*n*=30) due to their distance from the vessel. In addition, 11.8% of sightings were identified to species categories (i.e. similar looking species; *n*=8). During transits (Trinidad to Suriname) a total of 5 incidental sightings were recorded. Whilst off Trinidad these included a sighting with 14 bottlenose dolphins and one with unidentified dolphins and whilst off Guyana, a further two sightings were recorded involving dolphin sp. and a group of 4 *Stenella* sp. (Table 9.1). The dedicated survey was carried out in waters with depths of 1000-2000 m (51.3%) whilst 1.4% was carried out in waters with depths <1000 m, 35% between 2000-3000 m and 12.2% >3000 m. The SSTs recorded during the survey ranged from 26 to 30°C (mean 28.3°C). The SSTs were the highest between 11 June and 22 July and again between 16-24 August. The vessel was in seismic operation for 57.2% of the visual effort and data presented here are potentially influenced by unknown reactions of cetaceans to seismic operations. The species richness during the dedicated survey was nine. The Shannon-Wiener diversity index was 1.62 for the whole survey period.

The different species encountered and the species categories are described below. The sightings are depicted in Fig. 9.3 and 9.4 and photographic evidence for each species can be found in Plates 9.1-9.3.

Table 9.1 Summary of cetacean sightings (S) and number of animals (N) recorded during the dedicated (effort-related) survey (Legs 1-3), including information regarding incidental sightings recorded during transit to and from the study area. Those incidental sightings recorded in the waters of Trinidad/Guyana are marked (*). Opportunistic records (non-effort related at-sea sightings forwarded by oil companies) and strandings (†) previously recorded in Suriname are also listed.

Species	**All sightings (N)**	**S (N)**	**S (N)**	**S (N)**	**Incidental Sightings (N)**	**Relative Abundance Index (encounter rate N/100 km)**	**Opportunistic Records & strandings† (N)**
Cetacean species	*Leg 1-3*	*Leg 1*	*Leg 2*	*Leg 3*	*Leg1-3*	*Leg1-2*	*Other*
Balaenoptera physalus	-	-	-	-	-	--	2† (2)
Balaenoptera edeni	1 (1)	1 (1)	-	-	-	0.016	-
Balaenoptera borealis	-	-	-	-	-	--	1† (1)
Sei/Bryde's whale	3 (5)	1 (3)	2(2)	-	-	0.082	-
Balaenopterid	2 (2)	-	2 (2)	-	-	0.033	3 (4)
B. acutorostrata/bonaerensis	-	-	-	-	-	--	2† (2)
Balaenoptera bonaerensis	-	-	-	-	-	--	1† (1)
Physeter macrocephalus	8 (67)	1 (20)	5 (38)	2 (9)	-	0.955	4, 1† (27, 1†)
Globicephala macrorhynchus	-	-	-	-	-	--	1 (8)
Pseudorca crassidens	1 (3)	-	1 (3)	-	-	0.049	-
Peponocephala electra	3 (520)	1 (120)	1 (200)	1 (200)	-	5.269	-
Small Blackfish sp.	1 (30)	-	1 (30)	-	-	0.494	-
Stenella longirostris	9 (410)	-	4 (155)	5 (255)	1 (5)	2.552	2 (250)
Stenella attenuata	3 (290)	-	1 (60)	2 (230)	-	0.988	-
Stenella frontalis	-	-	-	-	-	--	3 (65)
Lagenodelphis hosei	2 (90)	-	1 (30)	1 (60)	-	0.494	-
Delphinus capensis	1 (50)	1 (50)	-	-	-	0.823	-
Steno bredanensis	2 (65)	-	1 (40)	1 (25)	-	0.659	1 (3)
Tursiops truncatus	-	-	-	-	1* (14)	--	1 (10)
Sotalia guianensis	-	-	-	-	2 (13)	--	*(Resident)*
Stenella sp.	1 (30)	-	1 (30)	-	1, 1* (4, 4)	0.494	-
Dolphin sp	24 (582)	6 (123)	6 (85)	12 (374)	1,3* (2, 19*)	3.425	-
Whale sp.	4 (4)	1 (1)	2 (2)	1 (1)	-	0.049	2 (3)
Total	65 (2149)	12 (318)	28 (677)	25 (1154)	10 (61)	16.38	17, 7† (370, 7†)

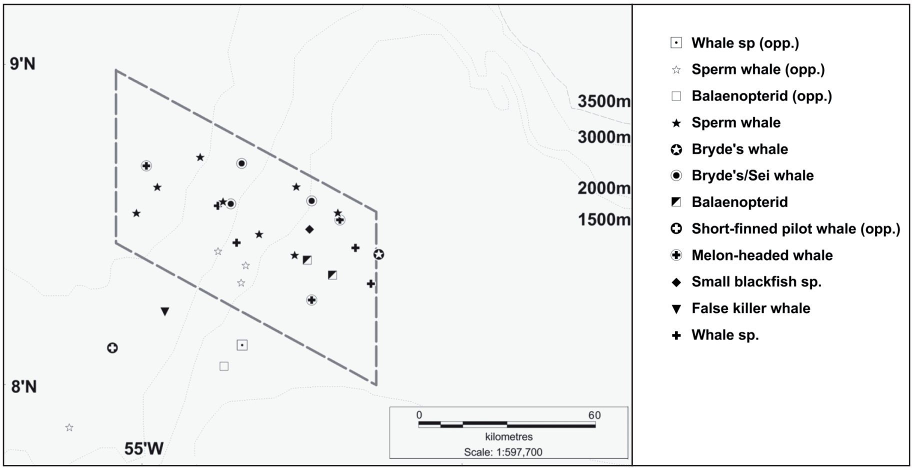

Figure 9.3 The main study area (in grey) and sighting positions of different whale and blackfish species recorded during a dedicated cetacean survey carried out from a geophysical seismic survey vessel within Suriname offshore waters between 17 May and 3 September 2012. Confirmed opportunistic records (opp.) contributed by various oil companies are also shown.

Bryde's whale (*Balaenoptera edeni*): The taxonomic status of Bryde's whale is complex and B. edeni is used here to refer to this species (IUCN, 2013). Three sightings of Bryde's/Sei whale were recorded, one sighting was confirmed as Bryde's whale through acoustic recordings and two balaenopterids were seen at close distances (i.e. at 400 m a juvenile and at 700 m). The confirmed Bryde's whale was seen in waters with a depth of 1225 m whilst the other whales were seen in 1217-2241 m water depth. All baleen whales were sighted between 14 June and 19 July.

Sperm whale (*Physeter macrocephalus*): Sperm whales were the most abundant whale species (0.955 ind/100 km; Table 9.1). An estimated 67 animals (including several sub-adults, at least three calves and no adult males) were seen in waters with an average depth of 2152 m (SD 711.4 m; Range 1293-2974 m) between June-August. The group-sizes ranged from 2 to 20. On one occasion, a small calf was seen making several short peduncle dives, behaviour which has been described as indicative of suckling (Gero and Whitehead, 2006).

Melon-headed whale (*Peponocephala electra*): Three sightings were made of melon-headed whales involving 485 animals (28 sub-adults, 7 calves). They were associating with Fraser's dolphins (*Lagenodelphis hosei*) and floating mats of Sargassum. This species was seen in 1191-3063 m water depth and sightings occurred on 9 June (120 animals), 28 June (200 animals) and 30 July (200 animals).

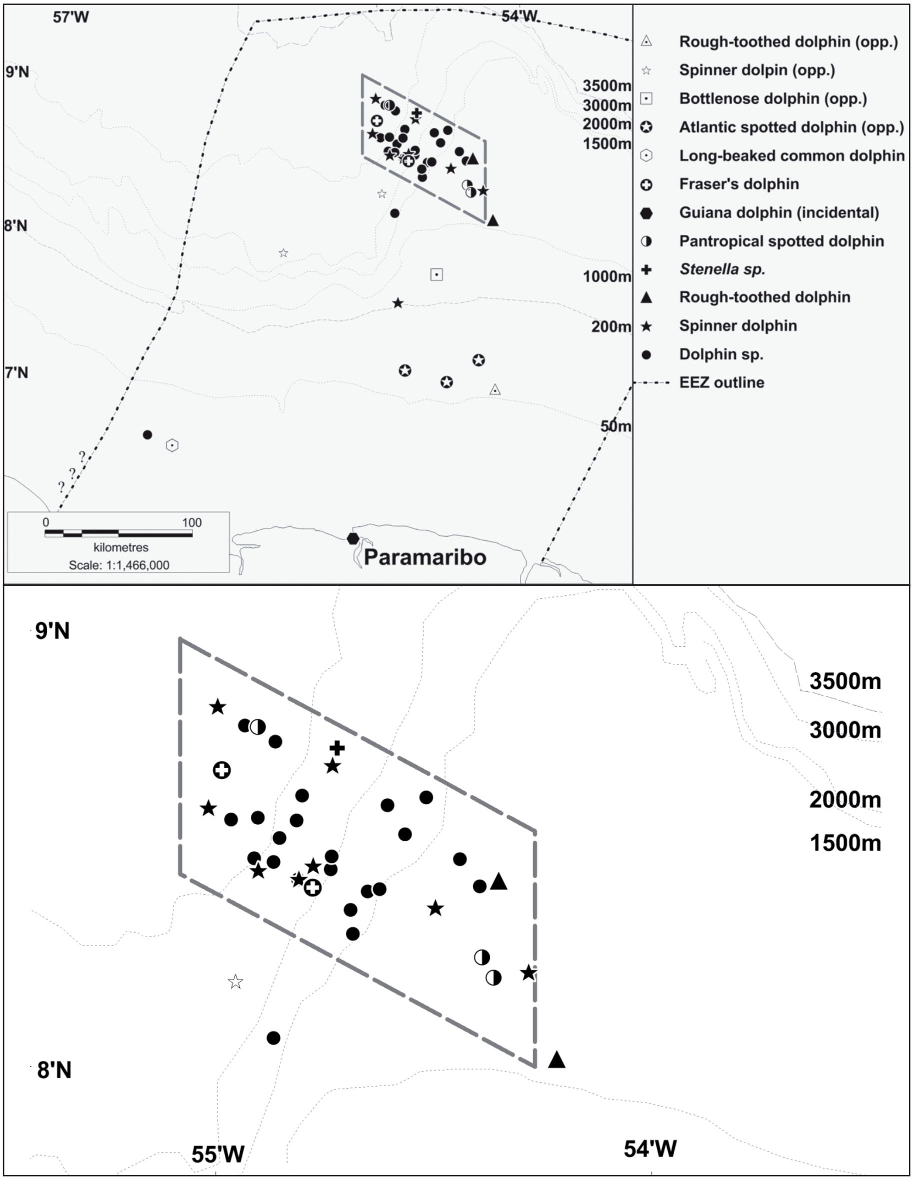

Figure 9.4 *The main study area (in grey) and sighting positions of different dolphin species recorded during a dedicated cetacean survey carried out from a geophysical seismic survey vessel within Suriname offshore waters between 17 May and 3 September 2012. Confirmed opportunistic records (opp.) contributed by various oil companies are also shown together with incidental records made during transits to and from the study area (some parts of the EEZ between Guyana and Suriname are disputed). All sighting records are shown at the top (A) and those within the study area are separately shown below (B).*

False killer whale (*Pseudorca crassidens*): On 13 July, a group of three false killer whales was photographed in 2444 m water depth.

Rough-toothed dolphin (*Steno bredanensis*): Rough-toothed dolphins were seen on two occasions: a) 1 July: water depth 1018 m, group size 40 and b) 24 August: water depth 1241 m, group-size 25. The group sighted on 1 July was observed for almost one hour and included one sub-adult and one calf.

Fraser's dolphin (*Lagenodelphis hosei*): Fraser's dolphins were sighted on two occasions (28 June and 20 August). The first record was a group of at least 30 to 40 dolphins which were associating with a group of melon-headed whales (water depth: 3063 m). The second encounter involved at least 60 dolphins, not associated with other species (water depth: 2100 m).

Common bottlenose dolphin (*Tursiops truncatus*): One incidental sighting of common bottlenose dolphin was recorded off Trinidad. The group of 14 was briefly bow-riding the vessel (water depth: 48 m). One adult displayed a large degree of scarring and was unusually pale and pinkish in colour (Plate 9.3F). This species was also recently recorded and photographed by the author in the coastal waters of Suriname (June 2013; Plate 9.3E).

Pantropical spotted dolphin (*Stenella attenuata*): Three encounters were recorded with pantropical spotted dolphins in 1140-3043 m water depth (11 July, 7 and 10 August) with group-sizes ranging from 30 to 200.

