DISTRIBUTION, DIVING BEHAVIOUR AND IDENTIFICATION OF THE NORTH ATLANTIC MINKE WHALE IN NORTHEAST SCOTLAND

By

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Declaration

"I hereby declare that this thesis has been composed by myself and represents work carried out by myself. It has not been accepted in any previous application for a degree. Information drawn from other sources and assistance received have been specifically acknowledged."

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ABSTRACT

The main objectives of this project, in collaboration between University of Aberdeen and the Cetacean Research & Rescue Unit (CRRU), were to study the site-fidelity, diving intervals and habitat use of minke whales in the southern outer Moray Firth, in northeast Scotland. Fieldwork was conducted between May 2006 and October 2007 and consisted of dedicated line transect surveys for the collection of (presence only) cetacean sighting data and behavioural samples. During the two summer seasons over 248 surveys and a total of 5077km of survey effort were completed. A total of 135 minke whales were encountered.

Additional data collected by the CRRU since 2001 were also included in some of the analyses.

In the first chapter the residence patterns of "naturally marked" minke whales in the Moray Firth and the possible exchange of recognised individuals between east coast and west coast of Scotland, and west Iceland has been explored through the use of photo-identification catalogues and fin-matching programs (FinEx and FinMatch). Results show six possible, although uncertain, matches, all of which need to be further analysed. Moreover, minke whales of both Scottish areas investigated in this study show small-scale site fidelity, some of them frequenting the same areas summer after summer.

In the second chapter, minke whale inter-surfacing intervals were analysed over a period of two summer seasons, 2006 and 2007. Significant differences in surfacing intervals were noted for different behaviours, in particular between foraging and travelling, and between feeding and travelling. Generalised additive model (GAM) results showed that surfacing intervals were also influenced by depth and time of day. Differences in surfacing intervals were interpreted as likely to be the result of variations in habitat utilisation, foraging strategies and changes in prey availability throughout the day. Furthermore, as in the majority of cases the frequency of diving intervals was heavily skewed, it was noted that the mean value often mentioned in diving studies was not a useful indicator of the diving behaviour. The results of this study may be relevant for methodologies used to estimate minke whale abundance from sighting surveys.

In the third chapter the summer occurrence of minke whales in the research area between 2001 and 2007 was studied with respect to topographic and tidal variables. Intra-annually, the occurrence of whales showed a typical increase from May to July and a subsequent decrease

from July to September, representing an offshore-inshore movement. In a preliminary attempt to establish the driving forces determining the whale incidence in the study area, a range of environmental variables were analysed in a Generalised Additive Model framework. Results show a strong positive linear relationship between tidal speed and whale occurrence, suggesting that current speeds may be important in explaining prey availability. Depth, longitude, month and year were all highly significant covariates, whilst seabed slope, tidal height and the direction of the tidal current showed a weaker significant effect; the highest incidence of whales was found in the eastern part of the study area, between the shoreline and 50m isobath, and where the seabed slope descends gently. However, the importance of these variables differs between months, reflecting the seasonal shift in minke whale distribution patterns.

In conclusion, although minke whales are not considered in danger of extinction due the global high population estimates, the environmental changes documented worldwide put all species under pressure. As climate change continues, a collective effort and further research in this area should focus on the relationships between oceanographic features and the different trophic levels. Lastly, an interdisciplinary approach between social and biological sciences would be advisable in order to integrate the precious local fishermen knowledge with the biological time series.

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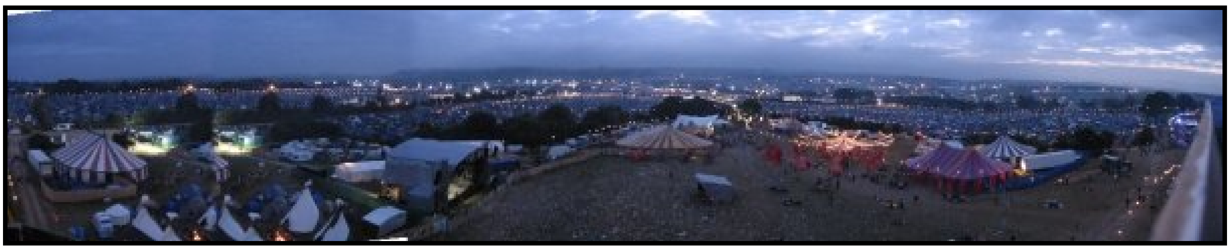
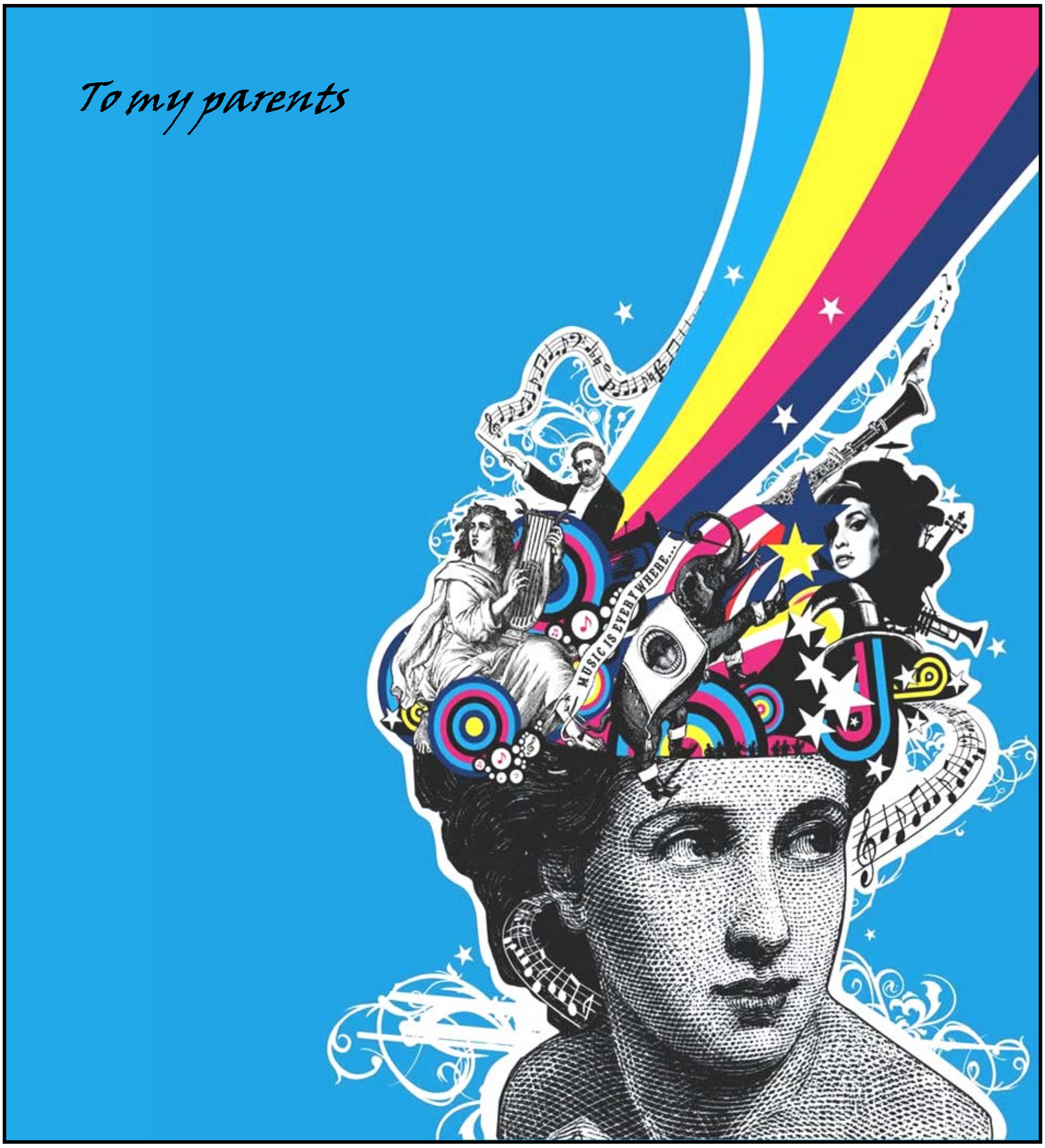


Credit: Livia Zap

To my parents



SUMMARY OF ACRONYMS

CITES	Convention on the International Trade of Endangered Species
Chl-a	Chlorophyll-a
CPR	Continuous Plankton Recorder
CRRU	Cetacean Research & Rescue Unit
e.g.	For example
GAM	Generealized Additive Models
GIS	Geographical Information System
GPS	Global Positioning System
HWDT	Hebridean Whales & Dolphins Trust
ICES	International Council for the Exploration of the Sea
IUCN	International Union for the Conservation of Nature
IWC	International Whaling Commission
JNCC	Joint Nature Conservation Committee
Km	Kilometres
m	Meters
NAMMCO	North Atlantic Marine Mammal Commission
NASA	National Aeronautics & Space Administration
NASS	North Atlantic Sightings Surveys
PHOTO-ID	Photo Identification
SAHFOS	Sir Alistair Hardy Foundation for Ocean Science
SCANS	Small Cetacean Abundance of the North Sea
SNH	Scottish Natural Heritage
SSB	Spawning Stock Biomass
SST	Sea Surface Temperature
TDR	Time-Depth Recorder
TIN	Triangulated Irregular Network
UD	Utilization Distribution
UK	United Kingdom

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

(credit: Centro Studi Cetacei)

1.1 OVERVIEW

1.1.1 Northern minke whale conservation status

The most recent abundance estimate for the northeastern stock area from the National Atlantic Sighting Survey is 112,125 (95% confidence interval 91,498-137,401) (NAMMCO, 1998). Minke whales remain the most abundant balaenopterid in the North Atlantic, and indeed in British waters (Reid *et al.*, 2003). Past surveys indicate that minke whale abundance is stable in all areas of the North Atlantic (Sigurjónsson 1995, NAMMCO 1999). However, not only do cetacean estimations carry a high degree of uncertainty, but there is also an increasing pressure on marine mammal populations through direct hunting, pollution, commercial fisheries, habitat degradation, collisions and sonar military sonar activity (Evans *et al.*, 2008). Thus minke whales are of conservation priority locally (under the NE Scotland Local Biodiversity Action Plan), nationally (under the UK Biodiversity Action Plan) and internationally (under the EU Habitats Directive, Berne Convention, Bonn Convention and the Convention on the International Trade in Endangered Species). Despite the annual harvest in the North Atlantic, it is likely that minke whales will remain an important component of the North Atlantic ecosystem for the foreseeable future due to their high numbers and fast reproductive rate (one calf per year, as all mature females caught by whaling activities each year are pregnant, Iwayama *et al.*, 2005).

Konishi *et al.* (2008) report for example that the energy storage (blubber thickness, girth and fat weight) in the Antarctic minke whale has been decreasing for nearly 2 decades. The Antarctic minke whale studied by Konishi (2008) depends largely upon the Antarctic krill and therefore the author concludes that the decline of fat storage of these baleen whales is due to a decrease in krill abundance, which in turn could derive from a change in oceanographic parameters and/or inter-species competition for krill. Although the cited data derives from the southern hemisphere, variation in minke whale body condition in response to ecosystem changes has also been recorded for the northern minke whale by Haug and colleagues (2002) and this may be an issue if minke whales are resource-limited animals. Continued efforts towards monitoring the species status could provide a better understanding of inter-species interactions and ecosystem shifts.

1.1.2 Marine Protected Areas and Cetaceans

The majority of marine mammals spend at least part of their lives in coastal areas (Crespo & Hall, 2001), being affected by humans coastal development. The destruction of marine habitats can be the result of dredging and commercial trawling for fish (Ruckelshaus & Hays, 1998). Habitat degradation may be defined as "a shift in the characteristics of an area from favourable factors to increased disadvantageous factors" (Bjørge, 2001). On a global scale, habitat degradation is the major proximate cause of biodiversity loss (Stedman-Edwards, 2001). The consequence of local destructions is the fragmentation of the remaining environment (Ruckelshaus & Hays, 1998), with a consequent reduction of available resources. If this reduction reaches a critical threshold, the living biota is unlikely to be retained (Lambeck, 1997). As a result of the concern about the preservation of marine species and habitats, massive effort has been devoted to the definition of the correct design of those areas assigned to the conservation of this environment. According to the IUCN (1994) definition, a Marine Protected Area (MPA) is "any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or the entire enclosed environment". In general, the term Marine Protected Area is used to refer to areas set aside by law or other means, to preserve part of the entire enclosed environment (Gubbay, 2005). These areas are effective tools for the achievement of the three core objectives of living resources conservation (IUCN, 1980):

- The maintenance of ecological process and systems
- The preservation of genetic diversity
- The sustainable use of species and ecosystems

In 2005 the <u>inner</u> part of the Moray Firth, northeast Scotland, was appointed MPA to protect the bottlenose dolphins, their habitat and the submerged sandbanks (SNH, 2006). However, the present study brings more evidence of the equal importance of the <u>outer</u> Moray Firth, being as rich in marine biodiversity as the inner Firth and a summer feeding ground frequently used by minke whales.

Indeed, the order *Cetacea* (which includes whales, dolphins and porpoises) are part of the marine mammals targeted in marine conservation. Eric Hoyt (2005) recognises four reasons, a part from their intrinsic value, why they can effectively help the design and management of a marine protected area:

1. Cetaceans can lead public education and create a constructive community identity.
2. Cetacean conservation done properly is an example of ecosystem conservation. Even if established around a single species, protecting these animals in their wide range can potentially protect all the organisms and habitats included in that area.
3. Presence and absence of cetaceans can be used to monitor the marine environment health. Marine predators may provide a useful indication and protection of productive areas (Hooker & Gerber, 2004).
4. The popularity of cetaceans can represent a driving force extending the managed area and increasing available funding.

The aims and objectives of the present study, as mentioned at the end of this section, lay within these four reasoning, especially the third one for which the presence and/or absence of minke whales could be used to monitor the health of the marine food-web.

1.1.3 The North Atlantic minke whale and its diet

Minke whales (*Balaenoptera acutorostrata* Lacépède, 1804) are the smallest of the Balaenopteridae family and they are observed feeding in all of the Moray Firth mainly during the summer months.

The baleen whales are so named for their feeding apparatus, plates of keratinous baleen hanging from the roof of the mouth (Figure 1.1) to strain planktonic organisms and relatively small fish. The shape of the rostrum is particularly typical of the minke whale: it is very narrow and pointed upon which there is a single, longitudinal ridge. The species name describes this distinctive feature of minke whales as '*acutorostrata*' translates into 'sharp snout' (Reeves et al, 2002).

Fig.1.1. The 'sharp snout' and baleens of the minke whale. From Carwardine (2000).

Minke whales are distributed worldwide and they have recently been split into two species by most (but not all) authorities: the Antarctic minke whale (*Balaenoptera bonaerensis*) and the 'common' or 'northern' minke whale (*Balaenoptera acutorostrata*). There may actually be a third minke whale species, the 'pygmy' minke whale, which is found in the southern hemisphere, but is genetically distinct from the Antarctic minke whale (Best, 1985; Arnold *et* *al.*, 1987; Wada *et al.*, 1991). Genetic and stable-isotopic studies within the northern hemisphere provided information on the existence of 4 genetically differentiated sub-populations in the North Atlantic minke whales (Andersen *et al.*, 2003; Born *et al.*, 2003). The major four groups identified by these authors (1. West Greenland, 2. East Greenland and Central Atlantic, 3. NE Atlantic and 4. North Sea) are regarded as sub-populations in a biological sense and as meta-populations (number of groups connected by dispersal of individuals between them; Levins, 1969) in a more ecological sense, which have been isolated and evolved in response to regional differences in ecological conditions, such as oceanography, prey type and prey availability. In fact, because of the great oceanographic variability of the shallow continental areas within the North Atlantic (Anonimous, 2003), no one organism forms the dominant food supply for minke whales (Skaug *et al.* 1997). Capelin (*Mallotus villosus*) and sandeel (Ammodytidae) are important food for minke whales in West Greenland waters whereas polar cod (*Boreogadu saida*) seems to be of greater importance in the East Greenland (reviewed by Neve, 2000). Krill (*Thysanoessa* sp.) and herring (*Clupea harenigus*) are two of the most prominent prey items in the diet of minke whales in the northeast Atlantic where gadoid fish (cod, *Gadus morhua,* saithe, *Pollacius virens,* and haddock, *Melanogrammus aeglefinus*) are also important prey (reviewed by Haug *et al.*, 2002). Within the NE Atlantic area, there are regional differences in prey preferences. Consumption of herring has been recorded in the Barents Sea and the northwestern coast of Norway whereas consumption of krill is more pronounces in the Svalbard area (Folkow *et al.* 2000; Haug *et al.*, 2002). Herring is a predominant food item in the Norwegian Sea whereas sandeel (Figure 1.2.) dominate the minke whale diet in the North Sea, as well as in the Moray Firth. In this latter areas, mackerel (*Scomber scombrus*) and other fish (i.e clupeids such as herring and sprat) constitute the remainder of food items (Olsen & Holst, 2001; Pierce *et al.*, 2004).

Fig.1.2. 0-group (~6 cm) sandeel caught in the study area in the presence of feeding minke whales.

1.1.3 Overview on methods used for this project

Early whalers recognised that relationships existed between whale distributions and oceanographic features which would enable them to locate whaling grounds more easily.
For the last few decades, a growing movement for the conservation of cetaceans recognised that knowledge of how environmental variables influence cetacean distribution can also enhance conservation measures.
General methods used in order to collect the data used to describe cetacean distribution and habitat use include visual observations made from dedicated line transect boat surveys (e.g. Cañadas *et al.*, 2001; Hooker at al., 2001; Moore *et al.*, 2002; Hastie *et al.*, 2004; Canning *et al.*, 2008; Tetley *et al.*, 2008), opportunistic boat surveys (MacLeod *et al.*, 2004; MacLeod *et al.*, 2008), and also land-based surveys (Mendes *et al.*, 2002; Canning, 2007). The advantage of a dedicated line transect approach is that sighting data can be taken alongside the continual recording of oceanographic parameters such as water depth, sea surface temperature (SST), salinity and chlorophyll-a concentration. This allows for precise allocation of environmental parameters to sightings. However, dedicated use of suitably-equipped vessels is expensive. The alternative is to use vessels of opportunity, like whale-watching boats, ferries, or seabird/fisheries surveys, whilst oceanographic data can be obtained from alternative sources (e.g. satellite archives).

In the present study, data were recorded from dedicated boat-based transects by the Cetacean Research & Rescue Unit (CRRU), whereas environmental variables, as for example bathymetry, seabed topography and SST, were all derived from existing datasets and models (data extrapolation is described in the fourth chapter).

Statistical methods used for the data analysis include one-way analysis of variance (ANOVA) and chi-squared analysis to identify significant differences in diving behaviour, and generalised additive modelling (GAM) to describe the relationships between environmental variables and the occurrence/behaviour of minke whales. Furthermore, a Geographical Information System (GIS) was used to map the spatiotemporal site fidelity and to determine the habitat use of the whales in the area.

Small-scale movement patterns and habitat use of individual minke whales have been documented in Canadian waters (Tscherter, 2007), in the Pacific (Hoelzel *et al.*, 1989; Dorsey *et al.*, 1990) and in the UK (Gill, 2000) using individually-distinctive natural markings, otherwise called the photo-identification method. Around the UK, a long time series of identification photographs of natural markings has been collected in the Inner Hebrides, as a collaborative project between Hebrides Whales and Dolphins Trust (HWDT) and Sea Life Survey (SLS). The collaboration has been now extended to the study area examined in this research, on the east coast of Scotland, with the intention of establishing minke whale movement patterns and site fidelity. For this reason a recently established minke whale photo-ID catalogue in Iceland has been also analysed for comparison.

Moreover, the recognition of individual minke whales has been used to test seasonal aggregations when foraging (Lyans *et al.*, 2001), to measure the stability of their dorsal fin edge marks (Morris & Tscherter, 2006), to assess their individual response to food stress (Tscherter & Weilenmann, 2003) and to show their individual surface feeding strategies (Hoelzel *et al.*, 1989; Thomson *et al.*, 2003). In this research the recognition of a whale identity has been essential when collecting behavioural/diving samples, and digital photography has been a valuable tool to ensure the focal follow of the same individual throughout the sampling period (usually 30 minutes).

1.2 RESEARCH AREA

Data used in the present study were collected during the months of May to October, from 2001 to 2007 for the second and fourth chapters, and in 2006-2007 for the third chapter, from an 880 km^2 area within the southern outer Moray Firth in northeast Scotland (Fig. 1.3). The area was divided into four routes, each approximately 1 minute of latitude apart on a north-south axis. These included three dedicated outer routes (routes 2 to 4 respectively) and an inner coastal route (route 1) (Fig. 1.4.). Sharing large-scale environmental determinants, such as water circulation and climate patterns, the Moray Firth is an integral part of the North Sea and Atlantic Ocean beyond (Wright *et al.*, 1998; Eleftheriou *et al.*, 2004). Bounded on two sides by land, it is generally defined as the area of sea from Duncansby Head in the north, to Inverness in the south-west, to Fraserburgh in the east (Harding-Hill, 1993) (Figure 1.3.). The area to the west of a line drawn from Helmsdale to Lossiemouth is defined to as the "inner" Moray Firth, while the remaining sea to the east of this limit is the "outer" Moray Firth.

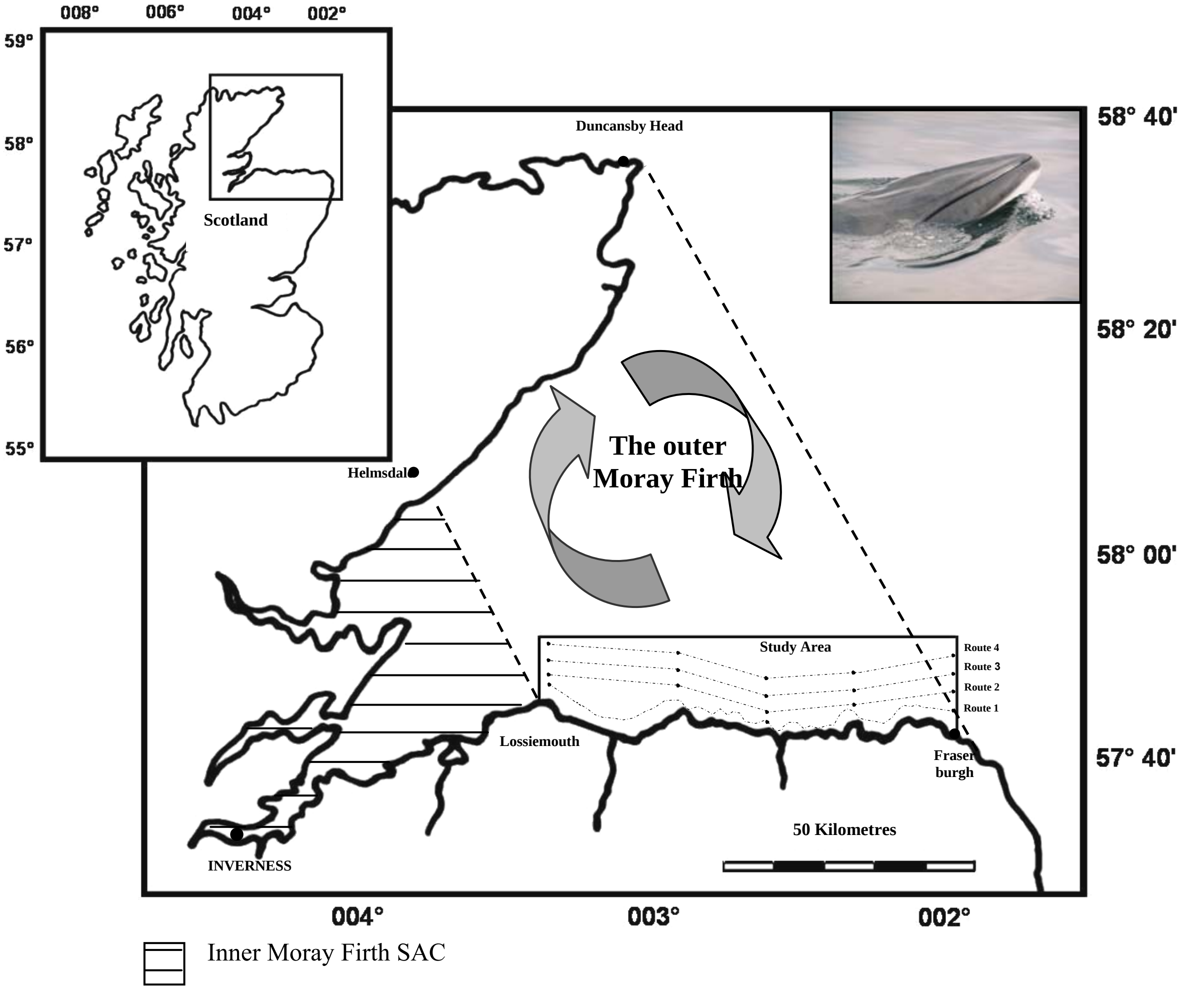


Fig. 1. 3. Map of the Moray Firth showing the position of the 880 km^2 study area along the southern coastline of the outer firth between Lossiemouth and Fraserburgh (N 57° 41´, W 003° 15´). Arrows show the direction of the current circulation. Adapted from Robinson *et al.* 2007.

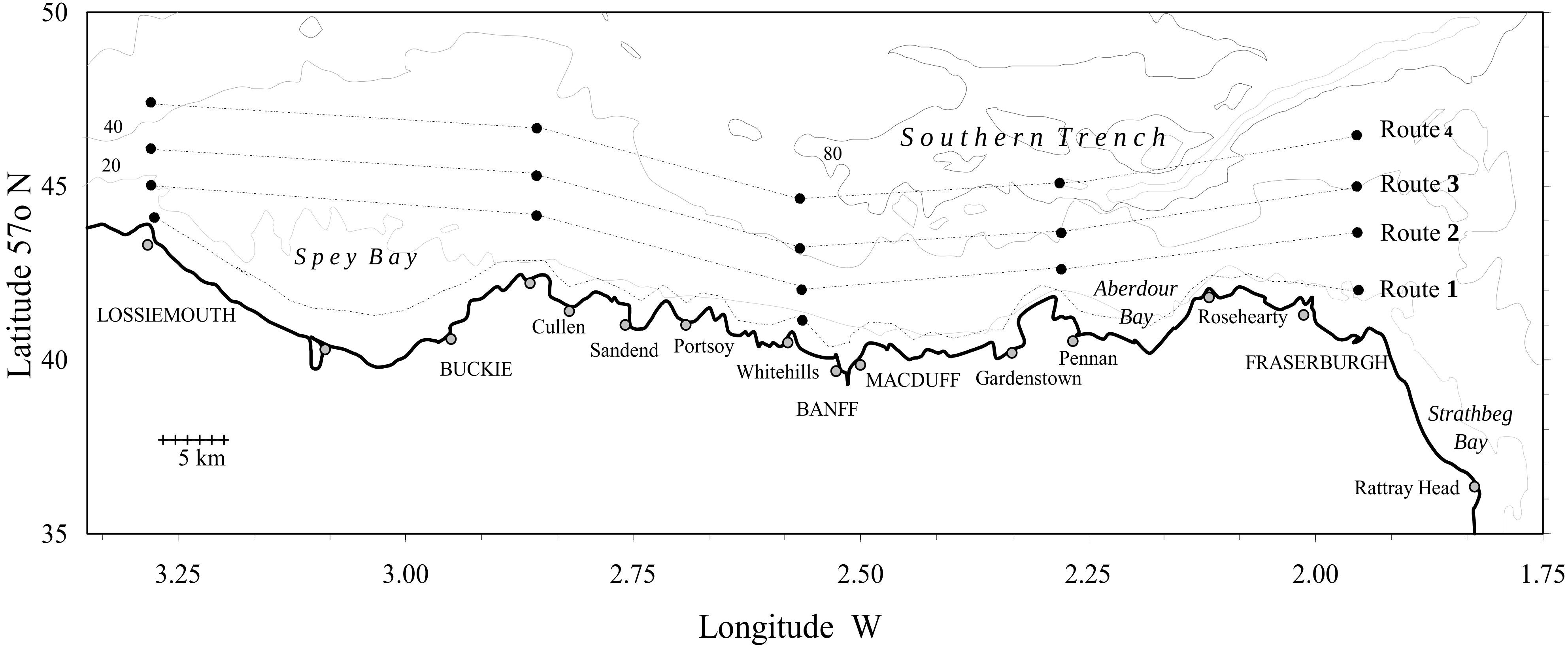


Fig. 1.4. The southern coastline of the outer Moray Firth study area and the survey routes used during systematic boat surveys. Four dedicated routes were used: three outer routes lying perpendicular to the coastline (routes 2 to 4 respectively), each approximately one minute apart in latitude, and an inner coastal route (route 1) along which minkes are regularly encountered during the latter summer months. Also shown are isobaths.

The characteristics of this large embayment (measuring some 5,230 km^2) vary greatly within its extent. In the inner firth, the seabed slope descends gently from the shore to a depth of around 50 metres approximately 15 km from the coast, while the outer firth more closely resembles the open North Sea. Sediment characteristics also vary considerably throughout. The main marine input is produced by the Dooley current which brings mixed cold waters down from the north, waters that circulate in a clockwise direction (Wilson 1995). The resulting frontal zones are subsequently characterised by strong horizontal gradients in surface or bottom temperatures (Reid *et al.*, 2003). The Moray Firth is internationally recognised as a site of outstanding biological importance and the inner firth was officially appointed a Special Area of Conservation for the bottlenose dolphin (*Tursiops truncatus*) in March 2005 (Scottish Natural Heritage, 2006).

Species recorded in the Moray Firth comprise fish such as herring (*Clupea harengus*) which as juveniles move into areas of the inner firth to over-winter in substantial quantities (Wilson, 1995). The Moray Firth is also an important site for over-wintering sprats (*Sprattus sprattus*) in the North Sea. Mackerel (*Scombrus sombre*) pass through the Moray Firth whilst on migration during the summer and autumn months (Reid *et al.,* 1997). However, the species thought to be the most important and abundant in the Moray Firth is the lesser sandeel (*Ammodytes marinus*), which is responsible for the large diversity and abundance of seabirds found there (Hislop *et al.,* 1991, Ollason *et al.,* 1997; Wright & Begg 1997). Other species present include the cod (*Gadus morhua*), whiting (*Merlangus merlangius*), haddock (*Melanogrammus aeglefinus*) and the Atlantic salmon (*Salmo salar*) (Greenstreet *et al.,* 1998; Lusseau *et al.,* 2004). This makes the Moray Firth one of the most important areas for birds in the UK and contains a significant part of Britain's seabird population (Wilson, 1995). Examples of these include the gannet (*Morus bassanus*), kittiwake (*Rissa tridactyla*), guillemot (*Uria aalge*), razor bill (*Alca torda*), puffin (*Fratercula arctica*) and shag (*Phalacrocorax aristotelis*) (Ollason *et al.,* 1997; Wanless *et al.,* 1997; Wright & Begg 1997; Garthe *et al.,* 2003).

1.3 AIMS OF THIS STUDY

Cetacean studies face a major limitation as the animals are hidden by the vast water mass and can be seen at the surface only for a very small percentage of their activities. Hence, there is still a great deal of information about minke whales' home range, migrations, reproductive grounds, competition with other baleen whales, feeding strategies and diving behaviour yet to be discovered. Unless fully-equipped ships and expensive technology (e.g. underwater cameras and satellite tags) are available, the shape of dorsal fins (photo-identification) and breathing intervals are probably the most obvious measurements which can be recorded as the whale appears at the water surface. These types of data, although collected relatively cheaply, still provide useful information on the species habitat use.

In the light of what we already know about this species, and within the logistical constraints of a research conducted by a charitable organisation such as the CRRU, the underlying objectives of the present MPhil study are:

1. to explore the residence patterns of "naturally marked" individuals (through photographs of their dorsal fins) in the Moray Firth, and to investigate evidence of large scale movements by comparing them with catalogues of known animals from the west coast of Scotland and Iceland;

2. to investigate diving behaviour (i.e. breathing intervals) with types of activity, such as feeding, foraging or travelling and as function of water depth and time of day in order to provide an insight on the whales' habitat use in the research area;

3. to identify environmental and oceanographic factors that may influence their local home range and temporal occurrence, such as depth, slope, aspect, sediment, lat/long, month/year and tidal variables.

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CHAPTER 2

MINKE WHALE PHOTO-IDENTIFICATION IN THE MORAY FIRTH: SITE FIDELITY AND A COMPARISON BETWEEN CATALOGUES

2.1 ABSTRACT

Visual identification of naturally acquired marks has been a popular method of animal identification and population estimation over the last forty years. In cetaceans, marks occurring along the edge of the dorsal fin have proven useful in identifying individuals. In this study the aims are 1) to explore the residence patterns of “naturally marked” individuals in the Moray Firth, through photographs of their dorsal fins and 2) to determine whether there is exchange of recognised individuals between east coast and west coast of Scotland, and west Iceland. Considering only the best quality photographs, there are twenty-four “marked” individuals in the eastern Scottish catalogue, forty in the western Scottish catalogue, and twelve in the Icelandic catalogue. Comparison using a fin-matching program, FinEx and FinMatch, resulted in six possible matches, all of which need to be further analysed. Minke whales of both Scottish areas investigated in this study show small-scale site fidelity, some of them frequenting the same areas summer after summer. The photo-ID project in Iceland was started only in 2007 and so conclusions on site fidelity are necessarily postponed for the future. To estimate the potential exchange rate between the three areas, or to make population estimates, more individuals need to be recognised and more high-grade photos need to be taken. This preliminary analysis provides a first step towards a more integrated approach to northern minke whale studies.

2.2 INTRODUCTION

Photo-identification is a technique mainly used on species that bear distinctive features, such as natural markings, which can be used to identify individuals. It has been used as a monitoring tool on a variety of marine and terrestrial species, mostly applied to cetaceans (e.g. Hammond *et al.*, 1990; Karczmarski & Cockcroft, 1998; Wilson *et al.*, 1999; Calambokidis *et al.*, 2004; Mizroch *et al.*, 2004; Coakes *et al.*, 2005), pinnipeds (Vincent *et al.*, 2005) manatees (Langtimm *et al.*, 2004), otters (Gilkinson *et al.*, 2007), sharks (Anderson & Goldman, 1996), but also most of the terrestrial African vertebrates (as reviewed in Würsig & Jefferson, 1990). It is a relatively cheap, non-invasive technique allowing the re-sighting of an individual numerous times without applying artificially marks. This is vital for species that are difficult to tag because of their size and elusive nature (Kohler & Turner, 2001), or because they do not retain the marks for the duration of the evaluation (Gamble *et al.*, 2008).

Individual identification of study animals broadens our understanding of such things as population size, migratory routes, site fidelity, preferred habitat, life spans and reproductive histories. In addition, some kinds of behavioural studies are dependent on identifying individuals within a focus population in order to estimate the abundance, interpret social interactions and associations of animals, quantify rates of behaviour and gain an overall understanding of social structure within groups.

Studies of many cetacean species took a great leap forward with the introduction of photo-identification techniques in the 1970s. Roger Payne was the first to document the ability to distinguish individual right whales by taking and comparing photographs of the callosity patterns found on their heads (Payne *et al.*, 1983). The unique saddle pattern coloration and distinct shapes of dorsal fins proved useful to Bigg *et al.* (1987) for identification of specific animals in the study of killer whales populations. Bernd and Melanie Würsig, gave further validity to the use of photo-identification by determining that individual bottlenose dolphins could be identified through the comparison of photographs of their dorsal fins, most of which displayed curves, notches, nicks and tears (Würsig & Würsig, 1977). Most cetaceans display individually specific coloration patterns or uniquely curved edges of flukes and dorsal fins as well as scars which accumulate over their lifetimes through interaction with other cetaceans, predators and the environment.