Spinner dolphin (*Stenella longirostris*): Eight sightings of spinner dolphins were recorded between 11 July and 3 September and one incidental sighting was recorded during transit on 25 July whilst heading back to Paramaribo. The dolphins were seen in waters with a mean depth of 2251 m (SD 720.95, n=8, range 1154–3094 m) but the incidental sighting occurred in waters with a depth of 200 m. The group size ranged between 5-100 animals (at least 14 sub-adults and 4 calves).

***Stenella* sp.:** Two sightings were recorded involving Stenella sp. and one sighting was recorded off Guyana on 16 May in 78.6 m water depth.

Long-beaked common dolphin (*Delphinus capensis*): On 17 May long-beaked common dolphins were observed whilst in transit between Trinidad and Suriname at a distance of 66 km from the coast (water depth: 35.8 m). This species was also recently recorded and photographed by the author in the coastal waters of Suriname (June 2013; Plate 9.1C-D).

Guiana dolphin (*Sotalia guianensis*): The Guiana dolphin was seen on two occasions at the mouth of the Suriname River during transits to and from the study area.

9.4.2 OPPORTUNISTIC RECORDS (NOT EFFORT-RELATED)

A total of 17 opportunistic records were accepted which related to the periods December 2008-March 2009 and August-October 2012 (Table 9.1; Fig. 9.2 and 9.3).

Mysticetes: Two sightings with large whales were recorded as humpback whale (*Megaptera novaeangliae*) in October 2012. However, no photographs were available to confirm species and these sightings were therefore classed as whale sp. Three sightings of unidentified large balaenopterids were recorded on 2 October 2012 (water depth: 1282-1776 m).

Odontocetes: Sperm whales were recorded in September 2012, totalling four confirmed sighting records of 27 animals. Short-finned pilot whales (*Globicephala macrorhynchus*) were recorded on 7 September 2012 in 2549 m water depth (Plate 9.3). Rough-toothed dolphins were recorded once in shallow waters (49 m) in January 2009. Two sightings of spinner dolphins were recorded in the months of August and September (water depths: 1946-1974 m). One sighting involving bow-riding bottlenose dolphins was recorded on 8 October 2012 in 451 m water depth. Three sightings of Atlantic spotted dolphins (*Stenella frontalis*) were recorded between December 2008 and March 2009 (Plate 9.3). The water depths ranged between 57 and 72 m. This species was also recently recorded on several occasions by the author in the coastal waters of Suriname (June 2013; Plate 9.3G-H).

9.5 DISCUSSION

Records of cetacean species in Suriname waters were anecdotal and this study confirmed the presence of 13 species, of which 11 are new species records for Suriname. The most abundant species were the sperm whale and melon-headed whale. It was found that the spinner dolphin and pantropical spotted dolphin were also frequently encountered in large groups. The relative abundance index for all cetaceans (16.38 ind/100 km) was relatively low as was expected considering the survey was confined to deep water only (1200-3300 m). When comparing these estimates to other systematic surveys in tropical regions in the East Atlantic, off Gabon in West Africa, the estimates were found to be much higher in areas which spanned both deep and shallow waters (20.9 ind/100 km; De Boer, 2010). Indeed, tropical shallow shelf waters, for example off the Maldives in the Indian Ocean, generally hold a much more diverse and abundant cetacean community (35.3 ind/100 km; Clark et al., 2012).

The diversity of cetaceans, as measured by the Shannon-Wiener index was relatively high (1.62). This index assumes that all species are represented in a sample and that they are randomly sampled (Ricklefs, 2007). This is difficult to achieve with the current survey design; however, the 4-months duration of the dedicated study together with the systematic transect lay-out probably increased our chances of recording different species. The present index is similar to those presented for Aruba (1.29) by Luksenburg (2013). Various other studies have used the Shannon-Wiener index to measure local diversity of cetaceans (Dulau-Drouot et al., 2008;

Gannier, 2009; Kizka et al., 2010); however, comparison with the present study is hampered by differences in spatial and temporal sampling effort among survey areas.

Caution is also required because overt responses to the seismic sound source by some cetacean species may have occurred. For example, responses by short-finned pilot whales and Atlantic spotted dolphin were documented off West Africa (Weir, 2008ab; Cerchio et al., 2010).

9.5.1 SPECIES ACCOUNTS

Mysticetes: Bryde's whales off the north coast of Venezuela (Olesun et al., 2003) have low frequency calls with a specific frequency of 44Hz which was close to those recorded during the present detection (a 40 Hz signal was located in approximately the same position where the whale was seen at the time of the sighting; De Boer et al., 2012). This species is the only baleen whale present year-round in significant numbers within the WCR (Reeves, 2005) and especially in the southern Caribbean (e.g. Notarbartolo di Sciara, 1983; Romero et al., 2001; Debrot et al., 1998). No other sightings or stranding records of Bryde's whales are known for Suriname or adjacent waters; however, they are common in Venezuela (Romero et al., 2001; Acevedo-Galindo 2007). The distribution of Bryde's whales appears to be seasonal with whales occurring mainly to the east between March and August whilst from August to December the whales occur further west (Notarbartolo di Sciara, 1983). This might explain the lack of sightings in the present survey from August onwards. In the coastal waters off central Venezuela, the Bryde´s whale can be present between October-February (Acevedo-Galindo 2007; Bolaños-Jiménez et al., 2007a).

Odontocetes: Sperm whales were seen regularly and most frequently in the vicinity of the Demerara Plateau. In the northeast of the Caribbean, sperm whales are strongly seasonal and are rarely seen from April through September (Mignucci-Giannoni 1998). In the southeast of the Caribbean, between November and March, sperm whales are consistently found (Ward et al., 2001). Sightings and strandings of sperm whales have also been reported off Venezuela (Bolaños-Jiménez and Villarroel-Marín, 2008a). Three at-sea sightings were reported for French Guiana in October (Mannocci et al., 2013). The present study highlights that this species is relatively abundant between June and September and that it uses the area for breeding/nursing.

Melon-headed whales were recorded in deep waters throughout this survey and within the region this species occurs in the Gulf of Mexico, off the Lesser Antilles and Dominica (Ward et al., 2001). A mixed group of melon-headed whales and Fraser's dolphins was reported off Carriacou (IFAW, 1996). Records exist for Puerto Rico and Venezuela (Mignucci-Giannoni, 1998; Bolaños and Villarroel-Marın, 2003).

Plate 9.2 Photographs of melon-headed whale (A-B), Pantropical spotted dolphins with calf (C-D), spinner dolphin (E-F) and rough-toothed dolphins (G-H). Photographs © M. de Boer (E-H) and A. Williams (A-D)

False killer whales were seen only once and the distribution of this species in the Caribbean is poorly known (Ward et al., 2001). In the southern part of the Caribbean, it has been reported in Colombia (Alberico et al., 2000; Pardo et al., 2009), Aruba (Luksenburg, 2011) and the coastal waters of Venezuela (Bermúdez-Villapol and Boher, 1996; Romero et al., 2001).

Short-finned pilot whales were recorded on only one occasion in September yet this species is regarded as very common in the Caribbean (Ward et al., 2001). Off French Guiana this species was recorded regularly in October (Mannocci et al., (2013) and also during boat-based surveys (September-December 2009; Vines et al., 2010). Pilot whales have also been recorded in Venezuela but only in the eastern waters (e.g. Romero et al., 2001).

Rough-toothed dolphins were observed on three occasions and this species is generally regarded as uncommon in the Caribbean with reports for the Gulf of Mexico, the West Indies, Colombia, Venezuela (e.g. Romero et al., 2001) and off Aruba (Luksenburg, 2013). Off French Guiana this species was validated by Van Canneyt et al. (2009).

Fraser's dolphins were encountered on two occasions yet no records for Suriname or adjacent waters currently exist. Within the Atlantic Ocean the reported number of sightings of Fraser's dolphins is low (e.g. Hersh and Odell, 1986; Weir et al., 2013). Records exist from the Puerto Rican Bank (Mignucci-Giannoni et al., 1999), the Lesser Antilles including Dominica, St. Vincent, the Grenadines (Caldwell et al., 1976; ECCN 2000) and the Gulf of Mexico (Würsig et al., 2000). Other sightings, offshore Guadaloupe, offshore Carriacou and offshore La Martinique have also been reported (IFAW, 1996; Boisseau et al., 2000; Rinaldi et al., 2006; Jérémie et al., 2006). Recently, Fraser's dolphins were reported off the leeward shore of Dominica (Gero and Whitehead, 2006) and offshore Montserrat (Weir et al., 2011). Within the region, two dolphins stranded in Venezuela (June 1999; Bolaños and Villarroel-Marın, 2003) and one dolphin stranded on Bonaire (August 2011; Witte et al., 2012).

Common bottlenose dolphins were recorded twice and are generally described as common in the coastal waters and outer edge of the continental shelf in the Gulf of Mexico and in the waters of the Caribbean and southwards to Venezuela and Brazil (Swartz and Burks, 2000; Ward et al., 2001). In the Venezuelan Atlantic, near Trinidad and Tobago, this species has been observed in mixed aggregations with Atlantic spotted dolphin (Bolaños-Jiménez et al., 2007a). Bottlenose dolphins were reported in high densities in the continental slope zone off French Guiana (Mannocci et al., 2013) and probably regularly occur within the Guiana Shield.

Atlantic spotted dolphins were recorded only in shallow waters during this survey and no previous records for Suriname or adjacent waters currently exist. Off Venezuela, the species is widespread in both inshore and offshore waters (Romero et al., 2001; Acevedo-Galindo, 2007), in Colombia it is found to be more common than pantropical spotted dolphins (Vidal, 1990; Pardo and Palacios, 2006) and this species was recently recorded off Aruba (Luksenburg, 2013).

Pantropical spotted dolphins were recorded in deep waters (>1000 m) and this species has been reported off the Dominican Republic, Dominica, St. Vincent and the Grenadines, St. Lucia, Tobago, Colombia (Ward et al., 2001) and the ABC Islands (Debrot et al., 1998) but only one record is known for Venezuela (eastern sector; Romero et al., 2001). Confirmed at-sea sightings were reported off French Guiana between September-December 2009 (Vines et al., 2010).

Spinner dolphins were sighted regularly and mainly in deep waters and commonly occur in the Caribbean, the Gulf of Mexico, and throughout the West Indian chain southwards to Venezuela (Würsig et al,. 2000). It has also been recorded in the Bahamas, Cuba, Puerto Rico, Dominica, St. Vincent, the Grenadines and the Caribbean in general (e.g. Jefferson and Lynn, 1994; Romero et al., 2001). The species also occurs off the ABC Islands and they are fairly common off Venezuela (Debrot et al., 1998; Romero et al., 2001; Acevedo-Galindo, 2007; Luksenburg, 2011).

Long-beaked common dolphins were recorded on one occasion in shallow waters and this species commonly occurs along the eastern coasts of Venezuela in areas with coastal upwelling (Romero et al., 2001; Bolaños-Jiménez et al., in press). A recent review by Jefferson et al. (2009) shows that the species is expected to occur off the Guianas. The only reliable records are of a long-beaked common dolphin captured off Trinidad in April 2006 (Boisseau et al., 2006), a stranding in the Gulf of Paria (J. Bolaños-Jiménez, unpubl. data), a sighting off Aruba (Luksenburg, 2013), and recently the species was validated for French Guiana (Van Canneyt et al., 2009), central-western Venezuela (Bolaños-Jiménez et al., in press) and Colombia (Palacios et al., 2012). The species has not been confirmed to occur in most of the Caribbean Sea, i.e. Central America, Greater Antilles or West Indies (Jefferson et al., 2009).

Guiana dolphins were recorded at the entrance of the Suriname River. This coastal species is the most frequently encountered cetacean in Suriname which may swim up rivers, particularly during the dry season, when the saltwater incursion is further upriver and the salinity is high enough (Gomez-Salazar et al., 2010). Recently, causes for concern were raised regarding dolphin displacement following river seismic activities in Suriname (Pool, 2012). The Guiana dolphin is known to be incidentally killed in gillnets at the mouths of the Suriname and Coppename Rivers and also in French Guiana (Vidal et al., 1994; Husson, 1978, Van Waerebeek, 1990; Plouvier et al., 2012). The Guiana dolphin is listed as Vulnerable in Venezuela (Bolaños-Jiménez et al., 2008) and its status in Suriname has yet to be established.

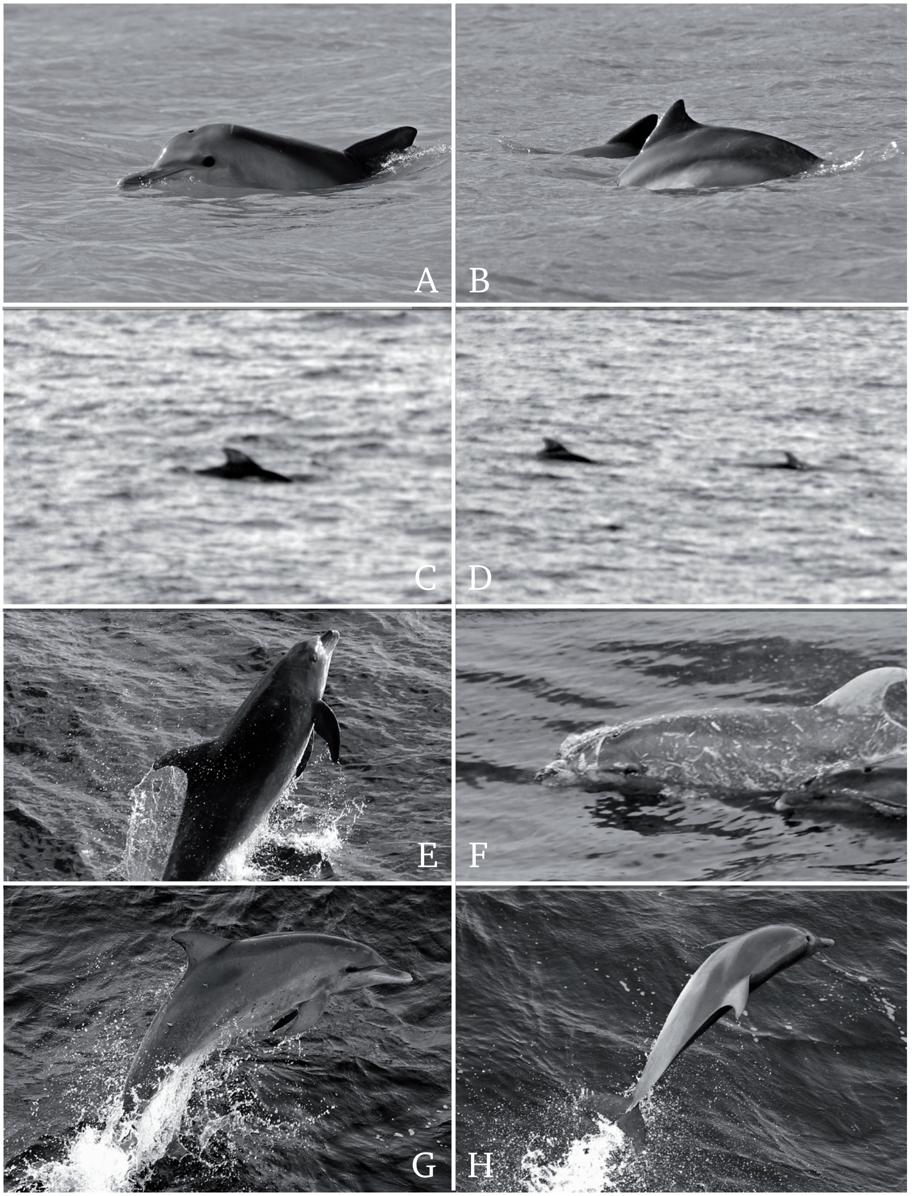

Plate 9.3 *Photographs of Guiana dolphin (A-B), short-finned pilot whale (C-D), bottlenose dolphin (E-F) and Atlantic spotted dolphin (G-H). Photographs © M. de Boer (A-B, E-H) and F. Penin (C-D).*

9.5.2 PREVIOUS RECORDS FOR SURINAME

Several cetacean species have previously been reported in Suriname waters (Husson, 1978; Table 9.1).

Mysticetes: A stranding of a sei whale was recorded in 1964 in NW Suriname (Husson, 1978) and the skull of this specimen was recently examined by the author at the NZCS in Paramaribo. It was concluded that the skull probably was that of a sei whale (K. Van Waerebeek, pers.comm.). There are a few records for sei whales in the Caribbean and the species is considered rare (Notarbartolo di Sciara, 1983; Romero et al., 2001).

Two or three records of fin whale are reported for Suriname in 1910 and 1923 (Husson, 1978). The baleen morphology as shown in Husson (1978) seem to be consistent with that of the fin whale although physical inspection of the baleen would be required to exclude other large rorquals (K. Van Waerebeek, pers. comm.). The author could not locate the fin whale specimens at the NZCS. There are a few records for fin whales for the Caribbean (Slijper et al., 1964), for Colombia (Prieto Rodríguez, 1988; Vidal, 1990); Venezuela (Lira et al., 1995; Swartz and Burks, 2000; Romero et al., 2001) and the Gulf of Mexico (Jefferson and Schiro, 1997). On the basis of a stranding in August and a sighting in March, Bolaños-Jiménez and Villarroel-Marín (2008b) speculated that Venezuelan waters could be visited by fin whales coming from both the north and southern hemispheres. More recently, fin whales were sighted off French Guiana during aerial surveys in October 2008 (Mannocci et al., 2013).

The skeleton of a minke whale (unknown stranding date) was collected around 1923 or 1924 near Coppename Punt in Suriname and identified by Husson (1978) as *Balaenoptera acutorostrata*. However, the identification cannot be verified, as insufficient voucher material is available. More recently, another minke whale stranded in Suriname (approximately 12 years ago, P. Ouboter, pers. comm), but no associated data appear to exist. Only occasional records of common minke whale are known for the NE Caribbean (Rice 1998). Another record of minke whale involved an animal seen swimming in the Coppename River in October 1963 which was subsequently killed and identified as Antarctic minke whale *B. bonaerensis* (Husson, 1978). This specimen showed a wide, conspicuous dark band along the outer margin of the baleen plates which were recently inspected and photographed by the author at the NZCS in Paramaribo. The colouration and morphology of the baleen as shown by the photos are consistent with those of the Antarctic minke whale (K. Van Waerebeek, pers. comm.). A specimen of *B. bonaerensis* recently recorded in Togo (Gulf of Guinea, western Africa) led Segniagbeto and Van Waerebeek (2010) to conclude that this species may at least occasionally cross the equator into the Northern Hemisphere.

Odontocetes: A sperm whale stranded in 1938 was described by Husson (1978). The Guiana dolphin was originally described by P.J. Van Beneden in 1864 based on dolphins taken at the mouth of the Marowijne (Maroni) River (Husson, 1978), i.e. at the border area between French Guiana and Suriname.

9.5.3 SPECIES INVENTORY

An inventory of the cetacean species for Suriname and those previously documented within the Guiana Shield and along the Venezuelan Atlantic region is shown in Table 9.2 and shows that Suriname has a species rich and diverse cetacean fauna. It is expected that increased future survey effort expanding to shelf and coastal waters and carried out year-round will likely result in the identification of more species, especially those that are known to occur elsewhere within the WCR. The survey described here can only provide a ‘snap shot’ view of the presence and distribution of cetaceans recorded during the months May-September (dedicated survey) and August-March (opportunistic records). The data show that the Suriname cetacean community is primarily composed of odontocetes (sperm whales and dolphins). Mysticetes, particularly large balaenopterids were also observed although their occurrence was probably seasonal with Bryde’s/Sei whales recorded only during June and July when the SSTs were reaching 30°C. The opportunistic records highlighted that large baleen whales were recorded from early October onwards and that shelf waters are probably more important for the dolphin community compared to deep waters.

Cetaceans are vulnerable to human-related threats in the WCR, including direct exploitation (removal from populations by live-captures), incidental bycatch in fishing gear (Van Waerebeek, 1990; Vidal et al., 1994), habitat degradation or loss from coastal development, pollution, acoustic disturbances, unregulated whale-watching operations and vessel strikes (e.g. Reeves, 2005; Borobia and Barros, 2006; Bolaños-Jiménez et al., 2007b). Information on the occurrence of cetaceans in the Guianas is therefore vital to investigate and subsequently mitigate such potential threats. The listing of Protected Areas under the (SPAW) Protocol is under development (UNEP, 2012) and the present study therefore provides a timely overview of baseline data to inform UNEP’s Marine Mammal Action Plan for the WCR. It is emphasized that more systematic at-sea surveys, photo-identification and behavioural studies are needed in order to assess the status of cetaceans and to develop effective regionally and nationally specific conservation measures not only in Suriname waters but within the Guinea Shield as a whole. It is considered important and recommended that all research activities in this area document and report their opportunistic records, in order to gain a better understanding about the occurrence, distribution and ecology of cetacean species within the Guiana Shield.

Table 9.2 List of cetaceans occurring off Venezuela, Suriname and French Guiana, including strandings (†), sightings (x) and those expected to occur based on records elsewhere within the Wider Caribbean Region.

Species	**Latin name**	**Venezuela**	**Suriname**	**French Guiana**
Humpback whale	*Megaptera novaeangliae*	x	*(unconfirmed)*	x
Fin whale	*Balaenoptera physalus*	x	†?	x
Sei whale	*Balaenoptera borealis*		†	
Bryde's whale	*Balaenoptera edeni*	x	x	*expected*
Common minke whale	*Balaenoptera acutorostrata*		†	
Antarctic minke whale	*Balaenoptera bonaerensis*		†	
Sperm whale	*Physeter macrocephalus*	x	x , †	x
Dwarf sperm whale	*Kogia sima*	x	*expected*	*expected*
Pygmy sperm whale	*Kogia breviceps*	*expected*	*expected*	*expected*
Cuvier's beaked whale	*Ziphius cavirostris*	x	*expected*	x
Gervais beaked whale	*Mesoplodon europaeus*	x	*expected*	*expected*
Blainville's beaked whale	*Mesoplodon densirostris*	*expected*	*expected*	*expected*
Killer whale	*Orcinus orca*	x	*expected*	x
Pygmy killer whale	*Feresa attenuata*	x	*expected*	*expected*
Melon-headed whale	*Peponocephala electra*	x	x	x
False killer whale	*Pseudorca crassidens*	x	x	x
Short-finned pilot whale	*Globicephala macrorhynchus*	x	x	x
Risso's dolphin	*Grampus griseus*	x	*expected*	x
Bottlenose dolphin	*Tursiops truncatus*	x	x	x
Rough-toothed dolphin	*Steno bredanensis*	x	x	x
Long-beaked common dolphin	*Delphinus capensis*	x	x	x
Striped dolphin	*Stenella coeruleoalba*	x	*expected*	x
Frasers dolphin	*Lagenodelphis hosei*	x	x	*expected*
Pantropical spotted dolphin	*Stenella attenuata*	x	x	x
Atlantic spotted dolphin	*Stenella frontalis*	x	x	*expected*
Spinner dolphin	*Stenella longirostris*	x	x	x
Clymene dolphin	*Stenella clymene*	expected	*expected*	*expected*
Guiana dolphin	*Sotalis guianensis*	x	x , †	x

Data sources: Husson 1978; Romero et al., 2001; Ward et al., 2001; Bolaños and Villarroel-Marın, 2003; van Ganneyt et al., 2009; Vines et al., 2010; Mannocci et al., 2013; this study.

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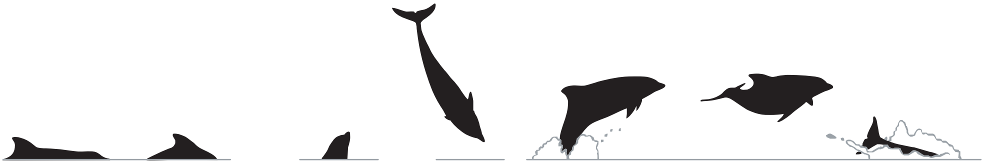
CHAPTER 10

SYNTHESIS

Bottlenose dolphin



The continuously expanding anthropogenic activities in marine waters – i.e. coastal systems, high seas[1] or polar seas[2] – increases the chances that the habitat quality of marine mammals will be degraded. In this thesis I have focussed on cetaceans and conclude that for most species our knowledge regarding their true distribution, abundance, status, and in a wider context their ecological roles within marine systems, are yet to be fully understood. For instance, the Cetacean Specialist Group of the International Union for Conservation of Nature lists many species of cetaceans as *Data Deficient* meaning that there is not enough information to ascertain their status (IUCN, 2013). This obviously, seriously hampers the adequate management of cetacean populations, including e.g. Environmental Impact Assessments for planned human activities. Nevertheless, management authorities in most countries are obliged by law and urged through conventions to offer protection and implement mitigation measures against human-related impacts.

This lack of information is mainly caused by the fact that cetaceans can move over large distances, e.g. between feeding grounds or between feeding and calving grounds. For most species, the distribution is generally patchy and some areas are more densely occupied than others. In order to obtain adequate basic data on their distribution, abundance and status, large-scale dedicated cetacean surveys are a means of obtaining good data. However, to assess trends in abundance, such surveys need to be conducted repeatedly. This is often hampered by logistical and budgetary constraints.

In order to address the lack of data and the emerging conservation needs, this study sets out to explore the use of flexible survey designs, using multi-method approaches and Platform of Opportunity (PO) based data, and in particularly adopting these in areas which have received little spatial or temporal survey coverage. This synthesis draws together the major findings, discusses the implications and relevance of using PO-based data for estimates in numbers and distribution as well as conservation management purposes including e.g. designation of Marine Protected Areas.