Since the mid 1970s, when it was first used, photo identification has passed from film-based photographs, with formation of slides and large photographic catalogues, to digitalisation of photography and computer software for faster and more objective categorisation and individual recognition databases. The efficiency of the method for identification of individuals has increased due to advances in technology. Digital photography for example, is less labour intensive, more affordable and reliable (Markowitz *et al.*, 2003). Whilst programs with recognition algorithms might be time consuming and costly during development, they avoid long term problems such as high running costs and time-consuming analysis, disadvantages that are considered to be most important in photo identification (Hillman *et al.*, 2003). Nevertheless, automation does not produce perfect results, since the final decision will be determined by the observer, again introducing a degree of subjectivity to the analysis (Araabi *et al.*, 2000; Kelly *et al.*, 2001).

To prevent errors in identification, usually pictures are examined by several researchers before being catalogued (Whitehead, *et al.,* 2001). However, if there are too few distinct markings it may prove impossible to match right and left dorsal fin images, resulting in the identification of one animal as two different individuals, or a "false negative". Photo quality is of extreme importance when sorting and identifying individual animals from pictures. Stevick *et al.* (2001) identified a significant relationship between the quality of photographs and the number of errors in identification of animals as well as the overrepresentation of certain individuals that had more distinctive features. False positives, meaning the identification of two different animals as the same one, and false negatives are often the result of discrepancies in photo quality. Stevick *et al.* (2001) further suggested that maintaining high standards for the quality of photographs could reduce rate of error and eliminate bias.

Computer-assisted dorsal fin matching programs are now coming to the forefront. These tools can reduce the time involved to sort, identify and catalogue individuals. Programs such as FinBase, FinEx and FinMatch can trace fin/fluke contours, calculate dorsal ratios and compare all pre-existing catalogued photos. These software packages provide scientists with a smaller number of possible matches, greatly reducing the amount of time otherwise spent manually sifting through pictures (Kreho *et al.*, 1999). Matches produced by the software can give confidence limits for the nearest match, further assisting researchers in their decision. These programs can also help bring to light errors in previous classifications by identifying false negatives or false positives.

Much has been learned about mysticetes through long-term studies based on the identification of individual whales (see Hammond *et al.*, 1990). Unfortunately, minke whales lack the great variability in natural markings that has facilitated detailed investigations of larger co-familiars (such as humpback whales, *Megaptera novaeangliae).* This, together with the difficulty of photographing them owing to their relatively small size and great speed, has hindered studies based on photographic identification, although studies of small localized populations have been possible (Dorsey, 1983; Dorsey *et al.*, 1990; Stem *et al.*, 1990; Gill, 1994; Tscherter & Morris, 2005). In general, however, minke whale social structure and migratory movements (if any) remain poorly understood.

In Scotland the Hebridean Whale and Dolphin Trust (HWDT) has co-ordinated a photo-identification study of minke whales in the inshore waters of the Hebrides (West of Scotland) since 1990, while the Cetacean Research & Rescue Unit (CRRU) started to collect photo-ID images of minke whales in 2001 (see Fig. 2.1). Chiara Bertulli, a researcher working with the Elding Whale Watching operator (www.elding.is) responsible of the 'Minke whales and white-beaked dolphins of Faxaflói Research Project', started gathering minke whale ID pictures in 2007 in west Iceland (Figure 2.1.). The regular sightings of minke whales in all these areas provide an excellent opportunity for the behavioural and ecological study of this species and in particular to investigate the spatiotemporal site fidelity of marked minke whales in the research area (northeast Scotland) and to explore the movement patterns between different areas (northeast Scotland, west Scotland and west Iceland).

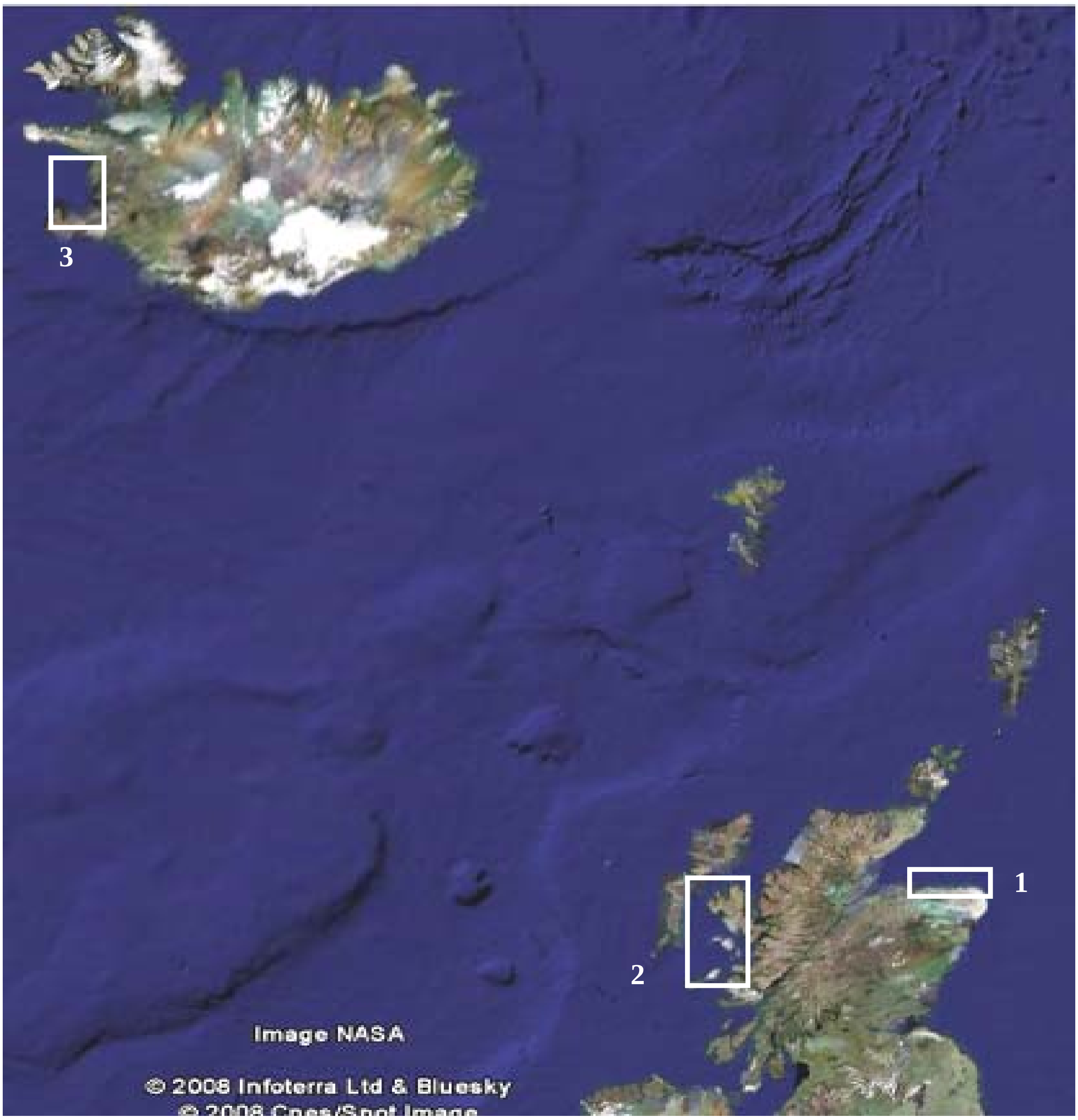

Fig. 2.1. The three study areas considered in this analysis: 1) the outer Moray Firth in northeast Scotland, 2) Inner Hebrides in west Scotland and 3) Faxafloy Bay in Iceland.

2.3 METHODS

For the creation of the CRRU minke whale ID catalogue, minke whales were photographed during systematic but weather-dependent boat surveys, between 2001 and 2007 inclusive.

During encounters at sea, photographs were taken with either a Canon EOS 350D digital reflex camera with Sigma f.4-5.6 135-400 mm APO lens and/or a 35mm Nikon F5 auto focus camera with F2.8 100-300 mm zoom lens (using Fuji 200 or 400 ASA colour print film). The aim during an encounter was to take sequential photographs of the dorsal fins and backs of each whale encountered. The most efficient method of doing this was to pre-focus the camera on the sea where the whale was anticipated to surface, thus minimising the time required to focus on the subject itself. The photographs were taken at a perpendicular angle to the body axis of the animal. The capture of both left and right dorsal fins was sought-after, but was not always possible due to the speed, behaviour and/or approachability of the subject(s). If possible, the boat was positioned adjacent to the whales with the sun behind the photographer, so that the features of the dorsal fin and back of the subject were lit up. While the photographer was taking pictures, notes were taken on the environmental variables, behaviour of the whale, encounter start and finish time, GPS position and a visual landmark. Images were then entered into a relational database and categorised according to the nature and form of their identifying features. Bad quality images (out of focus, blurred, taken with a bad angle or in bad light conditions) were not catalogued.

A computer-assisted matching software package, FinEx and FinMatch™ developed by Leiden University as part of the EC EuroPhlukes Network (an initiative to store Photo-ID data from cetacean-recording groups all across Europe in a single database), was then employed to isolate false positive or false negative errors.

The Hebridean Whale and Dolphin Trust photographic dataset, collected by a local whale-watching business, conducted by Brennen Fairbairns of Sea Life Surveys, and by HWDT staff on board the research and education vessel “Silurian”, comprises seventy-five individual minke whales catalogued according to distinctive fins, fin marks, small marks on fin and body scars. However, only 40 animals were chosen for this analysis based on high photograph quality. This photo-ID catalogue was provided by the HWDT Scientific Director, Peter Stevick. The area covered by the HWDT vessels comprised the Isle of Mull, part of the Scottish mainland (Ardnamurchan Point), the Islands of Coll, Tiree, Eigg, Muck, Rum and the Treshnish Isles (see Fig.2.1) during the summer months, from 1990 to 2006. Lastly, the photographic dataset collected during the summer of 2007 in Faxafloi Bay (west Iceland) by

Chiara Bertulli comprised of sixty-seven individuals. As for the other catalogues, the photographs with highest quality were chosen for the analysis, reducing the Icelandic catalogue to twelve individuals.

2.4 RESULTS

2.4.1 CRRU Catalogue

From a preliminary analysis of the CRRU catalogue a number of general observations were made:

- A total of 46 “marked” individuals were identified from opportunistic photographs taken from 305 encounters, although only **twenty-four** individuals were catalogued, as the lower photo quality for the remaining individuals was inadequate for the analysis. **Fourteen** of these twenty-four catalogued animals possessed dorsal edge marks (DEMs) on their fins.

- 4 categories of markings were resolved from the processed images: (i) large, obvious nicks in the dorsal fin margin (33%); (ii) small or subtle nicks in the dorsal margin (28%); (iii) scarring on the back, lateral surfaces and/or head (25%); and (iv) peculiar or unusual dorsal fin shapes (13%) (Figure 2.2).

- The recapture rate of individuals exhibiting features other than dorsal edge markings (DEMs) was low (approx. 2%) and short-term, although unusual fin shapes and scarring (e.g. major scratches, lesions and parasite scars) were found to be useful supplements for the re-identification of whales with small or subtle DEMs or for those acquiring additional nicks.

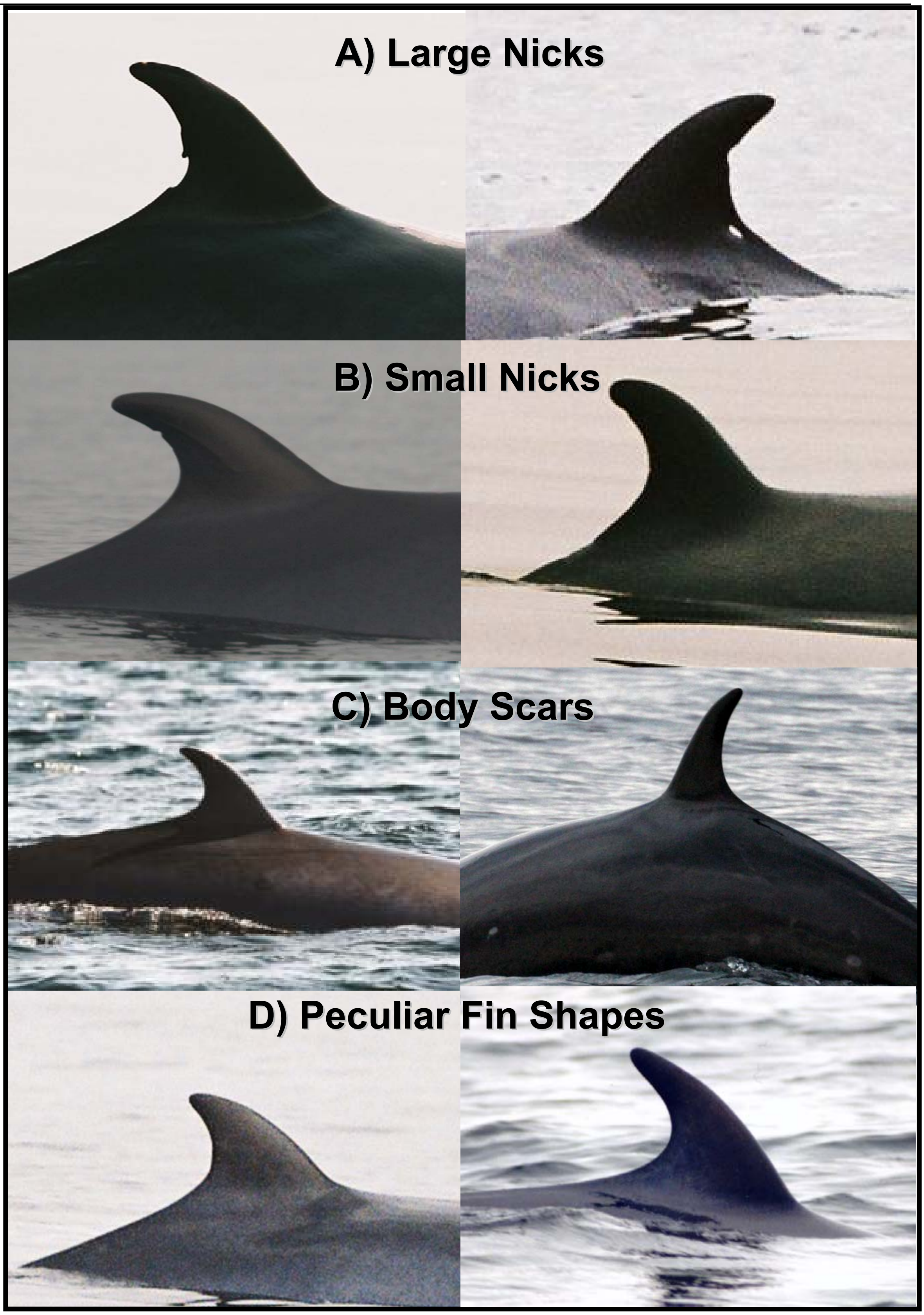

Fig. 2.2. Photographs from the CRRU catalogue illustrating the principal identification categories and fin features used in the identification of individual minke whales in the Moray Firth.

- The discovery curve (see Figure 2.3. and Table 2.1.), which it is used to illustrate the rate at which new (i.e. previously unencountered) individuals are photographed or discovered per standardised time period, is still increasing and has not reached its plateau. It is possible that a plateau will never be reached, if the animals encountered in the research area belong to an open population.

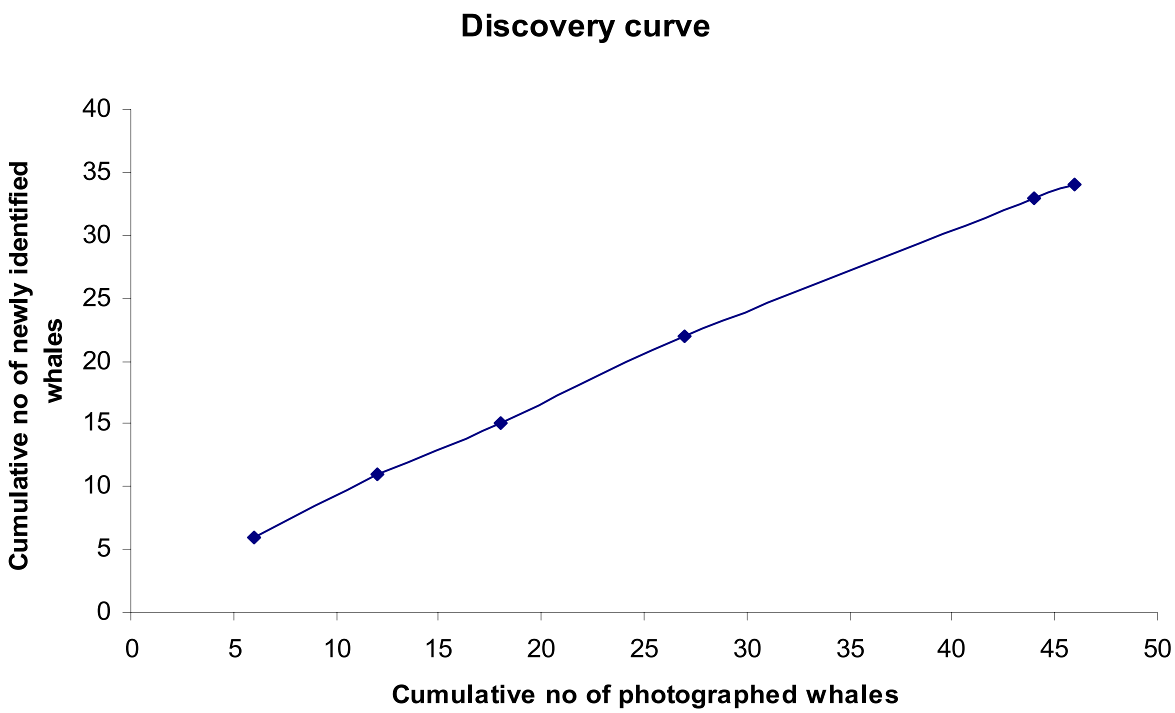

Fig. 2.3. The discovery curve is established by plotting the cumulative number of newly identified and photographed whales each year, from 2001 to 2007 inclusive.

Table 2.1. Cumulative numbers of newly identified whales, photographed whales (some of which were not included in the catalogue because of low quality) and recaptures.

Year	Tot newly identified whales	Tot photographed whales	Tot recaptures
2001	6	6	0
2002	11	12	1
2003	15	18	3
2004	15	18	3
2005	22	27	5
2006	33	44	12
2007	34	46	13

2.4.2 Temporal residence of identified whales

All identified whales, re-sighted within the same season and/or in different years, are listed in Table 2.2.

Table 2.2. Time and location of re-captured individuals. Coordinates are given in decimal degrees, after conversion from degrees, minutes and seconds (DMS).

ID #	Day	Month	Year	Time	Lat N	Long W	Area
1	**12**	**7**	**2003**	**16:48**	**57.6942167**	**-2.593133333**	**WHITEHILLS**
1	**17**	**8**	**2001**	**18:07**	**57.73415**	**-2.475316667**	**BANFF**
4	24	6	2006	16:19	57.73405	-2.29515	TROUP HEAD
4	15	9	2003	12:45	57.6927167	-2.411633333	GAMRIE BAY
4	12	8	2003	14:40	57.70265	-2.151316667	ABERDOUR BAY
4	4	9	2002	18:52	57.7084	-2.562966667	BANFF
4	28	8	2002	13:54	57.6978667	-2.548133333	BANFF
4	24	8	2002	16:15	57.6894	-2.580916667	WHITEHILLS
4	29	8	2001	17:43	57.7304833	-2.202833333	ABERDOUR BAY
4	28	8	2001	14:43	57.7007333	-2.308216667	TROUP HEAD
7	**3**	**9**	**2002**	**17:00**	**57.7037833**	**-2.670716667**	**PORTSOY**
7	**2**	**9**	**2002**	**16:08**	**57.7146**	**-2.792433333**	**CULLEN BAY**
7	**2**	**9**	**2002**	**12:02**	**57.7029833**	**-2.825733333**	**CULLEN BAY**
8	12	7	2006	12:05	57.7001	-2.26995	PENNAN
8	12	7	2005	21:26	57.6944167	-2.665816667	PORTSOY
8	12	9	2002	14:26	57.7024167	-2.7598	SANDEND
10	**28**	**7**	**2006**	**19:30**	**57.6919667**	**-2.210583333**	**ABERDOUR BAY**
10	**17**	**6**	**2006**	**19:25**	**57.7288833**	**-2.2438**	**TROUP HEAD**
10	**12**	**7**	**2005**	**21:18**	**57.6970167**	**-2.667516667**	**PORTSOY**
10	**23**	**7**	**2001**	**18:50**	**57.74415**	**-2.323483333**	**GAMRIE BAY**
12	12	8	2003	12:51	57.6936667	-2.217233333	ABERDOUR BAY
12	12	7	2003	16:48	57.6942167	-2.593133333	WHITEHILLS
16	**24**	**6**	**2006**	**16:50**	**57.7281833**	**-2.288783333**	**TROUP HEAD**
16	**6**	**6**	**2006**	**13:15**	**57.7447833**	**-2.717383333**	**SANDEND**
16	**4**	**7**	**2005**	**12:13**	**57.6947667**	**-2.32265**	**GAMRIE BAY**
16	**4**	**7**	**2005**	**19:24**	**57.6854833**	**-2.371883333**	**GAMRIE BAY**
20	5	6	2006	15:45	57.7139167	-2.36605	GAMRIE BAY
20	16	8	2005	14:57	57.70255	-2.241183333	PENNAN
21	**20**	**8**	**2006**	**17:31**	**57.6898833**	**-2.170983333**	**ABERDOUR BAY**
21	**16**	**8**	**2005**	**18:42**	**57.71525**	**-2.236683333**	**PENNAN**
23	17	7	2006	16:50	57.7253667	-2.078533333	SANDHAVEN
23	17	6	2006	18:38	57.72605	-2.29985	TROUP HEAD
25	**21**	**7**	**2006**	**15:17**	**57.7203333**	**-2.119733333**	**ROSEHEARTY**
25	**5**	**7**	**2006**	**21:06**	**57.6881333**	**-2.193433333**	**GAMRIE BAY**
26	20	8	2006	14:15	57.69035	-2.157883333	ABERDOUR BAY
26	21	7	2006	18:04	57.73645	-2.045	SANDHAVEN
26	5	7	2006	21:36	57.6817667	-2.186833333	GAMRIE BAY
29	**26**	**7**	**2006**	**18:15**	**57.70445**	**-2.267366667**	**PENNAN**
29	**21**	**7**	**2006**	**17:05**	**57.7233333**	**-2.096666667**	**ROSEHEARTY**
32	24	5	2007	12:25	57.6843667	-2.215066667	ABERDOUR BAY
32	30	8	2006	19:15	57.6967667	-2.262316667	PENNAN
32	22	8	2006	16:45	57.6839833	-2.1797	ABERDOUR BAY
32	20	8	2006	14:53	57.6894	-2.164	ABERDOUR BAY

The salient point of the re-sighting examination is that 41% of the animals photo-identified in the study area were recaptured on at least one or more occasions, and 19% were recaptured during at least 2 or more different survey years.

2.4.3 Location of identified whales

Besides this respectable percentage of animals frequenting the study area regularly, a small-scale spatial site fidelity also exists, with some of the individuals being re-sighted feeding not distant from previous encounters, both within the same season and in different years. A spatial representation of the recaptures is shown from Figure 2.4. to Figure 2.17.

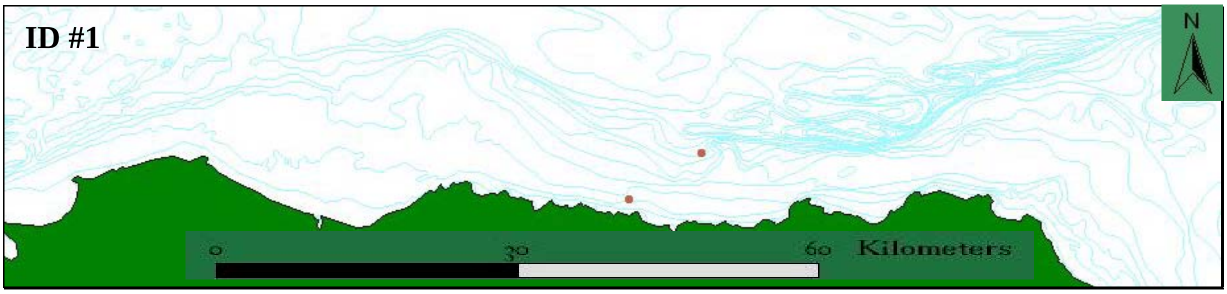

Fig. 2.4..Whale #1 photographed in 2001 and recaptured in 2003.

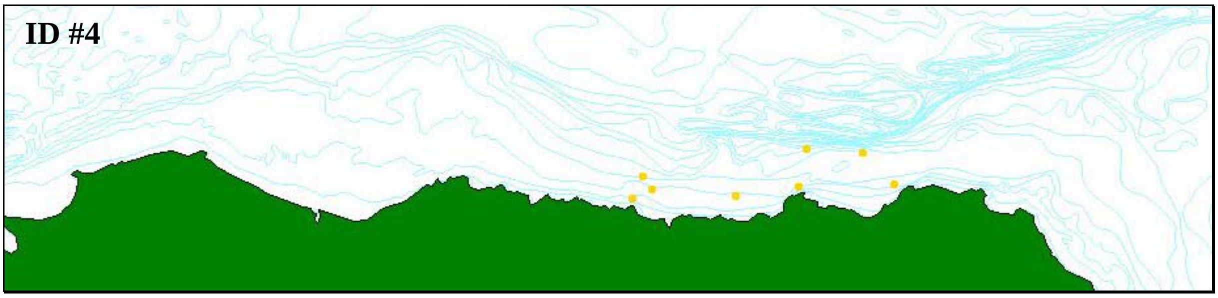

Fig. 2.5. Whale #4 photographed in 2001 and recaptured in 2002, 2003 and 2006.

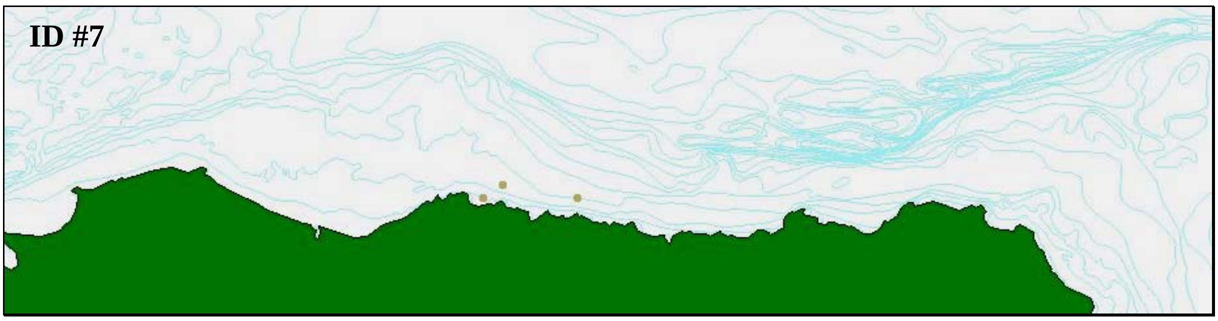

Fig. 2.6. Whale #7 photographed three different times in 2002.

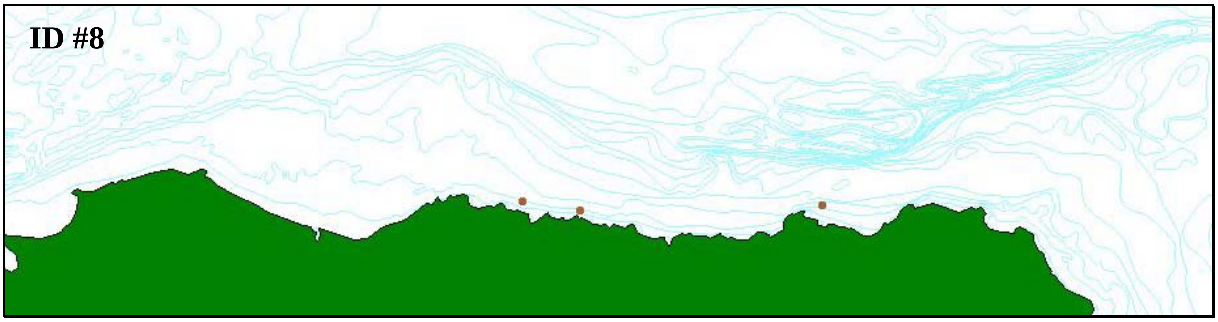

Fig. 2.7. Whale #8 photographed in 2002, recaptured in 2005 and 2006.

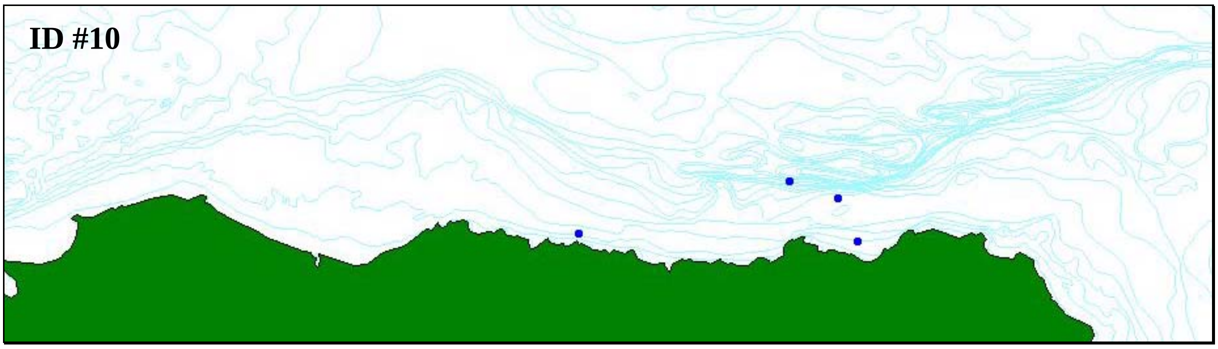

Fig. 2.8. Whale #10 photographed in 2001, recaptured in 2005 and 2006.

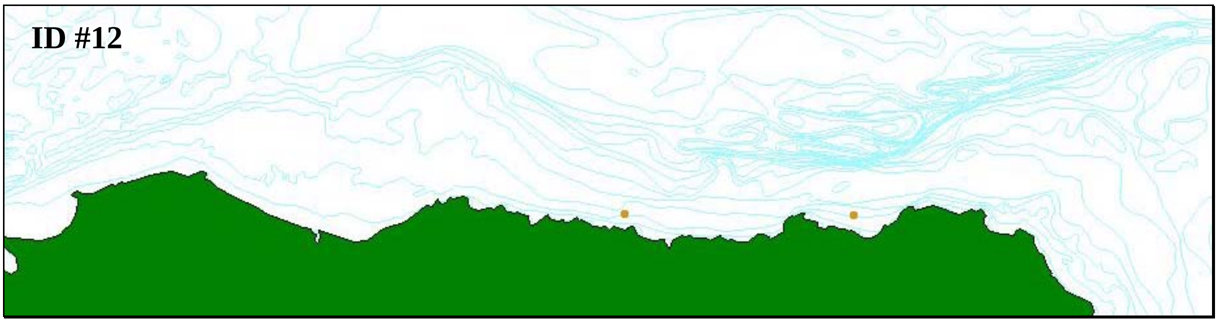

Fig. 2.9. Whale #12 photographed twice in 2003.

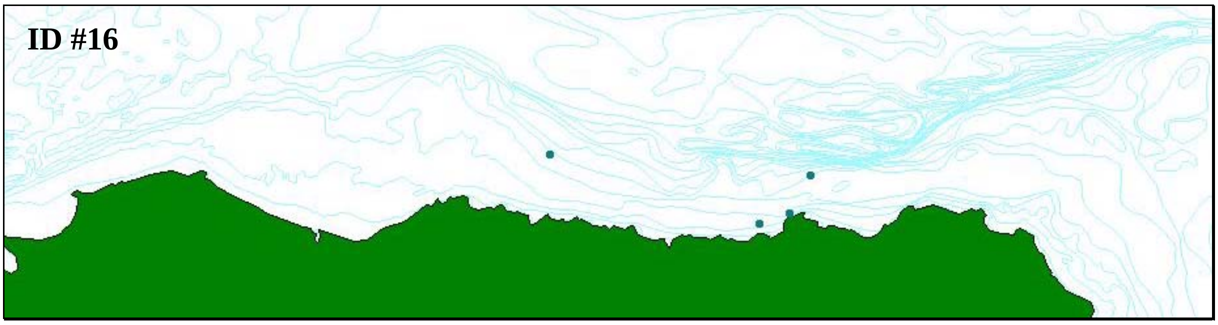

Fig. 2.10. Whale #16 photographed in 2005, recaptured in 2006.

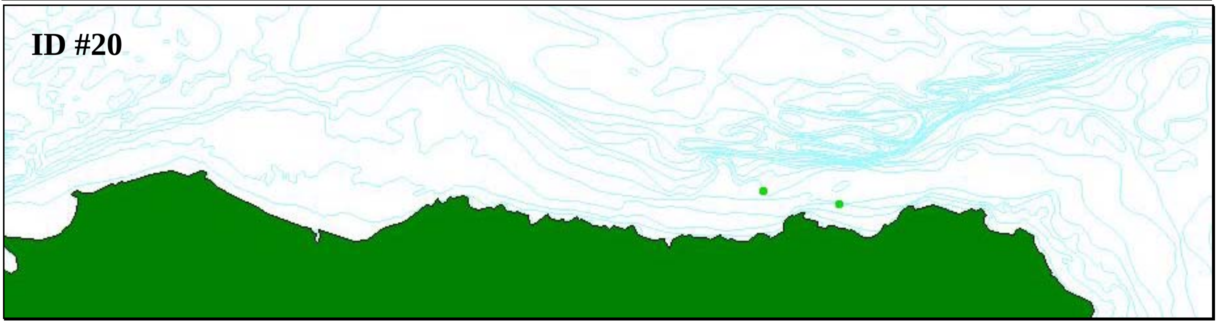

Fig. 2.11. Whale #20 photographed in 2005, recaptured in 2006.

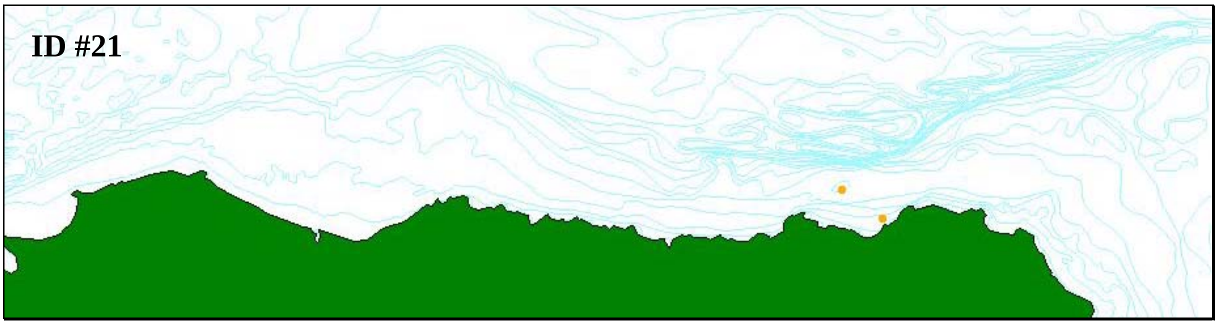

Fig. 2.12. Whale #21 photographed in 2005, recaptured in 2006.