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[1] **High seas** cover, in maritime law, all parts of the mass of saltwater surrounding the globe that are not part of the territorial sea or internal waters of a state

[2] **Polar seas** is a collective term for the Arctic Ocean and the southern part of the Southern Ocean.

I first provide an overview of the different PO-based data sets used in this study to assess the fine-scale spatial and temporal distribution of cetaceans. I next explore how PO-based data can complement standard survey designs and how these can overcome some of the knowledge gaps in survey coverage in space and time and for different species. I evaluate the extent to which the PO-based data is accurate and sufficient to provide answers about temporal or spatial variation in species occurrence. I assess the value of PO surveys for the conservation management of cetaceans and the low-cost aspect in particularly for development countries and under-recorded areas. Finally, I highlight the value of multi-method approaches and make recommendations to fill existing gaps through the optimisation of future PO survey efforts and how such data can be implemented as part of multi-method approaches and/or feed multiple data-sets.

10.1 COMPLEMENTARY VALUE OF PO-BASED DATA

Cetacean monitoring often consists of estimating population abundance or density across a wide area (e.g. SCANS surveys), monitoring of changes in the patterns of occurrence of cetacean species within an area can also provide important information (Evans and Hammond, 2004). PO vessels provide a low-cost tool for cetacean research and may provide opportunities to survey otherwise infrequently or hardly studied offshore habitats. The different PO-based datasets used in this thesis to assess the fine-scale spatial and temporal distribution of cetaceans, are listed in Table 10.1. In the next section I demonstrate their complementary value.

10.1.1 BRIDGING THE GAP

The majority of offshore cetacean surveys are made from research vessels during a narrow time-window in the summer months, when weather conditions are most suitable (e.g. Scans surveys 1994 and 2005; SCANS-II, 2008; T-NASS, 2008). These surveys are important, because they can enable absolute population estimates to be generated for large areas. However, due to their high costs they generally are not carried out in other seasons or in a range of subsequent summer seasons and consequently this type of surveys has long time-windows between surveys. Early signs of changes in the distribution or population sizes may therefore go unnoticed until the next survey is carried out. For example, minke whales were more abundant in the northwest North Sea in 1994 but their distribution had shifted to the central North Sea in 2005 (Hammond et al., 2013). Such observed change in distribution, is yet unexplained but may be related to environmental factors such as climate change and/or a change in prey availability (MacLeod, 2009; Hammond et al., 2013). It is therefore important to collect data on a more regular basis.

Table 10.1 Overview of the different types of Platforms of Opportunity used in this study.

This thesis		**Type of Platform of Opportunity**				
Chapter	Running title	Fisheries monitoring vessel	Supply vessel	Wildlife Operator	Fixed point (Island)	Geophysical (seismic) survey vessel
2	Winter abundance estimates for common dolphins in the English Channel	X				
3	Interactions between common dolphins and pelagic pair-trawl fishery	X	X	X		
4	Spring distribution and density of minke whales in the Central North Sea		X			X
5	Photo-ID methods reveal site-fidelity of Risso's dolphins in a shallow coastal system			X	X	
6	Influence of topographic and dynamic cyclic variables on the distribution of small cetaceans				X	
7	Cetacean distribution and relative abundance in Gabonese waters					X
8	First record of a white rough-toothed dolphin off West Africa					X
9	Cetaceans observed in Suriname and adjacent waters		X			X

An example of collecting fine-scale data over a longer period of time is shown in Chapter 4, where a small-scale Line Transect (LT) survey in combination with PO-based surveys were carried out along the Dogger Bank. The use of PO-based data allowed for comparisons between indices of abundance (number of whales 100 km^{-1}) to other regions, seasons and surveys. For example, the index of abundance in April-May (1.77 whales 100 km^{-1}) was much higher compared to those estimated from the SCANS surveys carried out in July (0.33 whales 100 km^{-1} for SCANS-I in 1994; Hammond et al., 1995) and 0.69 for SCANS-II in 2008; Hammond et al., 2013). This indicates that minke whales may temporarily congregate in particular areas. As such, PO-based data will become useful when monitoring changes in indices of abundance across areas but also seasons (spring *versus* summer, see section 10.1.5) and help to bridge the gaps (i.e. long-time windows) of large-scale surveys. Similarly, the study outlined in Chapter 2, provided the first abundance estimate for the winter population of common dolphins in the English Channel for which previously only summer estimates were available (e.g. Hammond et al., 1995; Cañadas et al., 2004; Hammond et al., 2013).

Indices of abundance are easier and quicker to obtain than absolute abundance estimates. When employing such indices, for example to monitor trends, an assumption is made that a consistent proportion of a population within the survey area is detected and therefore, any changes in the indices of abundance are assumed to reflect a change in absolute abundance. Studies focussing on indices of abundance have been carried out elsewhere using data from a ferry-based survey in the English Channel and Bay of Biscay (Kiszka et al., 2007). On a broader-scale, a coalition of ferry-based groups in Europe aims to identify trends in cetacean occurrence, distribution and abundance using analyses that can be conducted within each ferry route or using a combination of different ferry routes to provide a greater spatial coverage (Brereton et al., 2009). Such studies are also important to allow a more continuous data collection to help bridge the gaps of large-scale surveys.

10.1.2 IMPROVING ABUNDANCE ESTIMATIONS AND SURVEY DESIGNS

POs can be used for collecting information on the abundance estimation process itself. This was explored by Williams (2003) who found that POs proved valuable for collecting data to model the role of measurement error on abundance estimation. Williams (2003) furthermore suggested that PO surveys could potentially be used to train observers in survey protocols and for field-testing new methods to estimate *g(0)* (the detection probability on the track-line), measure radial distance or study how cetaceans respond to ships during sightings surveys (e.g. Leaper and Gordon, 2001; Palka and Hammond, 2001).

This is explored in Chapter 2, where a unique situation was used in which the same vessel acted as both PO and LT-survey vessel. LT-surveys could be carried out when the vessel was not carrying out *primary tasks* (i.e. fisheries monitoring). In addition, the PO-based data, although not suitable to estimate the local abundance because the survey track-lines failed to provide equal coverage probability, allowed for the observers getting trained in taking accurate distance and bearing readings and get familiar with survey protocols needed for LT-surveys. By manning two observer platforms during both LT and PO-based survey lines, we were able to achieve a high enough sample size to calculate *g(0)*. The findings also highlighted that estimates for the winter population of the common dolphins may have been positively biased by at least a factor of 1.5 as a result of responsive movement. This was further investigated by using the PO-based data which showed that the survey speed affected the dolphin responsiveness to the survey vessel.

Another example of improving the abundance estimation process is presented in Chapter 4. Unusual for this study was the combination of both PO and LT vessels. The timing of the LT survey unexpectedly supplied a ‘peak’ density for minke whales, whilst the PO datasets showed the temporal variability of the whales’ presence. The longer temporal coverage by the PO surveys highlighted the problem of timing a dedicated survey properly and furthermore showed that PO vessels can successfully be used to identify areas and periods of high density to improve designs for future line-transect surveys.

Finally, PO-based data can be used to review the reliability of abundance estimates. In Chapter 5, there was uncertainty about the extent to which the assumptions for an appropriate application of the mark-recapture technique were met. However, it was found that the mark-recapture estimates of Risso’s dolphins closely matched the opportunistic census technique estimates. The census technique therefore supported the reliability of the mark-recapture estimate. It is of interest to note here that LT-surveys for Risso’s dolphins failed to achieve a high enough sample size to allow for dolphin abundance to be estimated using distance-sampling techniques: a common problem with regards to this species and LT surveys. The PO-based boat surveys complemented the dedicated surveys by increasing the sample-size of the number of identified dolphins. Land-based data from Bardsey Island in Chapter 6 showed that the dolphins were foraging in localised shallow hotspots and this may have impacted the chances of detection during the LT-surveys. I conclude that the LT-survey design was not appropriate in this particular study and this is presumably a more common problem encountered in LT-surveys. The used multi-method approach might ameliorate this drawback.

10.1.3 ADDING NEW KNOWLEDGE REGARDING THE STATUS OF A POPULATION

In Chapter 2 and 3, new information regarding the status of common dolphins was supplied for the English Channel during the winter months. The PO-based data used, showed that the overlap between pelagic fisheries and the common dolphin hotspot resulted in direct dolphin mortality through bycatch. In addition, our local strandings data highlighted that the number of stranded dolphins was probably much higher than previously reported and that the numbers of dolphins present in the region apparently are in decline.

In Chapter 5, new insights to the status of Risso’s dolphin in UK waters are presented. The practical difficulties of studying such irregular but seasonal aggregations of a relatively scarce species were highlighted and also alternative methods of analysing sparse opportunistic data were explored. This study confirmed the regular presence of Risso's dolphins off Bardsey Island and the presence of calves shows that the area is important for this species. Elsewhere, a similar approach was used to study the social structure of Risso’s dolphins in the Azores (Hartman et al., 2008).

10.1.4 IMPROVING SPATIAL RESOLUTION, E.G. FINE-SCALE DISTRIBUTION, HOTSPOTS AND HABITAT-USE

PO-based data can be used to better understand the fine-scale spatial and temporal distribution of cetaceans. In Chapter 6, a PO-based study was designed to explore how Risso's dolphin and harbour porpoise use the different habitats that surround Bardsey Island. This fine-scale study provided an insight into the spatio-temporal distribution of both species that single large-scale surveys may not capture. Using

Table 10.2 Overview of the complementary values of the PO-based data used in this thesis

This thesis		
Chapter	**Running title**	**Complementary value of PO-based data**
2	Winter abundance estimates for common dolphins in the English Channel	1) Improving the abundance estimation process 2) Adding new knowledge regarding the status of common dolphins 3) Improving knowledge regarding seasonal and inter-annual changes in distribution and abundance
3	Interactions between common dolphins and pelagic pair-trawl fishery	1) Adding new knowledge regarding the status of common dolphins 2) Improving knowledge regarding inter-annual changes in relative abundance 3) Improve the monitoring of threats 4) Monitoring small annual changes in indices of abundance
4	Spring distribution and density of minke whales in the Central North Sea	1) Bridging the gap 2) Improving the abundance estimation process 3) Improving knowledge regarding seasonal changes in distribution and abundance
5	Photo-ID methods reveal site-fidelity of Risso's dolphins in a shallow coastal system	1) Support the reliability of abundance estimates 2) Adding new knowledge regarding the status of Risso's dolphins
6	Influence of topographic and dynamic cyclic variables on the distribution of small cetaceans	1) Improving knowledge regarding fine-scale distribution 2) Improving knowledge regarding habitat-use
7	Cetacean distribution and relative abundance in Gabonese waters	1) Monitoring species occurrence 2) Long time-span increased the probability of detecting different cetacean species 3) Help to quantify the cetacean diversity 4) Improve knowledge regarding behaviour of poorly-known species, such as rough-toothed, Clymene and Fraser's dolphins
8	First record of a white rough-toothed dolphin off West Africa	
9	Cetaceans observed in Suriname and adjacent waters	

spatial modeling techniques (GAMs) on land-based data it was shown that porpoises and Risso's dolphins were linked to topographic and dynamic cyclic variables with both species using different core areas or hotspots. In addition to improving harbour porpoise and Risso's dolphin monitoring methods, the data presented in this chapter can direct future research focusing on the fine-scale distribution of these species within shallow coastal systems.

The different complementary values of PO-based data described in this section are listed in table 10.2

10.2 THE ACCURACY AND RELIABILITY OF PO-BASED DATA *VERSUS* SYSTEMATIC SURVEY DATA

Williams et al., (2006) explored the possibilities for analysing PO-based data collected onboard cruise ships in Antarctica. They found strong gradients in animal density and unbiased estimates of average whale abundance. Nevertheless, the precision of estimates from PO-based data is not comparable to that of dedicated LT-surveys and for these reasons it is often highlighted that data generated by POs should be taken merely as initial insights into cetacean distribution and as important starting points for designing systematic surveys (Evans and Hammond, 2004).

The spatial models, however, by using model-based methods rather than design-based, are suitable for PO-based data providing that the correct protocols are followed. For example, more survey effort is required to obtain representative survey coverage when the study area is more variable, otherwise the distribution will be incorrectly modeled (Macleod, 2010).

In Chapter 6, I show that models can be used on (long-term) land-based data. In this study, the data collection was restricted by the nature of the platform (i.e. Island). A consistent study design over a long-term period and the type of data analysis methods used were crucial in deriving robust data that were able to show new insights into the fine-scale preferences of Risso's dolphins and harbour porpoises. Furthermore, the data showed that the habitat-use of either species was different, but not driven by biases in the methodology and this supports the reliability of the obtained results.

Several examples in this thesis show how indices of abundance complemented the systematically-collected data and, more importantly, allowed for comparisons over time and comparison with other studies (e.g. Chapters 2-4). It has been shown that results from repeated dedicated surveys designed specifically for the species and geographical region of interest, provide estimates with narrow confidence intervals which can be used to make inferences about population trends over time (e.g. Taylor et al., 2007).

In Chapter 5, I found that the mark-recapture abundance estimate of Risso's dolphins closely matched the (opportunistic) census technique estimates and as such the census technique supported the reliability of the mark-recapture estimate. There was no correlation between the number of surveys conducted and the number of individuals identified and this indicates that the likelihood of re-capture was not affected by irregular survey effort. I consider that the PO-based census estimate provided a reliable estimate and furthermore was the least biased (Chapter 5).

In Chapter 4, the estimated indices of abundance for minke whales are corroborated by other studies. For example, the index of abundance in July (0.56 whales 100 km^{-1}) was similar to those estimated from the SCANS surveys carried out in July 1994 (0.33 whales 100 km^{-1}; Hammond et al., 1995) and July 2005 (0.69; Hammond et al., 2013). However, due to differences in survey platforms, methods, experience of observers and the number of observers used, data from different studies may not be directly comparable and caution is needed.

10.3 VALUE FOR CONSERVATION

Conservation managers nowadays seek more information than only the abundance of a species. For example, they are interested in knowing the presence of 'hot'- and 'cold'-spots within an area, i.e. the high and low density regions (e.g. Moulins et al., 2008). However, the low or difficult detectability of some cetacean species requires large amounts of survey effort, to ensure a high enough sample size to estimate abundance. Practical issues make it unlikely that there will ever be equal and frequent coverage of survey effort across large regions. Other marine species, i.e. seabirds and marine turtles, are similarly affected by low sample-sizes which constrain the potential for analysis of data and arguably may negatively impact conservation because species are under-represented (e.g. Ronconi et al., 2012; Scott et al., 2012). In order to identify hotspots for seabird species, scientists are now aiming to use a more comprehensive approach that integrates a variety of techniques (Ronconi et al., 2012). For example the use of behavioural data that complement survey and tracking data (Camphuysen et al., 2012).

Given the limited resources available for conducting large-scale surveys, this thesis shows how multi-method approaches and the use of PO-based data can obtain useful quantitative information, albeit at a small spatial scale, regarding cetaceans in areas for which previously little spatial or temporal survey coverage was available. The different studies provided information regarding the most commonly asked questions of conservation management, e.g. (a) which species occur here?; (b) is the area important to a species?; (c) how many animals are there?; and (d) is the population stable or declining? The different studies in this thesis furthermore may serve as examples where the platforms were opportunistic in nature with systematic data collection, but where the survey design was not conventional but flexible. The different studies presented in this thesis assisted conservation management purposes and these included new information regarding the four target species.

10.4 LOW-COST ASPECT, WITH A FOCUS ON DEVELOPMENT COUNTRIES AND UNDER-RECORDED AREAS

Poor knowledge on stock sizes and vital rates has prevented scientific committees (such as the one of the International Whaling Commission; IWC) from making a reliable evaluation of the status of many of the species that occur in equatorial tropical regions. Actually West Africa and northern South America are amongst the most poorly studied regions worldwide (Kashner et al., 2012).

Since many cetaceans in those regions are threatened by e.g. bycatch, habitat degradation, direct capture, and the general lack of data on species occurrence, they are in urgent need of protection (Jefferson et al., 1997; Reeves, 2005; Borobia and Barros, 2006; Van Waerebeek et al., 2008; Debrah et al., 2010; Weir, 2010; Weir and Pierce, 2012).

Systematic survey effort in some areas within the Caribbean and western tropical Atlantic has been limited and quantitative information is sparse (IWC, 2006). Nevertheless, various opportunistic sighting programmes have shown that the Wider Caribbean Region has a diverse cetacean fauna, although quality control in species identification remains a major challenge (IWC, 2006). The IWC Scientific Committee therefore recommended and encouraged wider participation in systematic small cetacean research programmes and coordination among such programmes within the Caribbean and western tropical Atlantic (IWC, 2006). The Committee noted and commended the published work in Gabon (Chapters 7-8; Weir, 2010), highlighting that it was an excellent example of how the use of POs should be intensified to collect data on distribution, relative abundance and behaviour of cetaceans (IWC, 2010).

10.5 THE VALUE OF MULTI-METHOD APPROACHES

One of the main goals of this study was to demonstrate the value of implementing multi-method approaches in providing a more complete picture regarding the cetacean distribution in areas that have received little or no effort. The visual PO-based data collected off Southwest England (described in Chapter 2 and 3) were used and compared with acoustic data obtained there and it was found that whistle parameters varied with behavioural context, group-size and between encounters (Ansman et al., 2007). The combination of different methodologies to solve problems associated with the choice of a single method has proven to be effective in other studies. For example Certain et al. (2008) combined aerial surveys with ship-based data. Another set of methods that are often combined are acoustic and visual survey methods (Boisseau et al., 2007; Booth et al., 2013).

In the different chapters of this thesis I further explored the use of different methodology approaches including PO methods, and showed that this facilitates studies of particular target species from a number of different angles. In Chapter 5, the outcome of one method was used to provide additional support for the Risso's dolphin population estimates produced. In Chapter 6, I identified core areas for Risso's dolphins (and harbour porpoises) and developed models to make inferences about their small-scale distribution. Chapters 5 and 6 combined therefore show that the use of a range of methodology approaches enabled me to investigate the different aspects of Risso's dolphin ecology from a number of different angles. Another example of this is outlined in Chapter 3, where a combination of strandings data and offshore PO-based data allowed me to investigate the interactions between common dolphins and fisheries. In Chapter 2, the combination of multiple datasets (Line-transect + PO-based) helped to identify possible biases such as a strong responsive movement from the dolphins towards the vessel which was affected by survey speed. In Chapter 4, the limitations of a single method approach was highlighted where the longer temporal coverage by the PO survey showed that there was a problem of timing a dedicated survey properly. Another example, where the outcome of one method was used to provide additional support to another method is described by Jones (2012). Here it was found that porpoise sightings beyond 2 km from the coast, assessed from land-based data, appeared to drop off. To explore whether this drop-off resulted from distant sightings not being recorded reliably, data collected during a PO survey (Wildlife Eco Boat Tours/ Marine Discovery Penzance) operating in the immediate area of the watch-point in 2008-2009 were analysed (De Boer, 2012a). This provided evidence that the porpoise distribution at distances greater than 2 km was more likely to be related to environmental variables or common habitat preference than caused by an artefact of methodology (Jones, 2012).

Another value of a similar approaches following the compilation of multiple-datasets, is shown by Best et al. (2012) who developed an online cetacean habitat modeling system using a geo-database (OBIS SEAMAP, 2013). This geo-database is a spatially referenced online database, aggregating marine mammal, seabird and sea turtle observation data from across the globe (since 2002). The like of such multi-source databases already play an important role, particularly in the creation of species-richness and species-range in under-recorded areas (CAR-SPAW-RAC, 2013; De Boer, 2012b). However, when assessing current knowledge on species distributions with the use of multiple-datasets, it is important to be aware of the effects of temporal and geographic sampling biases.

10.6 CONCLUDING REMARKS

The overall goal of this thesis is to demonstrate the complementary value of applying POs and implementing multi-method approaches, and using the acquired different data sets to obtain fine-scale distribution and abundance data in areas that have received little or no effort. Based on the outcome of the several studies provided in the different chapters, I conclude that indeed the use of POs – whether or not in combination with multi-method approaches – is a useful and reliable tool in addition to the standard large-scale cetacean surveys.

Firstly, they complement the infrequently carried out large-scale surveys, by bridging data gaps and improving the design of those surveys. Other complementary values include adding new knowledge regarding the status of a population and obtaining fine-scale distributional and relative abundance data. Secondly, because of their cost-effective nature and relative low logistical constraints, they are an attractive instrument for cetacean conservation management authorities. The approach of using POs enhances the acquisition of essential data to identify critical habitats for cetaceans, i.e. crucial areas for breeding, nursing/feeding, socialising and resting. Other uses of PO-based data include helping to determine the range of a species and documenting any range-shifts, trends and changes in distributions, at relatively short-time frames.

Management authorities in most countries are obliged by law to monitor cetaceans and offer protection to them. PO-based data can become important players in providing such information especially on a fine-scale basis giving insights into short-term changes and/or trends. Conservation management authorities should therefore consider the inclusion of (effort-related) PO-based data in multiple databases. PO-based data can also provide data to help understand the cetacean community structures in under-recorded regions or knowledge regarding poorly known species.

As emphasised in this study, a flexible study design and data analysis methods are crucial to derive useful data from POs. Another key requirement of collecting data from a PO is that the researcher must ensure that data collection is consistent and precise. It is also important that the sources of bias (such as track-line detection probability) remain constant over time rather than trying to minimise these. Quality control in species identification is also a major challenge and in future studies of similar design I accentuate that records should be accompanied by good descriptions and/or photographs. Finally, studies conducted from POs should be proactive, where researchers, as shown in this study, seek out research opportunities or other programs to share costs or provide logistical support for systematic studies which follow standard survey designs.

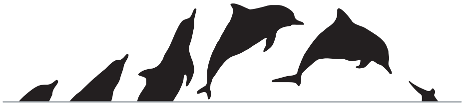
My conclusion on the relevance and effectiveness of this approach is corroborated by several other studies. For example, Boisseau et al. (2008) combined visual and acoustic surveys for harbour porpoise off NW Africa and Cheny et al. (2012) integrated multiple-data sources to assess distribution and abundance of bottlenose dolphins in Scottish waters. Kiszka et al. (2007) used ferries to investigate distribution and indices of abundance of small cetaceans according to years and seasons in the English Channel and Bay of Biscay. Other opportunistic photo-ID studies that added new knowledge regarding the status of a species, include those of Weir et al. (2008) regarding bottlenose dolphins off Aberdeen and Baird et al. (2008) on rough-toothed dolphins in Hawaii. Elsewhere, PO-based data, even when only based on a single survey, increased the understanding of cetacean distribution substantially with the potential to be applied to inform conservation management (e.g. De Boer, 2000; De Boer and Simmonds, 2001; Williams et al., 2006; Compton et al., 2007; Jayasankar et al., 2007; Weir, 2007; Afsal et al., 2008; Viddi et al., 2010; Palacios et al., 2012).

This study highlights that one does not need large-scale and very costly surveys to collect valuable information regarding the distribution and abundance of cetaceans, particularly in under-recorded regions. We recommend the use of multi-method approaches, involving PO-based data and/or multiple datasets, especially as spatial planning is becoming the framework for management of human activities within the marine realm.

ADDENDUM

REFERENCES
SUMMARY
NEDERLANDSE SAMENVATTING
CONTRIBUTING AUTHORS
PUBLICATIONS
ITSP (OPLEIDINGSPLAN)
FACTSHEETS TARGET SPECIES
ACKNOWLEDGEMENTS

Guiana dolphin



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SUMMARY

Cetaceans are generally elusive and live a fully aquatic life which consequently makes them difficult to study. In order to adequately manage cetacean populations, detailed knowledge about their status is necessary. This requires up to date information on distribution, abundance and habitat-use. The frequent execution of dedicated large-scale cetacean surveys is often hampered by logistical and budgetary constraints. This holds especially for cetaceans in offshore waters and these can therefore only be studied infrequently or hardly at all. This thesis describes the use of flexible survey designs, using multi-method approaches and (low-budget) Platforms of Opportunity (PO) to acquire data on fine-scale distribution and abundance of cetaceans in areas that have received little or no survey effort. I next investigate the relevance of PO-based surveys for the conservation management of cetaceans in under-recorded areas such as two tropical equatorial regions (Gabon and Suriname). In light of the scarce cetacean information available for these regions, the value of using POs is demonstrated.

The high levels of bycatch of small cetaceans reported in the English Channel raise both conservation and animal welfare concerns. I set out to conduct a line-transect (LT) survey and continued survey effort when the research vessel was in transit or carrying out primary tasks (PO). This survey provided the first estimate of short-beaked common dolphin abundance on winter pelagic trawl fishing grounds in the Western Approaches of the English Channel. The systematic LT-data, obtained via two platforms on the vessel, highlighted that the estimates may have been positively biased by at least a factor of 1.5 as a result of responsive movement. Nevertheless, the relative index for abundance was the highest recorded from comparable surveys in the North Atlantic and shows that the area is a very important winter habitat for common dolphins. The data from this survey showed that the winter population of common dolphins in the English Channel could well become depleted as a result of bycatch (Chapter 2).