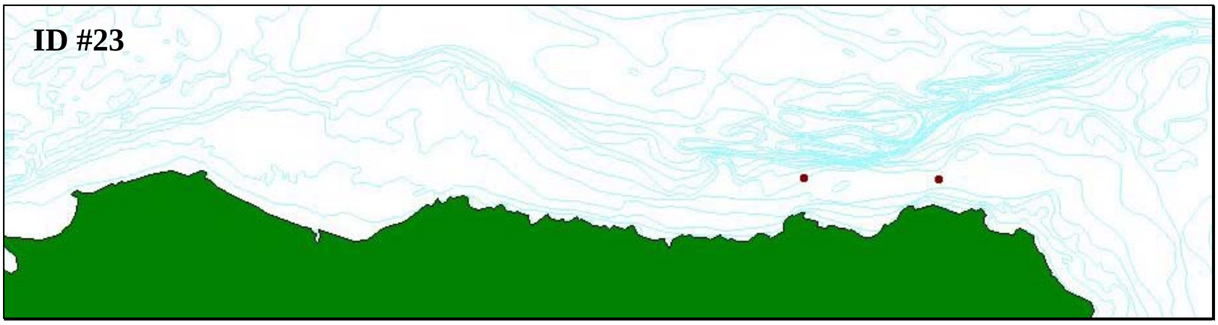

Fig. 2.13. Whale #23 photographed twice in 2006.

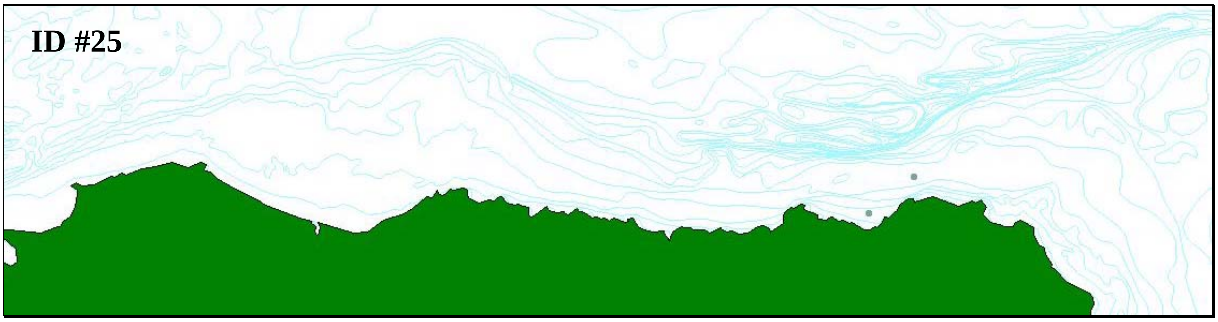

Fig. 2.14. Whale #25 photographed twice in 2006.

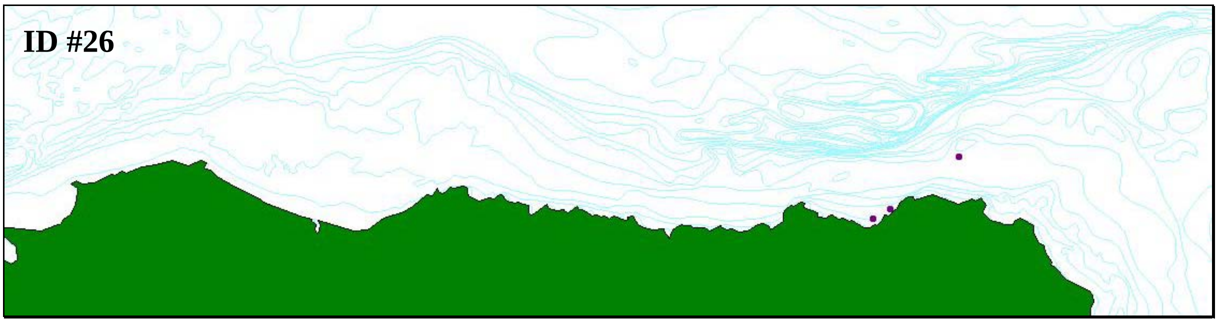

Fig. 2.15. Whale #26 photographed three times in 2006.

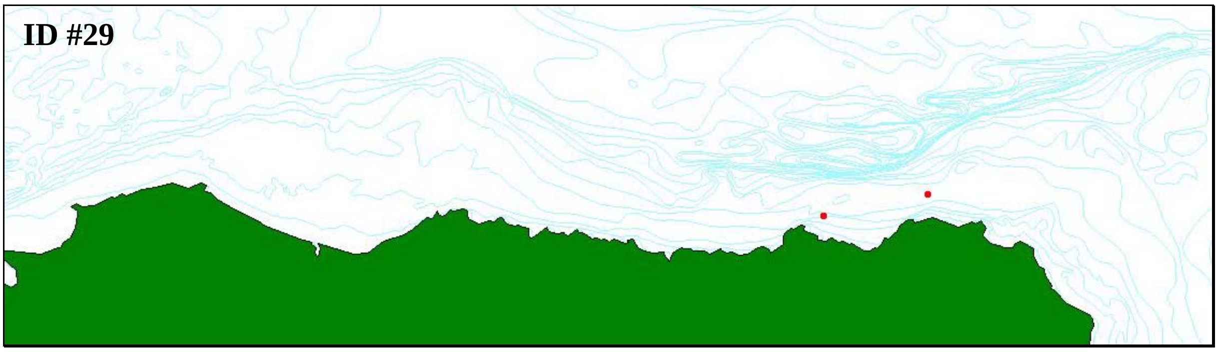

Fig. 2.16. Whale #29 photographed twice in 2006.

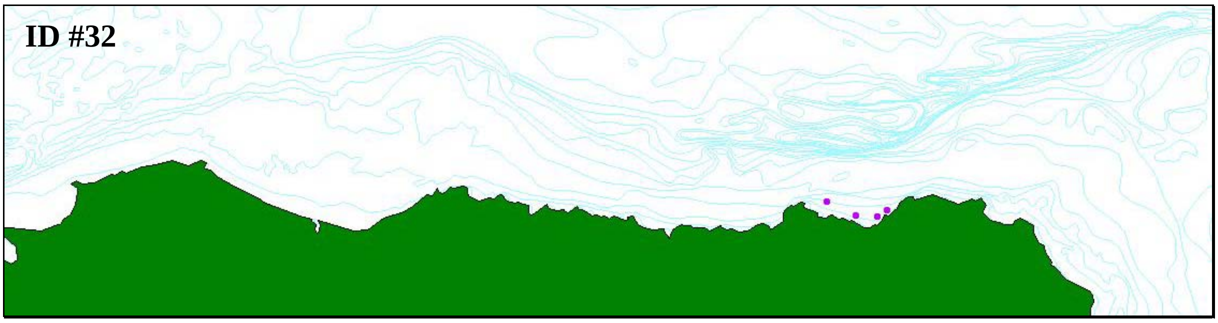

Fig. 2.17. Whale #32 photographed twice in 2006, recaptured once in 2007.

2.4.4 East-West Scottish catalogue comparison

The photo-ID catalogue provided by HWDT comprises eighty-four individuals, fifty-three (63%) of which have dorsal edge marks and thirty-one (37%) have no major DEMs but peculiar fin shapes and/or body scars. Photographic quality of thirteen of the fifty-three marked individuals was unsatisfactory for the analysis; therefore a total of **forty** recognisable animals from the HWDT catalogue were used for comparison with the **twenty-four** marked individuals from CRRU. After the contours of all high quality pictures from both catalogues were drawn in the Fin Extraction program and compared with one another in the Fin Matching program a few potential but questionable matches were found.

The FinMatch software calculates the probability that two fin photographs are from the same animal based on the shape and position of the nicks' contour on the fin. This software could be a useful supporting tool; however the ultimate decision is taken considering other factors too, for example body scars which are not seen by the program, the angle at which the animal is photographed and light conditions. The results derived from this analysis provided very uncertain matches which need more pictures on one or both sides to be confirmed/disconfirmed; in many cases, in fact, too often only one side was available, making the final decision impossible to take. Amongst the few uncertain matches found, only two are worth to be mentioned and these are between the Icelandic and the eastern Scottish catalogues.

Possible matches in the Icelandic/CRRU catalogues:

i) **AURORA & #21 (CRRU).** A questionable match which need a further investigation.

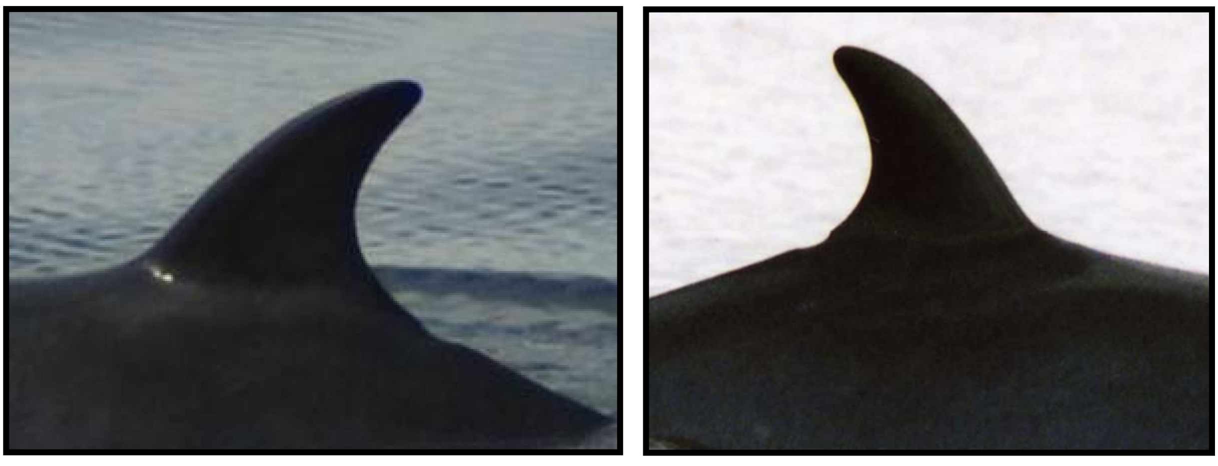

Fig. 2.22. Fins of Aura (Icelandic catalogue) and # 21 (CRRU), respectively.

ii) **ARCH AND #24 (CRRU).** In this case the Finmatch program can not estimate the matching probability, as these fins do not present dorsal edge marks; however, the peculiar arched shape of the both fins suggests a potential match. A further investigation should aim to match the white mark, presumably left by a parasite, on the left side of #24 (indicated by the white arrow).

Fig. 2.23. Dorsal fins of Arch (Iceland catalogue) and #24 (CRRU), respectively.

2.5 DISCUSSION

For both pinnipeds and cetaceans the identification of the individuals has proven to be an effective method to long-term studies of life history traits, such as age-structure, group structure and associations, reproduction rates, sexual segregation and also population size estimates, site fidelity and seasonal movements (Hiby & Lovell 1990; Forcada & Aguilar 2000; Vincent *et al.* 2001; Saayman & Tayler 1973; Würsig & Würsig 1977; Katona *et al.* 1979; Balcomb *et al.* 1982). Today it is recognised that with high grade photographs, a reasonable portion of the population of almost any cetacean species can be individually identified (Würsig & Jefferson, 1990).

Little is understood of the processes which lead to the formation of these marks. A study by Tetley *et al.* (2007) was conducted to determine if the characteristics of these marks differed between individuals from two distinct geographical areas in the Moray Firth, Scotland, and Skjálfandi Bay, Iceland. A dorsal fin layout system was used to test for differences in the proportion of marks occurring in different positions (anterior, posterior, upper, lower, tip) and differences in morphology (rounded, squared, triangular, indented, cut off) of the markings observed in each of the study areas for 19 (28 marks) and 26 (28 marks) known individuals respectively. When mark categories were compared between catalogues a significant difference was found in the relative position of marks (Chi-sq = 10.373, df = 8, p = 0.035). However, no significant difference was observed in the frequencies of dorsal edge mark morphologies between the two regions (Chi-sq = 0.769, df = 8, p = 0.943). It was concluded, although evidence derives from a small-scale study, that the unique processes by which these different shaped marks occurred were probably the same in both areas.

Although minke whales are only subtly marked compared to more interactive odontocete species, several studies (Dorsey, 1990; Gill, 1994; Tscherter & Morris, 2005) showed that marks occurring along the edge of the dorsal fin and supplemental body scars are useful in discriminating between individual minke whales. However, the high identification rates recorded for example in the St. Lawrence Estuary in Canada (Tscherter & Morris, 2005) could be facilitated by the high concentration of minkes and to the narrowness of the area investigated.

The results of this preliminary analysis were consistent with those of other studies (e.g. Gill, 1994) in that the recapture success is mainly based upon presence of large and small dorsal edge marks (DEMs). Body scars such as lesions, oval scars, rope scars, parasite marks, are thought to be less reliable than DEMs in recapturing individuals; however they can support a potential match.

The oval scars on other species of cetaceans have been attributed to lampreys (Pike, 1951; Nemoto, 1955) and to squaloid sharks (Jones, 1971; Shevchenko, 1971). Lampreys feed by attaching themselves to the skin of fish or mammals, rasping through the skin and sucking out the blood. The cookie-cutter shark attaches itself to its prey with its lips, and then spins to cut out a cookie-shaped plug of flesh from the larger animal leaving a deeper wound which takes longer to heal. Shevchenko (1971) states that lampreys can only cause circular wounds, and not oval ones.

If the oval lesions which are very often found on the lateral flanks of the whale and on the back behind the dorsal fin are confirmed to be cookie-cutter shark (*Isistius brasiliensis)* bites, then body scars could also give valuable information on the percentage of the minke population undergoing seasonal migration between the North Sea and the Tropics. This squaloid shark lives in the southern areas of the Northeast Atlantic (Compagno, 1984), primarily from about the Cape Verdes southwards and usually occurs far offshore over deep oceanic waters. It is considered a parasite and its bites are from ~ 3 to 5 cm wide. It is likely that the oval scars found on many of our minke whales were caused by the cookie-cutter shark

(Gulak S., Gubili C. & Pade N., personal communication), suggesting that these animals could indeed undertake migrations like other baleen species.

As see in other studies we recorded small-scale site fidelity in the Moray Firth, with a 40% of the animals "recaptured" on one or more occasions, which is a relatively high proportion considering the small amount (24) of marked whales captured in 7 years. This is also true for the western Scottish area (Gill, 1994). At this early stage we are not able to look at individual habitat preference within the study area, although the recaptured animals were more likely re-sighted in the same areas. We know from past research (Hoelzel *et al,* 1989; Dorsey *et al.*,1990) that some minke whales specialise on the entrapment of specific prey species and therefore they may prefer areas where that particular prey occur, rather than others. This could be happening also in the Moray Firth, however, such information is difficult to obtain in this instance, due to the lack of small-scale fisheries data.

In addition to providing a greater understanding of the distribution, site fidelity and behaviour of individual minkes in the Moray Firth, comparisons of existing records from different coasts within Scottish waters, and possibly with Iceland, could be useful in the interpretation of current distributional patterns, intra-population dynamics and the underlying behavioural ecology in coastal habitats. However, to determine the amount of exchange rate between these areas, more years of effort, quality assurance and standardisation of methodology are essential for accurate data collection and for achieving common standards in monitoring. One of the most critical steps is to ensure a common quality-grading standard. This can be achieved by restricting all quality-grading of the ID images to a single, experienced person, or through periodic double grading of images (grading by more than one person) throughout the season (Parsons, 2004). The compilation and continuous update of a photo-archive for recognisable minke whales in northeast Scotland provides a first step towards a more integrated approach to minke studies in coastal waters.

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CHAPTER 3

THE BREATHING INTERVALS OF MINKE WHALES PERFORMING DIFFERENT BEHAVIOURS IN NORTHEAST SCOTTISH WATERS

3.1 ABSTRACT

Minke whale inter-surfacing intervals were recorded over a period of two summer seasons in the coastal waters of the outer southern Moray Firth, in northeast Scotland. Significant differences in surfacing intervals were noted for different behaviours, in particular between foraging and travelling, and between feeding and travelling. Generalised additive model (GAM) results showed that surfacing intervals were also influenced by depth and time of day. Differences in surfacing intervals were interpreted as likely to be the result of variations in habitat utilisation, foraging strategies and changes in prey availability throughout the day. Furthermore, as in the majority of cases the frequency of diving intervals was heavily skewed, it was noted that the mean value often mentioned in diving studies is not a useful indicator of the diving behaviour. The results of this study are relevant for methodologies used to estimate minke whale abundance from sighting surveys.

3.2 INTRODUCTION

A prominent feature of the normal behaviour of marine mammals is their frequent and often prolonged breath-hold diving. The details of diving behaviour often are difficult to observe, as they occur below the sea surface. Whether making dives to forage, mate, socialise, or rest, cetaceans are well adapted to stay below the surface for extended periods of time (Würsig *et al.*, 1984; Dorsey *et al.*, 1989). Generally marine mammals exhale and inhale lung air rapidly, then retain that air in their lungs for prolonged periods of apnoea before exhaling again, even when resting at the surface. In the larger species of whales, dives of several minutes duration, whether for feeding or during migration, are followed by a series of several blows 20 to 30 seconds apart before another prolonged dive is initiated (Berta & Sumich, 1999). These short breath-hold ventilatory patterns of whales are assumed to optimize oxygen uptake relative to their time spent at the surface (Kramer, 1988).

Apart from infrequent surface displays such as surface feeding or breaching, the ventilatory behaviour of whales is certainly their most obvious activity. Studies on minke whale surfacing rates and patterns have served as an integral part of research on this species (Joyce *et al.*, 1990). The observations have a variety of applications, for example help in population abundance estimates, through the estimation of the g(0) – the probability of detecting a whale that is present within the area of observation when conducting line-transect surveys (Stern, 1992). The reliability of whale population estimates made from "cue-counting" census surveys depends upon accurate and well-documented studies of ventilatory patterns to provide correction factors so as to adjust results for unobserved submerged animals (Leatherwood et al, 1982; Kopelman & Sadove, 1995). Correct population estimates are ultimately important for conservation management and to evaluate maximum sustainable yield for countries which perform whaling activities, such as Norway, Iceland and Greenland in the northern hemisphere.