To study the interactions between pair-trawls and short-beaked common dolphins I used both boat-based (PO-based and LT-survey data) and strandings data. The relative abundance and group-size of dolphins was significantly higher in presence of pair-trawlers. The body-temperatures obtained from dolphin carcasses found near operating pair-trawlers indicated that bycatch mostly occurred at night. Strandings data highlighted that the number of dead stranded dolphins was probably much higher than previously reported and there was a significant difference in the age and gender-composition of carcasses with different fishing gears involved. Our findings showed that the overlap between fisheries and the common dolphin ‘hotspot’ is causing direct mortality through bycatch and, together with recent range-shifts, may have contributed to a localised decline of this species in this winter hotspot since 2007. This study highlighted that the application of multi-method approaches compared to a single method approach provided a better insight into

the fine-scale distribution and interactions between dolphins and fisheries in this winter hotspot (Chapter 3).

The density of minke whales was estimated in an area characterised by frontal features and high productivity northeast of the Dogger Bank in the central North Sea. Survey efforts were carried out at a finer scale than in earlier studies in the region, using two POs and one LT survey vessel. The minke whales temporarily congregated in the area, suggesting that the whales were taking advantage of the local spring abundance of sandeels. The density found was higher than previous studies have suggested for the central North Sea. The results correspond to recent observations of minke whale redistribution within the North Sea, and these may be related to a decline in sandeel availability elsewhere in the North Sea. The high density of whales indicated that this offshore bank slope is an important spring habitat for minke whales in the North Sea. The research provided new information during a period that had traditionally received little survey effort and will supplement on-going research and conservation work within the region (Chapter 4).

Long-term photo-identification data collected from Bardsey Island (Wales, UK) were used to estimate the local abundance of Risso's dolphins. Two different analytical techniques were used: (1) mark-recapture of well-marked dolphins using a 'closed-population' model; and (2) a census technique based on the total number of identified individual dolphins sighted over the study period. The mark-recapture estimates of 121 (left sides; 64-178 95% CI; CV 0.24) and 145 dolphins (right sides; 78-213 95% CI; CV 0.24) closely matched the census technique estimates (population size range of 90 – 151). It was found that the dolphins showed a degree of long-term and seasonal site-fidelity. A first long-distance match between Bardsey Island and Cornwall confirmed they can be wide-ranging animals. The study demonstrates that the combination of systematic and opportunistic photo-ID studies has complementary value as a population assessment tool by generating the first local abundance estimate for Risso's dolphins in UK waters (Chapter 5).

The influence of topographic and temporal variables on cetacean distribution at a fine-scale was investigated using Kernel analysis and Generalized Additive Models (GAMs). Land-based observations from Bardsey Island (North Wales) were carried out in summer from four different points between 2001-2007. Kernel density grids identified a core area (2.6 km^2) for dolphins to the West and for porpoises (2.8 km^2) to the East of the Island. Depth, slope and aspect (for both species) and a low variation in current speed (for dolphins) were important in explaining the patchy distributions. The measure of tidal stratification was shown to be important with porpoises preferring moderately stratified areas and the dolphins using more mixed waters. The prime temporal conditions in these tidal stratified systems appeared to be related to the tidal cycle (Low Water Slack and the flood cycle), lunar cycle (a few days following the neap tidal phase), diel cycle (afternoons) and seasonal cycle (peaking in August) but differed between the two species on a temporary but predictable basis. Understanding which topographic and cyclic variables

drive the patchy distribution of porpoises and Risso's in a Headland/Island system may form the initial basis for identifying potentially critical habitats for these species (Chapter 6).

The paucity of information on cetaceans in central West African waters indicates an urgent need for adequate documentation regarding the occurrence of marine mammals. Information on cetaceans off Gabon in tropical West Africa was summarised from PO-based surveys carried out in 2009. Thirteen cetacean species were identified comprising two baleen whale species, one sperm whale species and ten species of delphinid. Cetaceans were found throughout a range of sea surface temperature between 20.5° C and 27.5° C with the majority of effort and sightings occurring seaward of the shelf break. The study showed that Gabonese waters have a broad cetacean diversity, especially with a large and diversified delphinid community in the northern part. The sightings of Atlantic spotted dolphin were the first at-sea sightings confirmed for these waters. The poorly known Clymene dolphin presented a new state record for Gabon and was also the most abundant dolphin (Chapter 7). Of special interest was a sighting with an anomalously white pigmented rough-toothed dolphin calf in the southern Gulf of Guinea, 95 nm off the Gabon coast. Reports of anomalously pigmented cetaceans are infrequent and this incident represents the first record of a nearly uniformly white rough-toothed dolphin. Furthermore, there is little documentation concerning rough-toothed dolphins and this study contributes to the knowledge of the species in tropical West African waters (Chapter 8).

There is a growing need to identify critical areas for marine biodiversity conservation, both locally and regionally, along northern South America. The general structure of the cetacean community in Suriname was documented during a PO survey including 13 cetacean species, of which 11 were new for this area. The study revealed that the offshore cetacean community in Suriname is best described as primarily a tropical community, dominated by odontocetes (dolphins and sperm whales). Although the species diversity was relatively high, the overall cetacean relative abundance index was low which is consistent for tropical equatorial offshore waters. It is recommended that more continuous monitoring in different seasons is carried out in order to gain a better understanding of the occurrence, distribution and status of the different cetacean species that occur in the Guianas (Chapter 9).

This thesis shows how PO-based data can complement standard survey designs and how they help to overcome some of the knowledge gaps in survey coverage in space and time and for different species. The PO-based data used in this study also added new knowledge regarding the status of a population and provided a temporal insight into the fine-scale spatial distribution of species that single large-scale surveys may not capture.

The value of using POs is demonstrated for poorly known cetacean fauna in two tropical equatorial regions, Gabon and Suriname. Further cetacean surveys

are clearly needed and the present studies should be seen as part of an ongoing effort to both collect data when opportunities arise and to synthesise existing data in order to improve the current understanding of regional cetacean distribution, migration and critical habitat parameters.

This thesis highlights that one does not need very costly surveys to collect valuable information regarding the distribution and abundance of cetaceans, particularly in under-recorded regions. I recommend the use of multi-method approaches, involving PO-based data and/or multiple datasets, especially as spatial planning is becoming the framework for management of human activities within the marine realm.

NEDERLANDSE SAMENVATTING

Door hun volledig aquatische leven zijn walvisachtigen doorgaans onzichtbaar, waardoor zij moeilijk te bestuderen zijn. Voor een adequaat beheer van populaties van walvisachtigen, is gedetailleerde kennis over hun status noodzakelijk. Hiervoor is actuele informatie nodig over hun verspreiding, aantallen en het gebruik van hun leefgebied. Het uitvoeren van frequente, gerichte grootschalige tellingen van zeezoogdieren wordt vaak belemmerd door logistieke en budgettaire beperkingen. Dit geldt vooral voor de studie van walvisachtigen op volle zee en die soorten worden daarom slechts zelden of nauwelijks bestudeerd. Dit proefschrift beschrijft het gebruik van flexibele telmethoden, waarbij het toepassen van verschillende technieken, een zogenaamde multi-methoden benadering, en (relatief goedkope) Platforms of Opportunity (PO) worden ingezet om gegevens te verzamelen over fijnschalige verspreiding en abundantie van walvisachtigen. Dit heb ik met name gedaan in gebieden waar nog weinig of geen studies aan walvisachtigen zijn uitgevoerd. Daarnaast onderzoek ik de relevantie van PO-gebaseerde onderzoeken voor het behoud en beheer van walvisachtigen in gebieden waar weinig gegevens over zijn, zoals twee tropische gebieden dichtbij de evenaar (Gabon en Suriname). Aan de hand van die studies wordt de waarde van het gebruik van PO's getoond.

De hoge aantallen bijvangst van kleine walvisachtigen in visnetten zoals is waargenomen in het Engelse Kanaal, gaven reden tot zorg vanuit zowel natuurbehoud als dierenwelzijn overwegingen. Ik startte daarom line-transect (LT) tellingen vanaf een schip dat andere primaire taken dan alleen de tellingen had. Dit onderzoek werd ook voortgezet wanneer het onderzoeksschip in transit was of zijn primaire taken (PO) uitvoerde. Dit project leverde de eerste schatting op van de populatieomvang van gewone dolfijnen in een gebied met pelagische trawlvisserij in het westelijke gedeelte van het Engelse Kanaal in de wintermaanden. De systematische LT-data, verkregen vanuit twee platformen op het vaartuig, lieten zien dat de waarnemingen een overschatting geven van ten minste een factor 1,5 als gevolg van de aantrekkingskracht van het schip op de dolfijnen. Hoe dan ook, de waargenomen aantallen per gevaren kilometer (relatieve abundantie) zijn het hoogste, vergeleken met gelijksoortige onderzoeken in de Noord-Atlantische Oceaan. Dit geeft aan dat het gebied een zeer belangrijk overwinteringsgebied is voor de gewone dolfijn. De gegevens uit dit onderzoek laten zien dat de winterpopulatie van gewone dolfijnen in het Engelse Kanaal gevaar loopt sterk in aantallen achteruit te gaan als gevolg van bijvangst (Hoofdstuk 2).

Om de interacties tussen spannetten (net dat tussen twee vissersschepen wordt voortgetrokken) en gewone dolfijnen te bestuderen heb ik gegevens gebruikt die zijn verzameld met de boot (PO- en LT-data) en gegevens over dolfijnstrandingen. De relatieve abundantie en groepsgrootte was significant hoger in aanwezigheid van spannetten. De lichaamstemperatuur opgemeten bij dolfijnkadavers gevonden in de buurt waar spannetten werden gebruikt, lieten zien dat bijvangst vooral in de nacht gebeurde. Het onderzoek aan de dood gevonden dieren bracht aan het licht dat het aantal gestrande dode dolfijnen waarschijnlijk veel hoger was dan eerder werd geregistreerd en ook dat er een aanzienlijk verschil was in de leeftijd en sekse-samenstelling van karkassen afhankelijk van de gebruikte vistuigen. Onze bevindingen toonden aan dat de overlap tussen de 'hotspot' voor zowel de visserij als voor de gewone dolfijn de oorzaak is van directe sterfte door bijvangst, en dat dit samen met de recente verschuivingen in de verspreiding van de dolfijnen, kan hebben bijgedragen tot een lokale achteruitgang van deze soort in deze winter hotspot sinds 2007. Dit onderzoek onderstreept dat de toepassing van de multi-methoden benadering in vergelijking met het gebruik van slechts één methode, een beter inzicht geeft in de kleinschalige verspreiding en interacties tussen dolfijnen en de visserij in deze regio (Hoofdstuk 3).

De dichtheid van dwergvinvissen werd geschat in een gebied dat gekenmerkt wordt door de aanwezigheid van fronten en hoge productiviteit ten noordoosten van de Doggersbank in de centrale Noordzee. De tellingen die ik uitvoerde hadden plaats op een kleinere schaal dan toegepast in eerdere studies in dit gebied, door gebruik te maken van twee PO's en een LT onderzoeksschip. Het bleek dat er een tijdelijke toename van dwergvinvissen in het gebied was, hetgeen suggereert dat de walvissen profiteren van een lokale overvloed van zandspiering in het voorjaar. De dichtheid aan dwergvinvissen was hoger dan gemeten in vorige studies in de centrale Noordzee. De resultaten komen overeen met recente waarnemingen over verschuivingen in verspreiding van de dwergvinvis in de Noordzee, die kan worden gerelateerd aan een afname van zandspiering elders in de Noordzee. De hoge dichtheid van walvissen toonde aan dat deze ver uit de kust liggende bankhelling een belangrijke habitat voor dwergvinvissen in de Noordzee vormt gedurende het voorjaar. Het onderzoek leverde nieuwe informatie op voor een periode waarin traditioneel weinig tellingen zijn verricht en zal lopend onderzoek en natuurbehoudsinitiatieven binnen de regio aanvullen (Hoofdstuk 4).

Een langdurige foto-identificatie studie vanaf Bardsey Island (Wales, Verenigd Koninkrijk) werd uitgevoerd om de lokale populatie grootte van grijze dolfijnen te schatten. Twee verschillende analytische technieken werden gebruikt: (1) 'mark-recapture' van goed gemarkeerde dolfijnen waarbij een 'gesloten populatie-model' werd gebruikt, en (2) een teltechniek op basis van het totale aantal geïdentificeerde individuele dolfijnen waargenomen tijdens de studieperiode. De schattingen gemaakt met de mark-recapture techniek waren: 121 (linker kant gefotografeerd; 95% betrouwbaarheids interval 64-178, variatiecoëfficiënt 0,24) en 145 dolfijnen (rechter kant gefotografeerd; 78-213 en 95% CI; CV 0.24). Die sloten nauw aan bij de schattingen verkregen met behulp van de teltechniek die een populatiegrootte van 90 – 151 dieren opleverde. Vastgesteld werd dat de dolfijnen een zekere mate van langdurige en seizoensgebonden locatiegebondenheid vertoonden. Een eerste lange-afstand 'foto-match' tussen Bardsey Island en Cornwall bevestigde dat deze dieren een groot verspreidingsgebied kunnen hebben. De studie toonde tevens aan dat de combinatie van systematische en opportunistische foto-identificatiestudies complementair kunnen zijn bij het bepalen van een populatiegrootte en het genereren van de eerste schatting van een lokale grijze dolfijnenpopulatie in Britse wateren (Hoofdstuk 5).

De invloed van topografische en temporele variabelen op de fijnschalige verspreiding van walvisachtigen werd onderzocht met behulp van een Kernel-analyse en Generalized Additive Models (GAMs). Tussen 2001 en 2007 werden vanuit vier verschillende observatiepunten op Bardsey Island (Noord-Wales) zeezoogdierentellingen uitgevoerd in de zomer. Kernel dichtheidsrasters leverden een kerngebied op van 2.6 km^2 voor grijze dolfijnen ten westen van het eiland en voor bruinvissen van 2.8 km^2 ten oosten van het eiland. Diepte, helling en ligging waren voor beide soorten en een lage variatie in stroomsnelheid was voor dolfijnen belangrijk in het verklaren van de ongelijke verdeling in groepsgewijs voorkomen van beide soorten. ‘Getij stratificatie’ bleek ook belangrijk te zijn voor bruinvissen die een voorkeur toonden voor matig gestratificeerde gebieden en voor de dolfijnen die de voorkeur gaven aan meer gemengde wateren. De belangrijkste temporele omstandigheden in deze gestratificeerde getij- systemen bleken gerelateerd te zijn aan de getijdencyclus (laag-waterkentering en de vloedcyclus), de maancyclus (een paar dagen na de doodtij-fase), dag- en nachtcyclus (middagen) en seizoensgebonden cycli (piek in augustus), maar verschilde tussen de twee soorten op een tijdelijke maar voorspelbare basis. Het beter begrijpen van de rol die topografische en cyclische variabelen spelen in de verspreiding van bruinvissen en grijze dolfijnen in een landtong/eiland-systeem, kan een eerste basis vormen in het identificeren van potentieel kritieke habitats voor deze soorten (Hoofdstuk 6).

Het gebrek aan informatie over walvisachtigen in centraal West-Afrikaanse wateren wijst op een dringende behoefte aan adequate documentatie met betrekking tot het daar voorkomen van zeezoogdieren. Informatie over walvisachtigen uit Gabon in tropisch West-Afrika werd samengevat uit PO-gebaseerd onderzoek uitgevoerd in 2009. Dertien soorten walvisachtigen werden geïdentificeerd, bestaande uit twee soorten baleinwalvissen, een tandwalvissoort (potvis) en tien soorten dolfijnachtigen. Walvisachtigen werden gevonden in water met een zeeoppervlakte temperatuur tussen 20,5°C en 27,5°C, met de meerderheid van de tellingen en observaties gemaakt zeewaarts van het continentale plat. Deze studie toonde aan dat de wateren van Gabon een grote diversiteit aan walvissen vertonen, gedomineerd door een grote en diverse gemeenschap van dolfijnen in het noordelijke deel. De waarnemingen van de Atlantische gevlekte dolfijn waren de eersten op zee voor deze wateren. De slecht bekende Clymenedolfijn werd voor het eerst waargenomen in Gabon en was tevens ook de meest talrijke dolfijn (Hoofdstuk 7). Bijzonder was een waarneming van een abnormaal wit gepigmenteerd kalf van de snaveldolfijn in het zuiden van de Golf van Guinee, circa 95 zeemijlen uit de kust van Gabon. Gerapporteerde waarnemingen van abnormaal gepigmenteerde walvisachtigen zijn zeldzaam en dit geval is de eerste waarneming van een bijna geheel witte snaveldolfijn. Bovendien is er weinig documentatie over snaveldolfijnen en deze studie draagt daarom bij aan de kennis van deze soort in de tropische wateren van West-Afrika (Hoofdstuk 8).

Er is een groeiende behoefte om kritieke habitats (gebieden met een hoge ecologische waarde) voor zeezoogdieren te identificeren voor het behoud van mariene biodiversiteit, zowel lokaal als regionaal, in de zeegebieden ten noorden van Zuid-Amerika. De algemene structuur van de levensgemeenschappen van walvisachtigen in Suriname werd gedocumenteerd tijdens een PO-studie, waarbij 13 soorten walvisachtigen werden waargenomen. Daarvan waren er 11 nog niet eerder waargenomen in dit gebied. De studie toonde aan dat de populatie van walvisachtigen in Suriname het best kan worden omschreven als een hoofdzakelijk tropische gemeenschap, gedomineerd door tandwalvissen (dolfijnen en potvissen). Hoewel de soortenrijkdom relatief hoog was, was de algemene relatieve abundantie-index voor walvisachtigen laag, hetgeen in overeenstemming is met tropisch equatoriale gebieden op volle zee. Het wordt aanbevolen om meer systematische zeezoogdiertellingen uit te voeren in verschillende seizoenen om meer kennis op te doen over het voorkomen van walvisachtigen, hun verspreiding en de status van de verschillende soorten die in de Guyana's voorkomen (Hoofdstuk 9).

Dit proefschrift laat zien hoe PO-gebaseerde gegevens de meer traditionele standaard onderzoeksmethoden kunnen aanvullen en hoe ze kunnen helpen om een deel van de leemten te vullen in de huidige kennis, zowel in ruimte als in tijd, en voor verschillende soorten walvisachtigen. De PO-gebaseerde data in deze studie voegden ook nieuwe kennis toe met betrekking tot de status van een populatie en verschafte een tijdelijk inzicht in de fijnschalige ruimtelijke verspreiding van soorten die met eenmalige grootschalige onderzoeken niet zal kunnen worden opgemerkt.

De waarde van het gebruik van PO's is aangetoond voor de weinig bekende walvisfauna in twee tropisch equatoriale gebieden, Gabon en Suriname. Verder onderzoek naar walvisachtigen daar is duidelijk nodig en de huidige studies zouden moeten worden beschouwd als onderdeel van een doorlopende onderzoekinspanning om gegevens te verzamelen wanneer zich kansen voordoen, en om bestaande gegevens te synthetiseren. Daarmee kan naast de huidige kennis over de regionale verspreiding van walvisachtigen ook de kennis over migratie en kenmerken van kritische habitats worden verbeterd.

Dit proefschrift laat duidelijk zien dat men geen erg dure onderzoeken nodig heeft om waardevolle informatie te verzamelen over de verspreiding en omvang van populaties van walvisachtigen. Dat geldt met name voor die regio's waar nog weinig onderzoek heeft plaatsgevonden. Ik beveel het gebruik van een multimethode benadering aan, waarbij PO-gebaseerde data en/of meerdere datasets worden gebruikt, des te meer nu ruimtelijke ordening het kader wordt voor het beheer van menselijke activiteiten in het mariene gebied.

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- De Boer MN, Clark J, Leopold MF, Simmonds MP, Reijnders PJH (2013) Photo-identification methods reveal seasonal and long-term site-fidelity of Risso's dolphins (*Grampus griseus*) in shallow waters (Cardigan Bay, Wales). Open Journal of Marine Science, Special Issue on Marine Biology 3: 65-74.

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CERTIFICATE

The Netherlands Research School for the
Socio-Economic and Natural Sciences of the Environment
(SENSE), declares that

Marijke Nita de Boer

born on 17 August 1970 in Arnhem, The Netherlands

has successfully fulfilled all requirements of the
Educational Programme of SENSE.

Wageningen, 22 November 2013

the Chairman of the SENSE board	the SENSE Director of Education
Prof. dr. Rik Leemans	Dr. Ad van Dommelen

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KONINKLIJKE NEDERLANDSE
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The SENSE Research School declares that **Ms. Marijke de Boer** has successfully fulfilled all requirements of the Educational PhD Programme of SENSE with a work load of 36 ECTS, including the following activities:

SENSE PhD Courses

- Environmental Research in Context
- Research Context Activity: Development and Practical Use of a Marine Mammal Species Identification Guide
- Introduction to R for statistical analysis
- Basic Statistics

Other PhD and Advanced MSc Courses

- GIS Training
- Introduction into Statistical Modelling
- Master Class Scientific and Professional Publishing on Environment and Sustainability

Management Skills Training

- Co-organising the conference *Minimising the risk of injury and disturbance to marine mammals*, Paramaribo, Suriname

Oral Presentations

- *Monitoring core-areas and habitat-use of small cetaceans (Bardsey Island)*. Between Production and Conservation - IMARES PhD-Day, 30 November 2012, NIOZ/Texel
- *Marine mammals & turtles off Suriname – a regional perspective*. Minimising the risk of injury and disturbance to marine mammals, 19 November 2012, Paramaribo, Suriname
- *Fine-scale habitat use of Risso's dolphins off Bardsey Island (Cardigan Bay, UK)*. Workshop: Risso’s dolphins, European Cetacean Society, 25 March 2012, Galway, Ireland
- *Cetaceans off Cornwall using scientific data collected from wildlife operator Marine Discovery Penzance*. Workshop: Linking science to whale-watching, European Cetacean Society, 25 March 2012, Galway, Ireland
- *Studying cetaceans off Southwest England using dedicated and opportunistic methods*. Southwest Marine Ecosystems, 2 March 2012, Plymouth, UK
- Interactions between common dolphins (*Delphinus delphis*) and pelagic pair-trawl fisheries. Bottom-Up, IMARES PhD-Day, 25 November 2011, NIOZ/Texel

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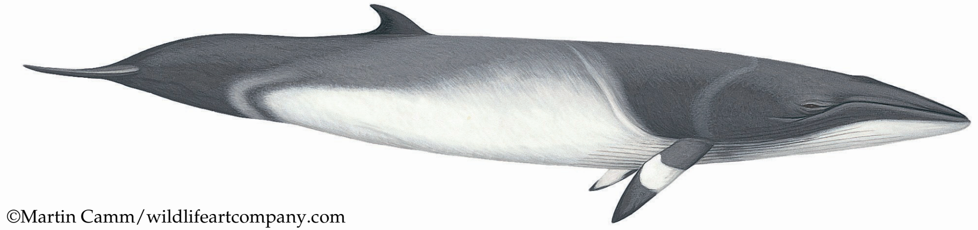
Drs. Serge Stalpers

FACTSHEETS TARGET SPECIES

Fact Sheets for harbour porpoise, Risso’s dolphins, short-beaked common dolphin, common minke whale and rough-toothed dolphin extracted from the *Species ID Guide of the most frequently occurring marine mammals* which was prepared by Marijke de Boer for the Research in Context Activity PhD-course (SENSE A1/A2)

Common minke whale (*Balaenoptera acutorostrata*) and Antarctic minke whale (*B. bonaerensis*)



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Adult: 7-10.7m (23-35ft)
Group size: 1-3, larger groups in feeding areas
Taxonomy: The common or Northern minke whale has one recognised subspecies; the dwarf minke whale with a length up to 7.8m and occurs in the Southern Hemisphere.

Characteristics:

- The smallest of the baleen whales
- Dark slender and streamlined body
- Relatively tall falcate dorsal fin
- Dorsal fin set well behind the centre of the back
- Pale patches (chevron) on lower flanks and behind head (variable)
- White area on upper flippers (C. minke)
- Uniform grey flippers (Ant. minke)
- Small bushy blow (usually not visible)
- Dorsal fin visible simultaneously with blowholes
- Highly pointed head
- Arches tailstock before a deep dive
- Does not lift fluke
- Breaches and may approach boats
- May be confused with beaked whales

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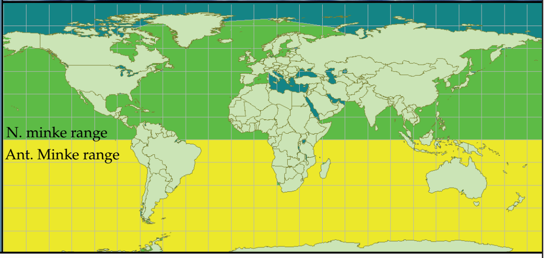

Occurrence:

The Common minke whale occurs in the North Atlantic and North Pacific from tropical to polar waters. The Antarctic minke whale has a circumpolar distribution in the Southern Hemisphere with summer feeding in Antarctic waters and winter grounds occasionally reaching the equator.

IUCN Status: Least Concern (Common minke whale)
IUCN Status: Data Deficient (Antarctic minke whale)

Risso's dolphin (*Grampus griseus*)

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Adult: 2.6-3.8m (8.5-12ft)
Group size: 15-100, 100s may gather in an area. Solitary or pairs also occur.
Taxonomy: Males are typically slightly larger than females.