Moreover, data on surfacing rates, ventilation patterns and diving behaviour are also important in assessing the reactions of whales to industrial disturbance such as shipping, oil exploration (Dorsey et al, 1989), as well as other potential sources of disturbance such whale-watching vessels.

Considerable variability is known to exist in the diving and ventilation rates of whales depending on season (Stockin *et al.,* 2001), and/or the type of activity they are involved in (Dorsey *et al.*, 1989). Foraging activities may vary further with the foraging depth (the depth at which target prey occur), and consequently within the same individuals over time. Thus, changes in the number of blows between dives and the duration of blow intervals can be used to interpret the decisions taken by animals in a particular behavioural state and given environment, or in response to varying biotic / abiotic factors in a heterogeneous ecosystem.

The present study aims to provide basic diving parameters for the various activities undertaken by the minke whales in the southern outer Moray Firth investigate sources of variation in surfacing rates and to compare them with results obtained in different regions.

3.3 MATERIALS & METHODS

All data used in the present report were collected during the months of May to October 2006 and 2007, from an 880 km^2 area within the southern outer Moray Firth, north east Scotland (see Chapter 1). Surveys were typically carried out, in either an easterly or westerly direction, from the centrally located port of Whitehills with two 5.4 m Avon Sea Rider offshore rigid inflatable boats equipped with outboard engines, full safety gear (VHF radios, 406 MHz EPIRB's, hand flares, re-rightable apparatus, hand-held compasses, 275N offshore lifejackets, survival suits, oars etc), a GPS/SONAR plotter and a detachable observation platform (Fig.). Surveys consisted of travelling along four predetermined transects, parallel to the coastline (see chapter 1). All surveys were conducted at speeds of 5 to 7 nm per hour, with a crew of 4 to 6 observers and at sea states of Beaufort 3 or less in good light conditions. If the sea state increased beyond 3 or the weather deteriorated, the survey was either halted temporarily until conditions improved, or was terminated. To assist observations binoculars were used while at sea. Cues used to locate the whales while surveying, included the presence of bird feeding rafts (often a sign of the presence of marine mammals) or direct observation of animals from their long dark backs and falcate dorsal fins when surfacing. Once a whale was sighted, progress was made to approach the animal, and at a distance of approximately 50 metres the boat was slowed to idle or turned to match the speed and direction of the whale if it was travelling in a predictable manner, that is following a constant route without changing direction. The time and GPS position was recorded for each individual encountered and

additional notes on the age-class, and behaviour of the subject were recorded. A distance was maintained to take identification photographs (usually within the first few surfacings) for the photo-ID catalogue. Only the most recognisable animals with distinctive dorsal edge markings (DEMs) were chosen for 30-minute visual ventilation/behavioural samples (focal follows). When whales were travelling, they could be followed for long periods as a result of their predictable direction of travel.
The following data were recorded at each surfacing: time (with a stop-watch to the nearest second); direction of travel; behaviour of the whale (see below for categories); sea surface temperature; depth; sea state and weather conditions; presence of seabirds; presence of fishing or whale watching vessels etc. To minimise the possibility of surfacings being missed during focal follows, the vessel was positioned in the same direction and at the same speed as the whale during long dives in order to be close to the whale when it re-surfaced. In the majority of cases, travelling, solitary whales had a predictable speed and trajectory. Samples during which surfacings may have been missed were excluded form the analysis. When several whales were encountered at the same time, digital identification shots were taken during surfacings to ensure the identity of the whale being followed.

The recorded diving intervals were then classified according to the following explanatory variables:

- Behaviour (e.g. feeding, foraging or milling, travelling),
- Depth,
- Time of the day.

The data distribution was checked for normality, log transformed and a parametric one-way analysis of variance (ANOVA) was chosen to ascertain significant differences in the dive intervals across categories. A generalised additive model was then used to assess the relationships between dive intervals (Gaussian distribution after log transformation) and the explanatory variables.

3.3.1 Definition of minke whale behaviours

The whales´ behaviour was categorised as follows:

- **Feeding.** Whales were considered to be feeding at the surface if they exhibited lunging activity (oblique, lateral, vertical or ventral) with distended ventral grooves or open mouthparts exposed to the air, or if they exhibited arching activity (lateral or ventral) with distended ventral grooves visible just under the surface.

- **Foraging (or suspected feeding).** Animals that were performing elliptical surface swimming patterns and dorsal arches, coupled with shallow diving angles over prey patches, although not directly observed lunging.

- **Travelling.** Clear movement of the animal along a straight course, in which the direction was kept constant for the whole behavioural sampling.

- **'Pacing' behaviour.** In August 2007**,** a young minke whale entered into the waters of Fraserburgh harbour and kept swimming in a circle in the shallow and contiguous basins of the harbour (~ 400 m^2) for three days, thus providing an opportunity to monitor the whale respiration pattern in unnatural conditions. A focal follow of 50 minutes was recorded with the stop-watch. By analogy with the behaviour of some caged mammals, we refer to this as "pacing". However, as this is data from just one animal, this behaviour has not been statistically compared with the other 3 behaviours.

3.3.2 Definition of diving profile features

The diving profile of cetaceans is typically divided in short and clustered inter-surfacing intervals, and long (and possibly deep diving) intervals (Figure 3.1.)

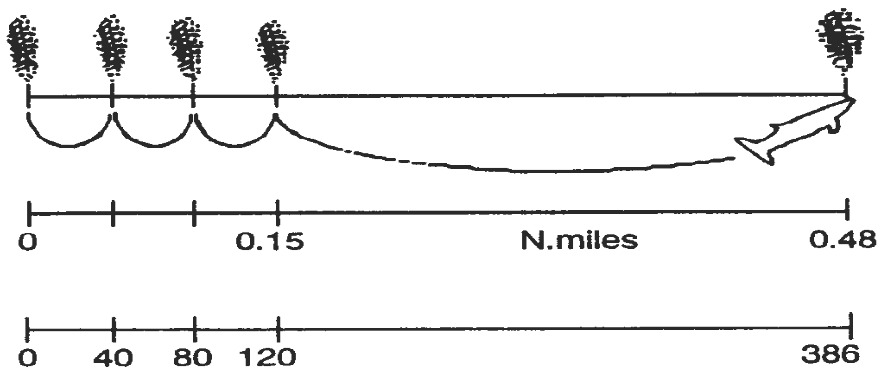


Fig. 3.1. Diagrammatic representation of the dive sequence of minke whales. From Stern (1992).

However, in the present study the majority of the samples examined did not present a clear discernible difference between short and long inter-surfacing duration (except for travelling individuals), therefore an overall average value of intervals between blows [segment a) in Fig. 3.2.] was calculated without making distinctions between short and long interval lengths.

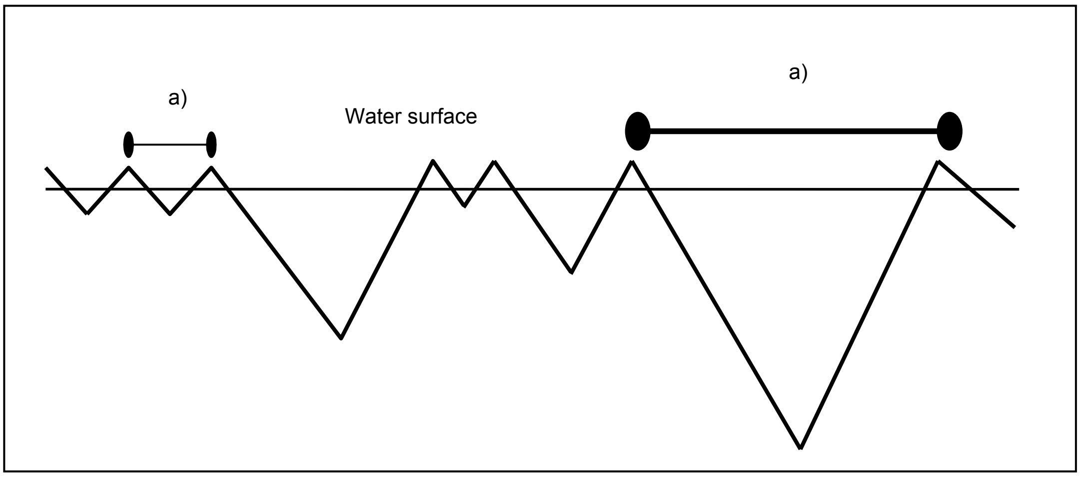


Fig. 3.2. Irregular diving profile of minke whales encountered in the outer Moray Firth. a) short and long intervals

3.4 RESULTS

3.4.1 "Pacing" whale in Fraserburgh harbour

The young whale behaviour was monitored for the first day of its 3 day stay in Fraserburgh harbour (2nd August 2007). [On the remaining days, a plan was being worked on to coax it out]. The 50 minutes of diving profile recorded showed that the whale performed 51 surfacings, for an average of one surfacing per minute (Mean dive interval = 60.92 sec; Std. Dev= 20.02 sec; Min = 29 sec; Max= 106 sec) as shown in Figure 3.3.

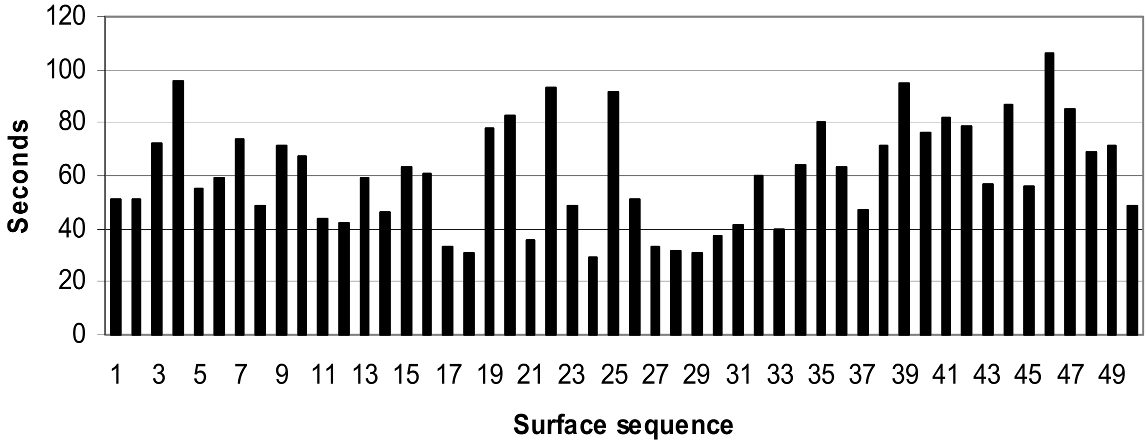


Fig. 3.3. Diving profile of whale trapped in the harbour.

3.4.2 Behavioural variations

A total of 22 focal follows (≥ 30 min), including 656 surfacing/diving sequences, was undertaken between May and October, in 2006 and 2007.

In the data exploration, when frequency distributions are plotted for each behaviour it can be seen that intervals between surfacings for feeding, foraging and travelling behaviours, are all strongly right skewed. All three distributions have similar modes (Table 3.1.) but the travelling distribution has the highest frequency of long intervals.

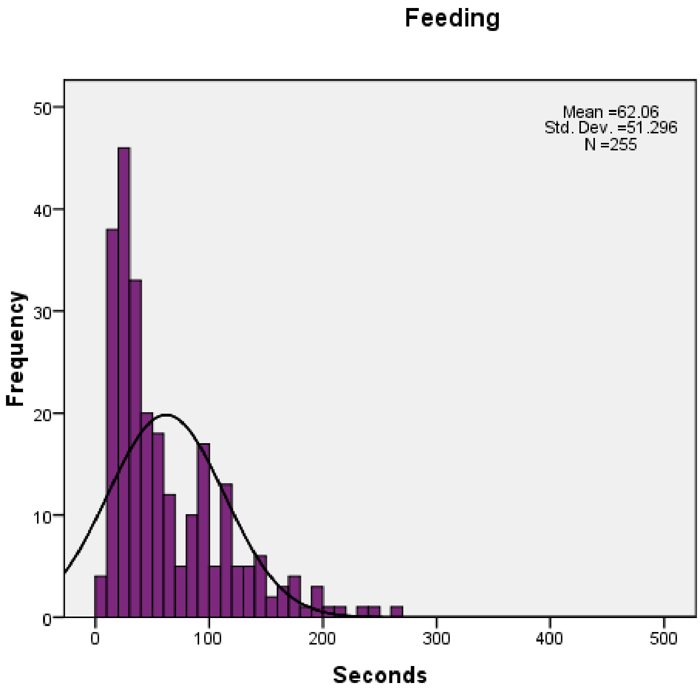


Fig. 3.4. Dive duration frequency for feeding minke whales (with normal curve). N refers to dive sequences of 6 individuals pooled together.

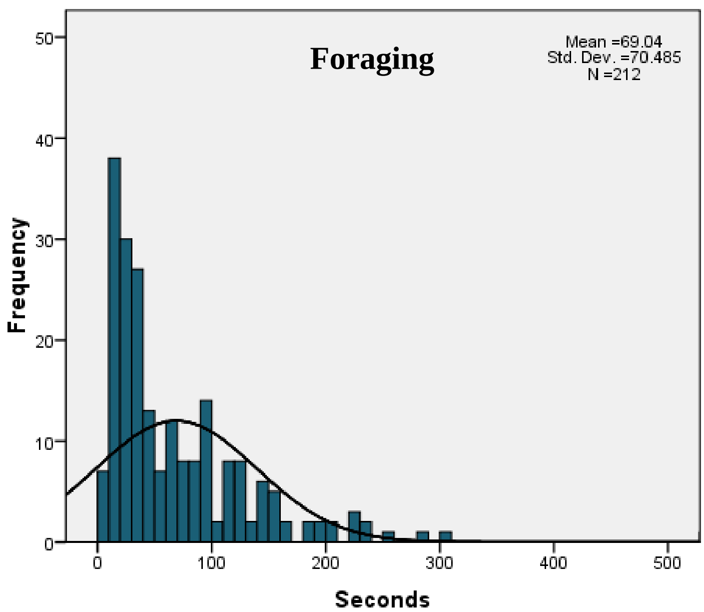


Fig. 3.5. Dive duration frequencies for 6 foraging individuals.

Travelling

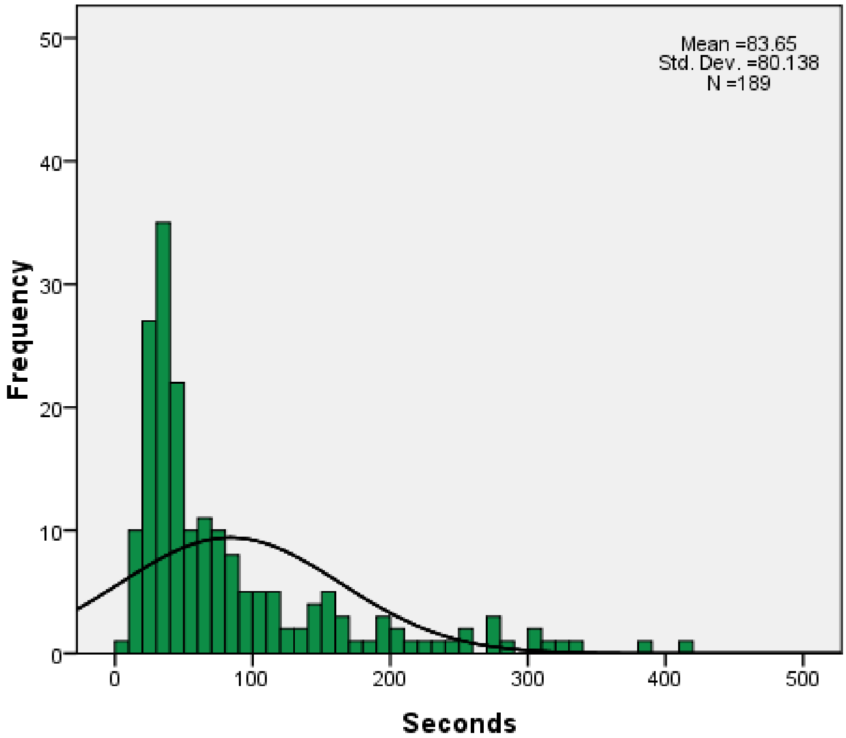


Fig. 3.6. Dive duration frequencies for 7 travelling individuals.

However, this was not true for the pacing behaviour, which presented a normal distribution and was therefore not compared statistically with the other three behaviours.

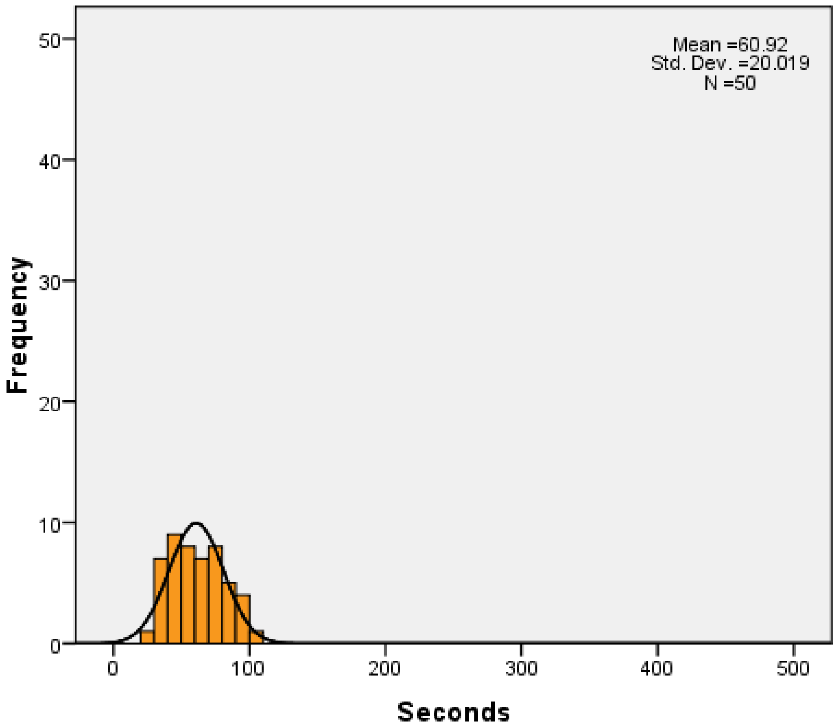


Fig. 3.7. Dive duration frequencies for the one "pacing" animal in Fraserburgh harbour.

For all sequences pooled together the mean surfacing interval was 69.9 sec (SD±66.7): 62.06 sec (SD±51.3) when feeding, 69.03 sec (SD±70.04) when foraging and 83.65 sec (SD±80.14) when travelling (Table 3.1.). However, as evidently shown in the distribution frequency plots, the mean is not a good indicator of the non-normal distributions.

Table 3.1. Descriptive statistical parameters determined for dive durations of feeding, foraging and travelling minke whales.

	Feeding	Foraging	Travelling	Pacing
Mean	62.05	69.03	83.65	60.92
Standard Deviation	51.29	70.48	80.13	20.02
Standard Error	3.21	4.84	5.82	2.83
Median	42	42	49	59
Mode	20	17	34	51
Minimum	5	0	9	29
Maximum	262	608	412	106
Count	255	212	189	51

After a log transformation of the non-normal data, a one-way ANOVA showed a significant difference between the three main behaviours (P=0.0024, F= 6.09), and a Tukey's post-hoc test, performed to locate the variation, showed that the difference was between Travelling versus Foraging and Feeding, however not between Feeding and Foraging. Results are shown in Table 3.2.

Table 3.2. Tukey's multiple comparison test.

Tukey's Multiple Comparison Test	Mean Diff.	q	P value
Feeding vs Foraging	-0.005085	0.2024	0.087 *ns*
Feeding vs Travelling	-0.1171	4.521	0.031*
Foraging vs Travelling	-0.1121	4.144	0.032*

ns=not significant

To establish whether the difference between behaviours depended on the frequency of short or long intervals, a finer division of the interval distributions was made within each behaviour and analised with a Chi-squared test. Results (Chi-Sq = 17.696, DF = 6, P = 0.0079) show that the difference is significant at both the upper and lower edges of the distributions.

3.4.3 Generalised additive model (GAM) results

The diving intervals (response variable, Gaussian distribution of log transformed data) were modelled according to the following formula: *Y1 ~ 1 + as.factor(BEHAVIOUR) + s(TIME, k = 4) + s(DEPTH, k = 4) + as.factor(BEHAVIOUR):TIME + as factor(BEHAVIOUR): DEPTH*, where '**s'** stands for smoother, '**k'** for (the maximum permitted number of) knots (degrees of freedom), '**as.factor'** nominal variable, and '**colon'** an interaction between two variables . Results are shown in Table 3.3. There is a weak but significant indication that depth and time of the day have an effect on the minke whale minke whale feeding behaviour. However, no other variable appears to be significant.

Table 3.3. Results of GAM showing the levels of significance attributed to each covariate in determining whales' diving intervals for parametric coefficients and smoothers, when the interaction between behaviour, time and depth is considered.

Parametric coefficients:

	Estimate	Std. Error	P
FEEDING :TIME	0.0882	0.0075	<2e-16 ***
FORAGING :TIME	-0.0419	0.0705	0.5525
TRAVELLING :TIME	0.0371	0.0669	0.5790
FEEDING :DEPTH	0.0087	0.0034	0.0119 *
FORAGING :DEPTH	0.0001	0.0039	0.9663
TRAVELLING :DEPTH	0.0027	0.0042	0.5249

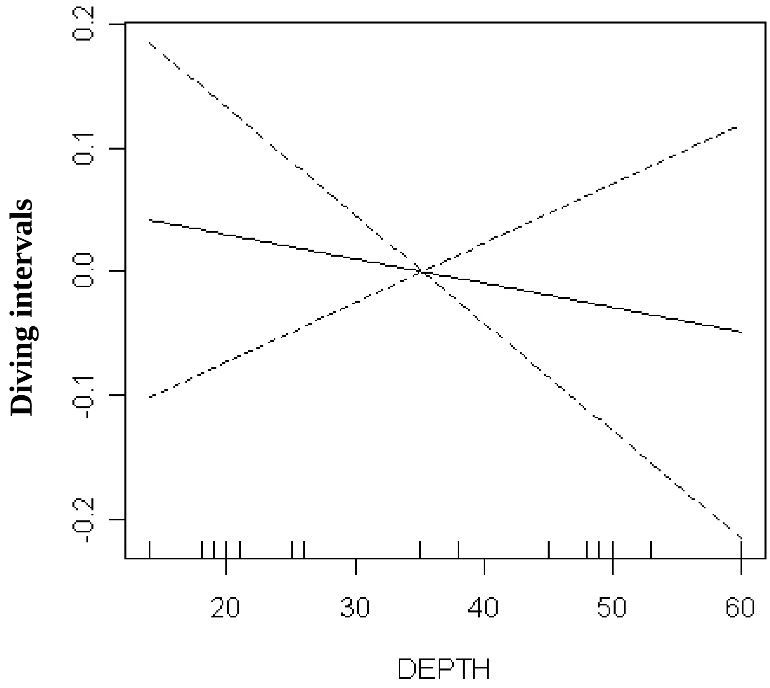
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '

Approximate significance of smooth terms:

	edf	F	P
DEPTH	0.1230	0.336	0.563
TIME	0.9228	0.307	0.580

R-sq.= 0.0348 Deviance explained = 5.32%

A)



B)

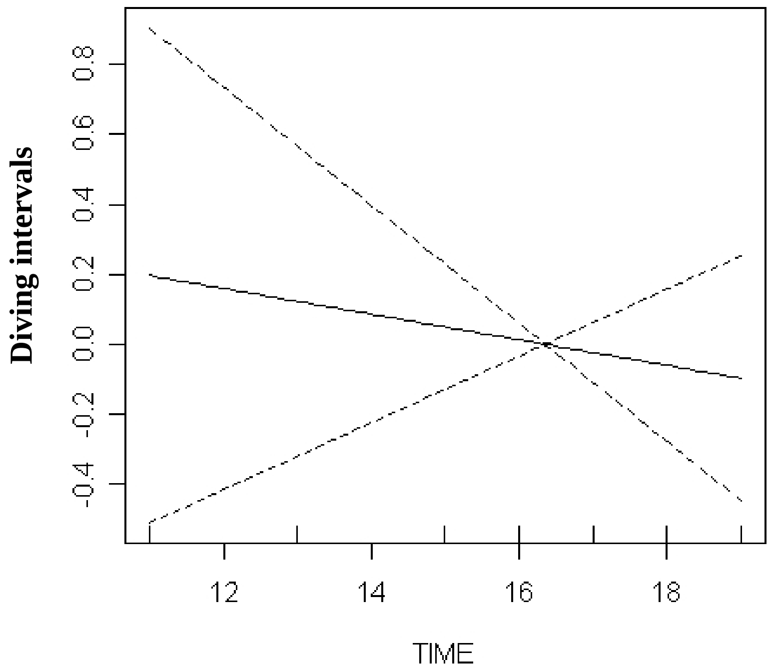


Fig 3.8. GAM output showing the significant explanatory variables fitted to diving intervals (the response variable). The fitted lines show the partial effects (solid line) of explanatory variables and the standard error bands (dashed lines)**. A)** The interaction between behaviour and depth has an effect on the diving intervals. **B)** The interaction between behaviour and time has an effect on the diving intervals.

3.5 DISCUSSION

The overall conclusion from the ANOVA is that the length of diving intervals is significantly different between behaviours. The frequencies of the dive for durations for the three main types of behaviours considered in this analysis showed that feeding animals tend to have fewer long surfacing intervals, implying a greater oxygen uptake for an activity that requires more energy, before gulping the fish bait balls. Moreover, as the bait balls are generally located at the interface between water and air (presumably trying to escape both aerial and sea predators), feeding minke whales spend more time at the surface compared to foraging or travelling ones which spend more time under the surface. As for the dive durations of foraging animals, the relative frequency of long intervals lay in between those for feeding and travelling behaviours, whilst travelling minke whales generally had a higher proportion of longer diving intervals, as expressed by Stern (1992).
However, the GAM model shows that feeding minke whales are also affected by time of the day and depth, although more data is required to explore this further. Stockin *et al.* (2001), who obtained similar diel differences in minke whale diving intervals in northwest of Scotland, concluded that these differences are probably due to changes in patterns in habitat utilisation and/or foraging behaviour. Prey species targeted by these whales may have changed during the day as the availability of prey changed. Thus, the diving behaviour may track small-scale changes in prey availability. However, it is still not clear how the minke whale breathing duration varies according to specifically targeted prey species. Most minke whale preys are small shoaling fish: it may be supposed that diving behaviour varies according to the size, density and dispersion of these shoals.

In the unfortunate case of the minke whale trapped in Fraserburgh harbour, it is interesting to note that the mean breathing pattern was slightly shorter (60.9 sec) than that for the most intense activity observed (feeding behaviour = 62 sec), although the proportion of short intervals was actually much lower. The young animal eventually and successfully left the harbour on the third day, providing a valuable occasion to study a wild animal in conditions which can be compared to captivity. The reasons why minke whales often enter harbours are still unknown.

Table 3.4. The mean dive intervals of *B. acutorostrata* from different geographical regions.

Author	Study area	SPWPH	Mean interval
Ward (1988)	Antarctic	48	75 sec*
Stern (1992)	California	38.6	93.3 sec*
Joyce *et al.* (1989)	Norway	52.4	68.7 sec*
Gunnlaugsson (1989)	Norway	52.7	68.3 sec*
Øien *et al.* (1990)	Norway	42	85.7 sec*
Joyce *et al.* (1990)	Iceland	65.90 °	54.6 sec*
Folkow & Blix (1993)	Norway	48.2**	74.6 sec
Stockin *et al.* (1990)	West Scotland (UK)	54.5**	66.1 sec
Curnier (2005)	East Canada	65.9 **	54.6 sec

SPWPH = Surfaces Per Whale Per Hour

° VHF radio tagged whale

* The authors give their results in number of surfaces per whale per hour (SPWPH); mean surfacing intervals in seconds were extracted dividing 1 hour (3600 sec) by the SPWPH.

** The authors give their results in seconds, as mean surfacing intervals (in brackets); number of surfaces per whale per hour was extracted dividing 3600 sec by the interval.

It is apparent from results of this study that the mean inter-surfacing interval is a poor representation of surfacing behaviour, because of the skewed interval distribution, and that modes possibly give a better representation of the diving behaviour, therefore allowing a more accurate population estimate. Nevertheless, most published studies report only the mean surfacing rate and not the distribution of surfacing intervals, which makes the initial objective of comparison between regions impossible to fulfill.

Published results on mean surfacing intervals studies are highly variable (Table 3.4.). For example, Stern (1992) measured 93.2 sec in California, whilst Joyce measured 95.8 in 1982 and 54.6 in 1990 in Antarctic waters. Minke whales around the Isle of Mull, Scotland had a mean surfacing interval of 66.1 sec (Stockin et al, 2001). Similarly, Gunnlaugsson (1989) found blow intervals of 68.3 sec in Icelandic minke whales, and Norwegian minke whales were found to have surfacing intervals of 68.7 (Joyce et al, 1989). There could be several explanations for these highly variable measurements, related for example to the data collection methodology. Stern (1992) points out that the whales can be easily missed when the vessel speed increases and the probability of sighting decreases, whilst Gunnlaugsson

(1989) notes that behavioural samples collected in shallow waters, which are relatively easy to keep track of, may not be representative of the whole population. Tagging these whales with time-depth recorders may have helped obtaining less biased data, however, this species more than others present logistic constraints (Panigada S., Evans P.G.H & Fahlman A., personal communication).

Despite the potential errors in data collection due to subjectivity and differences in experience of visual observers, there is evidence from this and previous studies (Dorsey *et al.*, 1989; Stockin *et al.*, 2001; Curnier, 2005) that a difference in minke whale diving pattern occurs when the animals are engaged in different behaviours, but there is also variation within the same behaviour. Minke whales are known, for example, to perform different feeding strategies (Hoelzel *et al.*, 1989) during which they seem to vary their breathing patterns (Curnier, 2005). Thus, in areas like northeast Scotland, where the whales exploit concentrations of fish 'prepared' and concentrated in bait balls at the air-water interface by flocks of feeding gulls and diving birds from above and often by predatory fish from below, whales may usually need no further entrapment effort (Robinson & Tetley, 2006). Consequently, the level of physical activity for these bird-associated feeders is presumably low and the mean breathing intervals are longer than for example the interval measured in the St. Lawrence, in Canada, by Lynas & Sylvestre (1988) and Curnier (2005). There the main form of surface feeding analysed is that of patch fishing, which requires a high expenditure of energy in order to corral the prey into tight bait balls before engulfment. This activity is of such an intense nature that it is reasonable to suppose that 'patch-feeding whales accumulate oxygen debts' (Curnier, 2005). Consequently, in order to repay this debt, high levels of gas exchange are required, which may explain the shorter surfacing intervals observed in Canada as suggested by Curnier, in comparison to other areas like Scotland. However, before comparing inter-regional differences in minke whale surfacing intervals, it may be advisable to focus on inter-individual differences within same areas, something that was not possible in this project due to the low number of identified animals.

Moreover, from the results of this and other breathing patterns studies, further research may focus on the creation of a model that estimates the conditional probability of detecting a minke whale g(0) based on the diving/breathing intervals determined for different behavioural states. In this respect a model-based approach, which can be either based on detailed analytical or simulation (Doi *et al.*, 1982) models of the diving behaviour, will allow an estimation of the fraction of animals that are never seen, according to geographical areas and behaviour.

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CHAPTER 4

INTERANNUAL MINKE WHALE *BALAENOPTERA ACUTOROSTRATA* OCCURRENCE AND THE EFFECT OF TIDAL AND ECOGEOGRAPHIC VARIABLES IN NORTH EAST SCOTLAND (UK)

4.1 ABSTRACT

The Moray Firth in northeast Scotland, a rift basin of the UK North Sea, is a summer feeding ground for the northern minke whale (*Balaenoptera acutorostrata*). Between 2001 and 2007, the summer occurrence of minke whales in the southern outer Moray Firth was studied with respect to topographic and tidal variables. Intra-annually, the occurrence of whales showed a typical increase from May to July and a subsequent decrease from July to September, representing an inshore-offshore movement. In a preliminary attempt to establish the driving forces determining the whale incidence in the study area, a range of environmental variables were analysed in a Generalised Additive Model (GAM) framework. Results show a strong positive linear relationship between tidal speed and whale occurrence, suggesting that current speeds may be important in explaining prey availability. Depth, longitude, month and year were all highly significant covariates, whilst seabed slope, tidal height and the direction of the tidal current showed a weaker significant effect; the highest incidence of whales was found in the eastern part of the study area, between the shoreline and 50m isobath, and where the seabed slope descends gently. The GAM succeeded in explaining 39.3% of deviance (variability) in the presence of minke whales.

However, the importance of these variables differs between months reflecting the seasonal shift in minke whale distribution patterns.

4.2 INTRODUCTION

The northern minke whale (*Balaenoptera acutorostrata*) occurs widely along the Atlantic continental shelf from Norway to France and throughout the North Sea, although less commonly in the southern North Sea and eastern Channel (Evans *et al.*, 2003; Reid *et al.*, 2003; Hammond, 2007). The wintering range of this species is poorly known. A general offshore movement has been observed in autumn (Anderwald *et al.*, 2008), although sparse sightings occurred in the Azores, Canaries, the Mediterranean Sea and North African waters (Van Waerebeek et al, 1999). Minke whales are thought to undertake seasonal migrations between temperate winter breeding grounds and summer feeding grounds in the southern hemisphere (Kasamatsu *et al.*, 1995) and in higher latitudes (Stewart & Leatherwood, 1985), however the seasonal movements of these animals around the UK remain unclear, and at least some individuals remain in relatively high latitudes overwinter (Anderwald & Evans, 2007). During the summer months it is the most abundant baleen whale species found in coastal waters of the British Isles (Northridge *et al.*, 1995; Reid *et al.*, 2003; Hammond *et al.*, 2007) where it is often seen feeding.

This small rorqual is the most euriphagous among all baleen whales, showing regional differences with respect to diet, preying on what is locally available small shoaling fish, mainly clupeids (herring and sprat), Ammodytidae (sandeel), mackerel and gadoids (e.g. cod) in the North Sea (Haug *et al.* 1995; Nordøy *et al.* 1995; Sigurjónsson *et al.* 2000; Neve, 2000; Olsen & Holst, 2001; Lindstrøm *et al.*, 2002; Haug *et al.*, 2002; Pierce *et al.*, 2004). A study of the species' seasonal and spatial distribution on the west coast of Scotland by MacLeod *et al.* (2004) showed how the minke whale habitat overlapped with suitable habitats of Ammodytidae and clupeids. We know that the bulk of fish catches in our study area, the Moray Firth (northeast Scotland) are made up of gadoids, clupeids and Ammodytidae (Greenstreet, 1998) and that these fish species are also found in minke whale stomachs stranded in Scotland (Pierce *et al.*, 2004). Although fine-scale fish catch data are not available for this area, Torres et al (2008) have argued that using environmental variables as a proxy for fish distribution usually results in a better prediction of the distribution of piscivorous predators than making direct use of fish distribution data (e.g. because the latter are less accurately measured and much more expensive to measure).

Thus, the aim of this study was to provide a preliminary description of the summer habitat utilised by the minke whales in this region, through the identification of the important environmental variables and driving forces influencing their presence, and spatiotemporal variation therein, and through the use of the kernel home range probabilistic technique (Silverman, 1986) to represent the ranging patterns of minke whales from 2001 to 2007.