Characteristics:

- Large robust pale dolphin
- Very tall falcate dorsal fin (centrally positioned)
- Blunt (bulbous) head with no beak
- Heavily scarred with white/pale scratches
- Young are light brown with little scarring; adults generally paler with age
- Head and back are often whiter than dorsal fin
- Long, pointed flippers
- Narrow tailstock
- Deep V-shaped crease on forehead (only visible at close range, see arrow)
- Surfaces slowly and can often be seen logging (lying motionless at surface)
- May be acrobatic (spy-hopping, breaching, tail-slapping, head-slapping)
- Usually avoid boats
- May be confused with bottlenose dolphins and pilot whales

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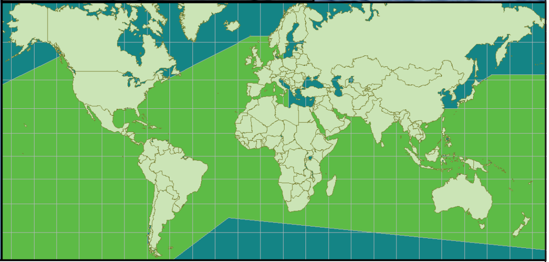

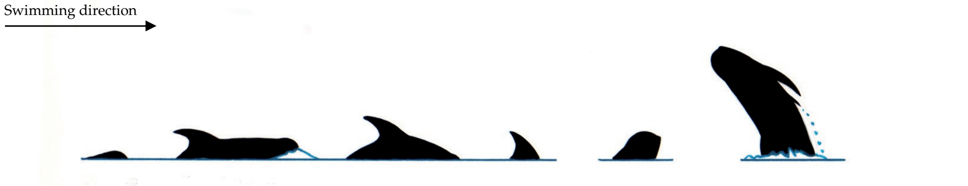

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Occurrence:

Risso's dolphins occur in deep tropical to warm-temperate waters worldwide. Prefers deep offshore waters (<1,000m) and near oceanic islands with a narrow continental shelf. Sometimes found in cooler waters during summer.

IUCN Status: Least Concern

Common dolphin (*Delphinus sp.*)

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Adult: 1.7-2.7m (5.25-8.8ft)
Group size: 10-1000
Taxonomy: Complicated but two species are recognised: the short-beaked common dolphin (*D. Delphis*) and the long-beaked common dolphin (*D. capensis*). A subspecies of *D. Delphis* is found only in the Black Sea (*D. d. ponticus*) and is classed as Vulnerable

Characteristics:

- Small slender torpedo-shaped body
- Tall falcate dorsal fin (centrally positioned)
- Dorsal fin may have light grey centre (*D.delphis*)
- Long prominent beak (up to 10% of body size: *D. capensis*)
- Dark V-shape patch under dorsal fin
- Huge foreside yellowish panel
- Hourglass pattern on flanks
- White underside
- Narrow tailstock (adult males have larger keel or post-anal hump)
- Dark beak-flipper stripe (variable)
- Variable eye-genital stripe (*D. capensis*)
- Fast energetic swimmer
- Acrobatic (breaching, tail-slapping)
- Approaches boats and bow-rides
- May be confused with *Stenella sp.*

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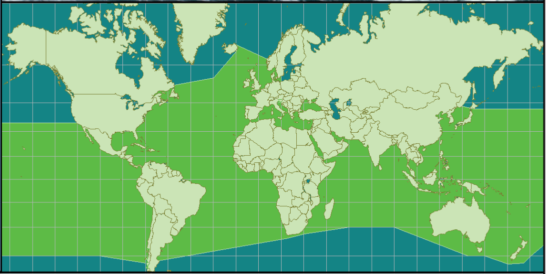

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Occurrence:

Delphinus delphis are widely distributed mainly in warm-temperate or subtropical waters. *D. capensis* prefer warm-temperate and tropical oceans. *Delphinus* have an oceanic habitat preference and are less common in shallow waters. The range of both *Delphinus species* may overlap in places but they are usually not seen in mixed schools.

IUCN Status: **Least Concern (*D. delphis*)**
IUCN Status: **Data Deficient (*D. capensis*)**

Harbour porpoise (*Phocoena phocoena*)


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Adult: 1.4-1.9m (4.75-6.25ft)
Group size: 2-8
Taxonomy: Four subspecies: N Atlantic -, Black Sea-, Western North Pacific- and Eastern North Pacific harbour porpoise. Hybrids occur between Dall's porpoise and harbour porpoise.

Characteristics:

- Robust but rather small porpoise
- Low, broad-based, triangular dorsal fin (centrally placed)
- Rounded head with no obvious beak
- Dark grey back with paler foresides and white underside
- Small dark and rounded flippers
- Thin dark grey mouth to flipper stripe (difficult to see)
- Surfaces in a typical slow 'rolling' movement
- Unlikely to approach boats
- Usually in small loose groups, mother-calf pairs or alone
- Occasionally breaches and tail-slaps (most often given when socialising)
- May be confused with Dall's porpoise which overlaps in the North Pacific or with hybrid: Dall's x Harbour porpoise


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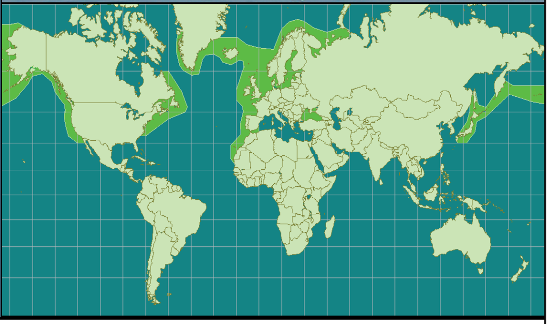

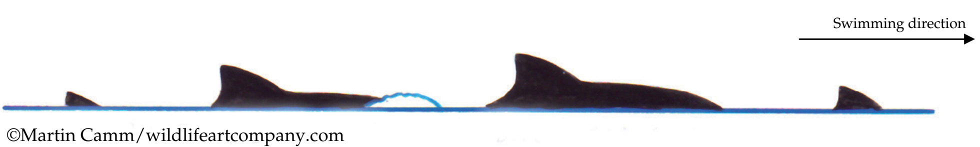

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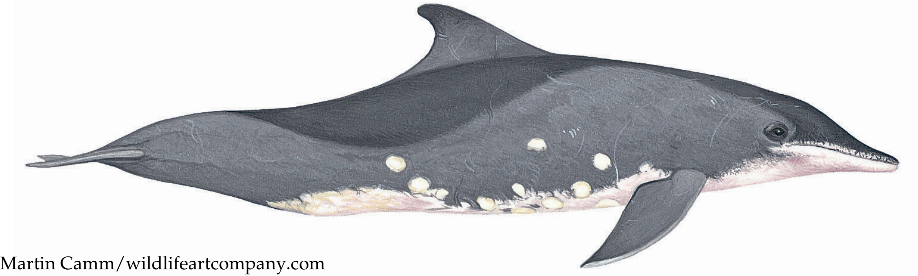
Occurrence:

Harbour porpoises occur in cold temperate and sub-Arctic waters of the Northern Hemisphere. They are a frequent visitor in the inshore waters but are also found further offshore.

IUCN Status: Least Concern (Endangered: Baltic Sea)

Rough-toothed dolphin (*Steno bredanensis)*



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Adult: 2.1-2.6m (7-8.5ft)
Group size: 10-20, up to 50-300
Taxonomy: Males are typically slightly larger than females and have a larger pronounced ventral keel or post-anal hump.

Characteristics:

- Large powerful dolphin
- Tall falcate dorsal fin (centrally positioned)
- Conical-shaped head with smooth sloping forehead (without distinct crease between forehead/beak)
- Long beak with whitish-tip and "lips"
- Dark, narrow grey cape (on upper side, best seen on bow-riders)
- Variable mottling and (white/pinkish) scarring to underbody and white chin
- Large flippers (set further back)
- Thick tailstock (males have post-anal hump/ventral keel)
- Slow swimmer exposing beak and chin out of the water
- May approach boats to bow-ride
- May be confused with bottlenose dolphins

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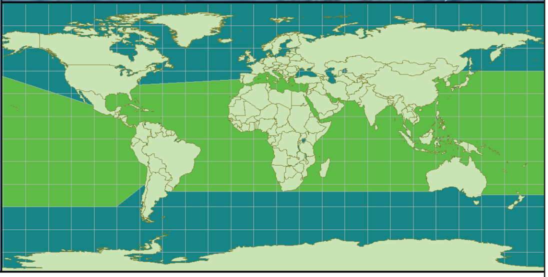

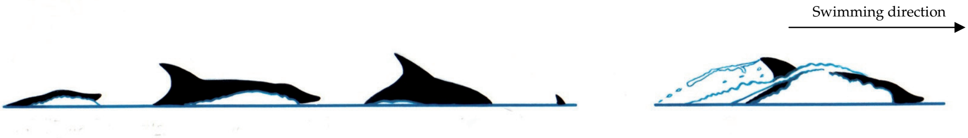

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Occurrence:

Rough-toothed dolphins occur in deep tropical and warm temperate waters worldwide (>25°C). They are most often found offshore, beyond the continental shelf. Few records from Indian Ocean, except from the Maldives and occasionally enters the Mediterranean.

IUCN Status: Least Concern

ACKNOWLEDGEMENTS

This thesis is really a *sea*-thesis.

The idea of actually attempting to do a PhD first came to me *at sea* whilst doing offshore seabird surveys together with Mardik Leopold and Kees Camphuysen on a rough and windy Monday back in October 2007 along the Dutch coast. I remember eating many salted ‘dropjes’ while in the process of brainstorming about this endeavor. Most of the data used in this thesis were collected *at sea* or when overlooking the *sea*. The toughest bits of analysis were also carried out *at sea* during my work breaks or sometimes at anchor during periods of bad weather. The habitat modelling sections were carried out on Texel which in itself is surrounded by the *sea*. The writing of the many different parts of this thesis also took place either on or gazing at the sea. For instance in Cornwall UK (with its spectacular often raging *sea* views) or Harwich UK (*sea* views of a more placid and gentler nature) and even onboard the Stena Line (Harwich to Hook van Holland ferry) and last but not least the EEZ waters of at least seventeen other nations[1].

Prompted by increasingly restricted budgets available for conservation research in these times of austerity, the modern scientist is forced to be creative and makes the best use of the tools that are available. Motivated by this challenge, I finally started my PhD in 2009. I did not fully appreciate at the time that this PhD was not going to be straightforward. Firstly, I had to combine the PhD alongside my work as a Marine Mammal Observer which involves travelling all over the world. Secondly and in retrospect rather stupidly, we bought a DIY (‘klus’) house which took up an awful lot of our time, energy and money. Thirdly, like most PhD’s, it all took ‘a bit’ longer than planned, just like the 'klus' house.

My interest in marine biology was sparked back in 1992 when working as a volunteer for a sea turtle protection project in Greece. During this time I was working mainly on small inflatables and found that after switching my attention towards cetaceans that I continued to prefer working on small boats or sailing vessels. These types of small vessels (observation platforms) are ideal as one is able to approach the animal much closer whilst keeping disturbance to a minimum, especially when simply drifting or travelling at slow speeds.

As opportunities presented themselves, I found myself working on larger boats which naturally led me to more offshore experiences. The thrill of crossing oceans and observing changes in marine life together with venturing into the unknown and not knowing what one was going to see next is difficult to describe. It is incredibly rewarding to detect an animal perfectly at home in its environment

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[1] Netherlands, Germany, Belgium, Denmark, Norway, Ireland, Greenland, Canada, France, Gabon, Congo, Angola, Ghana, Trinidad, Venezuela, Guyana and Suriname

and in such a wide area of water sometimes after having searched for many hours, days or even weeks. I have only included a portion of the entire data set that I have collected from these various platforms in this thesis. Indeed, I was fortunate enough to take part in research relative to the recording of marine mammals and seabirds onboard ice-breakers going back and forth to Antarctica or crossing the Indian Ocean and South China Sea but this is presented elsewhere. These earlier surveys were in many ways the foundation blocks of my sea-life and I want to thank the people involved in those early years who played such an important part in shaping my life!

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The last phase of this PhD was dominated by the analysis of the Bardsey data using habitat modeling. Without the assistance of **Geert Aarts** this analysis would not have been possible. Contrary to my initial concerns over what appeared such a huge and daunting task, it all turned out to be incredibly interesting and I thoroughly enjoyed working with you. There were some obstacles along the way, including a stranded humpback whale, yet we persevered and together, in the end, we succeeded. Thank you for your patience, the numerous Skype sessions, your good humour and your positive attitude towards the data that took so many years of field work to compile.

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Typically when onshore my life becomes very busy indeed, catching up on life and all that this entails, it is a mix between several countries and I am desperately trying to do all that needs to be done in the remaining weeks that I have left on land. I am sincerely grateful to everyone for their patience and flexibility.

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We have run out of milk quite some days ago, the coffee tastes bitter and the wind is picking up – a tropical storm is approaching and the swell is noticeably increasing. I sincerely apologise to anyone who I may have inadvertently forgotten to include in these acknowledgements.

COLOFON

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