4.3 MATERIALS & METHODS

4.3.1 Cetacean data

All cetacean data used in the present study were collected during the months of May to October, 2001 to 2007 inclusive. Dedicated boat surveys were conducted along an 82 km stretch of coastline of the southern outer Moray Firth in northeast Scotland (57°41'N 3°15'W), between Lossiemouth and Fraserburgh (Figure 4.1.). Four designated routes parallel to the shore, consisting of three outer routes and an inner coastal route, approximately 1.5 km apart on a north-south axis, covered a total survey area of approximately 880 km^2, with effort remaining consistent between years and spatial coverage being weather dependent. The survey transects were carried out using two independent 5.4 m inflatable outboard boats. Surveys were conducted at mean vessel speeds of 7 knots in visibility ≥1 km and Beaufort sea states ≤3.

A crew of two experienced and up to four additional observers searched the water during surveys using a continuous scanning method (Mann, 1999) from directly in front of the research boat, to 90 degrees left and right of the track line. When a minke whale was sighted, the time, GPS position and behaviour of the animal were recorded. At that point, searching effort was stopped and commenced again when the encounter with the animal had ceased and after the boat was repositioned back on the survey route from where the last encounter started. In case sea state increased beyond Beaufort 3, or the weather deteriorated, the transect would have been either temporarily halted until conditions improved or terminated. Further details of the protocols used by the Cetacean Research & Rescue Unit (CRRU) are discussed in Robinson *et al.* (2007).

As presence only data was recorded while on survey, absence records were derived in a second moment on the Excel spreadsheet from the combination of presence data, survey route, land point and survey time information. Therefore 'absence' was assumed where 'presence' was not recorded. Although this back-calculation might have not been exact, it served the purpose of this study.

4.3.2 Environmental data

Tidal data for the study area were obtained from POLPRED software, a tidal and current model created by the Proudman Oceanography Laboratory (http://www.pol.ac.uk/appl/polpred.html).

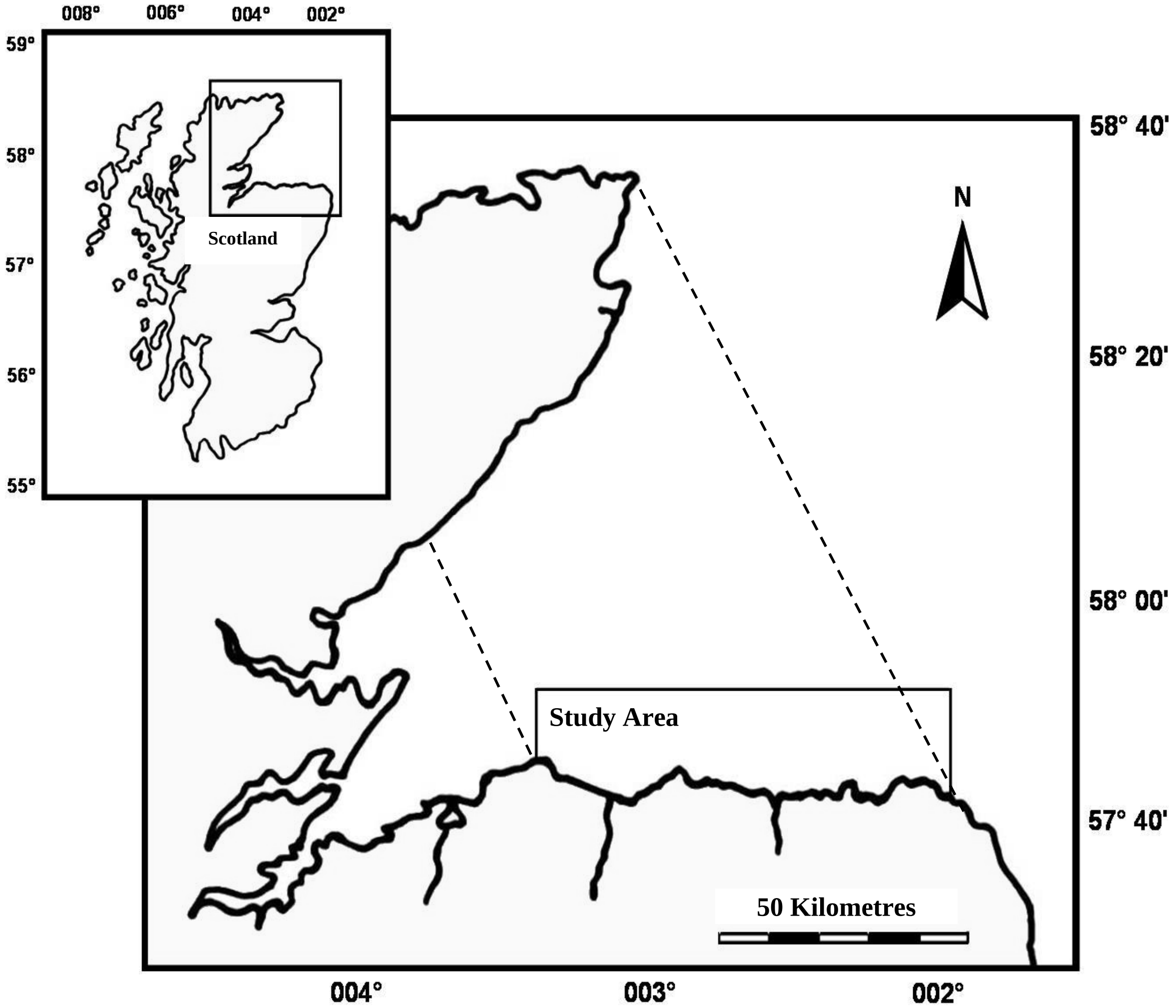

Fig. 4.1. The 880 km^2 study area along the southern coastline of the outer Moray Firth, in northeast Scotland. The area in between the dashed lines is the outer Moray Firth. Adapted from Robinson *et al.* 2007.

Data were extracted on current speed (m/s), tidal height (metres above extreme low tide), and tidal stream direction (graphical output can be viewed in Appendix 2).
The fixed ecogeographic variables used in this analysis consist of the digital bathymetry and sediment data provided by the British Geological Survey, and aspect and slope of seabed derived from the bathymetry data within ArcGIS 3.2. in grid cells of 1 km^2. The depth contour file of the British Geological Survey is a shape file which needs to be converted in a Triangulated Irregular Network (TIN) file in order to extract continuous values. The TIN is a continuous-faceted surface where all the irregularly spaced points within the coverage are connected with their two nearest neighbours to form a network of linked triangles with x, y (spatial co-ordinate) and z (parameter value at point (x,y)) values. This was done in ArcGIS 3.2, after loading the 3D and Spatial Analyst extensions, selecting the depth contours theme and choosing the "Create TIN from features" option under the surface menu. Following the creation of the tin file, slope and aspect were calculated under the surface menu. To extract depth, slope and aspect values from tins, a new button was created after loading up the "Grid Extract" script. As this script calculates the z value from a surface for each point in a point theme, clicking on the new button allowed the extraction of the z values of interest (depth, slope and aspect) from the highlighted sighting data (point features).

Other covariates included in the model are longitude, latitude, time, month and year. Their inclusion allows us to capture residual (unexplained) spatial and temporal patterns although it should be noted that this offers increased predictive power but little or no gain in explanatory power.

Additional data analysed in this study were: 1) the monthly sea surface temperature (SST) and Chl-a concentration, after downloading the HDF maps from the Oceancolor database at http://oceancolor.gsfc.nasa.gov, installing the Marine Geospatial Ecology Tool in ArcGis 9.2, converting the HDF files into Raster files and finally extracting the SST and Chl-a values for the study area (graphical outputs in Appendix 1); 2) the North Sea sandeel spawning stock biomass(SSB) obtained from ICES (2007); and 3) the zooplankton concentrations collected at 10m depth, during continuous plankton recorder (CPR) surveys, by the Sir Alister Hardy Foundation for Ocean Science (SAHFOS) in the Moray Firth (Richardson *et al.*, 2006).

Lastly, animals generally do not use their home range with equal intensity, and a concentration in certain areas over time is expected (Samuel *et al*., 1985). With the purpose of investigating the intensity of use of the study area across the years, the kernel home range probabilistic technique (Silverman, 1986) was applied in this study to represent the ranging patterns of minke whales from 2001 to 2007. The kernel technique consists of a nonparametric probability density that does not require a particular statistical distribution (Kernohan *et al*., 2001).

4.3.3 Statistical analysis

The relationship between occurrence of minke whales (the response variable) and all of the explanatory variables was analysed within a Generalised Additive Modelling (GAM) framework (Hastie & Tibshirani, 1990) in Brodgar 3.2. GAM was employed as the most appropriate statistical model due to the need to incorporate flexible non-linear relationships in the regression analysis. Presence/absence data (response variable) were analysed by specifying a binomial distribution of errors with a logit link function. Continuous ecogeographic variables were fitted as "smoothers", constraining the maximum number of degrees of freedom to 4 to avoid overfitting. For latitude/longitude and month/year variables, both univariate and bivariate smoothers were fitted. The latter option has the advantage of capturing both main effects and interactions but if only one of the pair of variables had an effect a single univariate smoother for that variable was preferred. Cross validation to decide the best number of degrees of freedom is a default setting in Brodgar. A forwards stepwise model selection procedure (Akaike, 1973) was employed, with variables selected and retained only if their effects were statistically significant. Residuals were checked for spatial patterns (autocorrelation) from east to west, but not from north to south due to the low number of data points.

4.4 RESULTS

4.4.1 Home range

Between 2001 and 2007, 14739 km were surveyed on effort, corresponding to 641 trips (transects) and 1103 hours at sea, for a total of 137 recorded sightings, comprising 330 individual whales. The spatial distribution of all minke whale sightings combined is shown in Figure 4.2. and illustrates their inshore progressive advancement observed during the summer season, with the animals mainly distributed on the outer route along the 50m isobath in May-June and close inshore on the coastal routes from July to October.

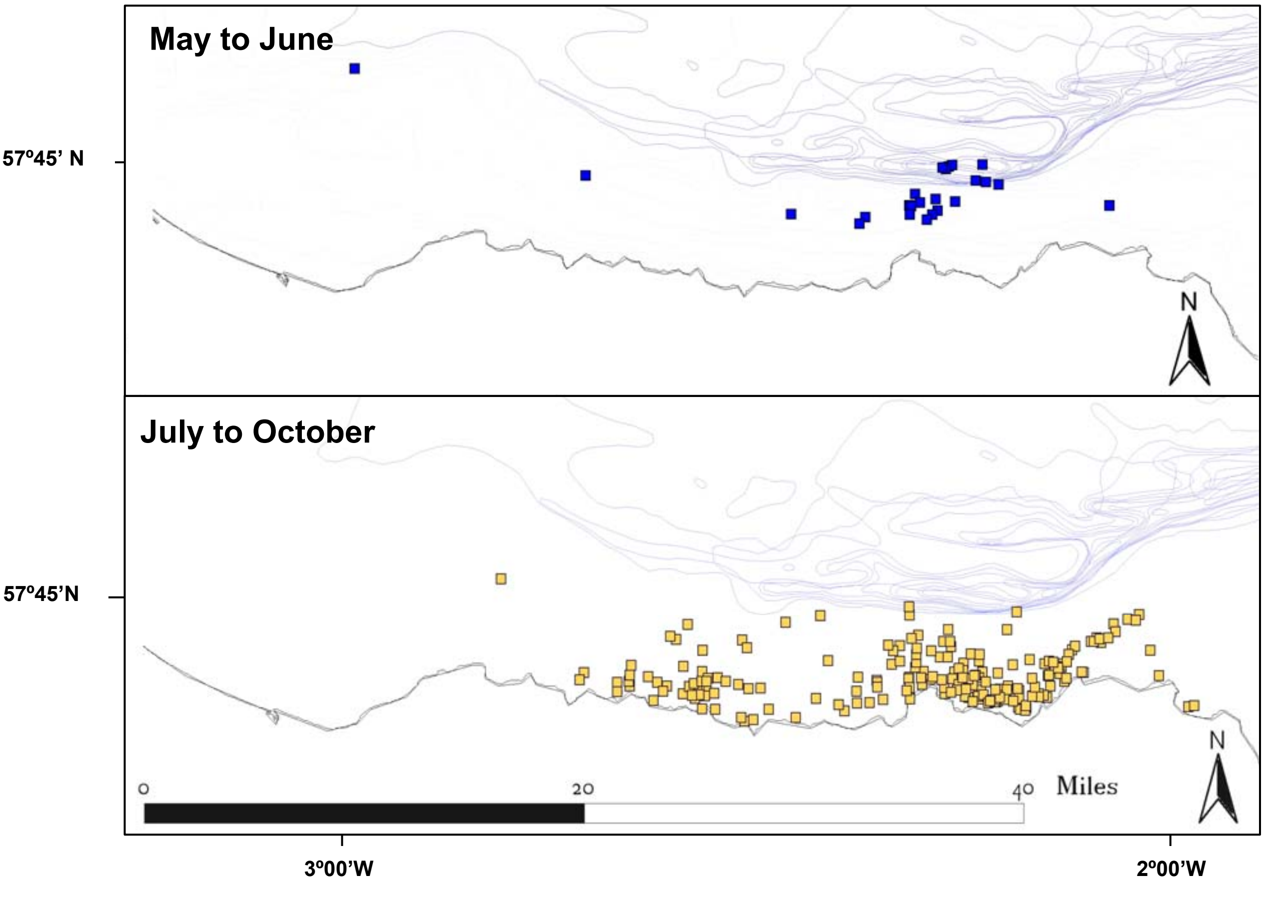

Fig. 4.2. All sightings (N=314) to show the gradual inshore minke whale progression during the summer season.

The area most utilised by minke whales from 2001 to 2007 is represented in Figure 4.3. However, the Kernel distribution shows a small-scale variability in spatial distribution of core areas from year to year: the 95% and 50% (core area) contour probability of the total space used by the whales across the years is illustrated in Fig 4.4.

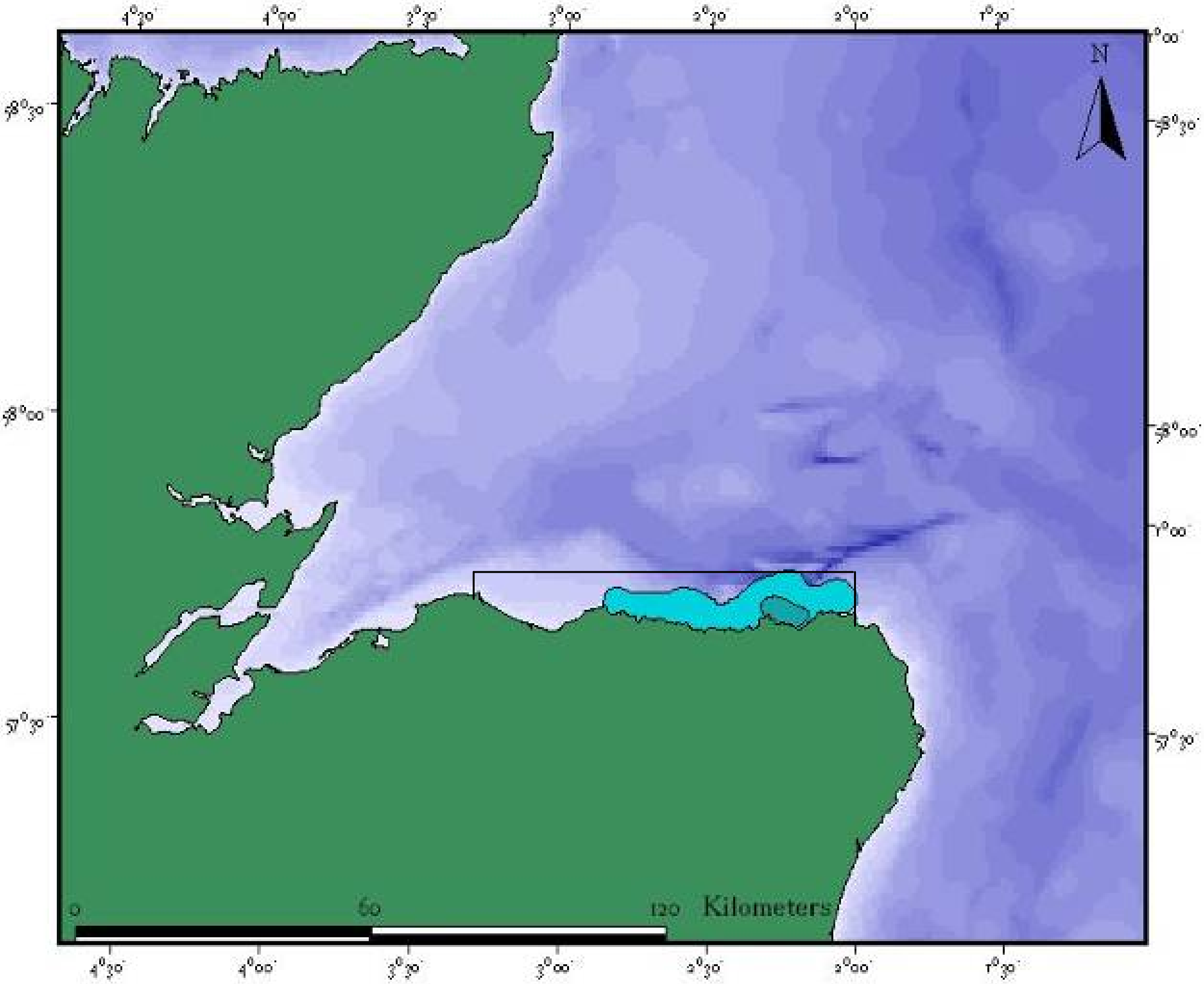

Fig. 4.3. Extension of Kernel density (95% probability of encountering a minke whale in light blue; 50% probability in dark blue) for all sighting data (2001 to 2007) combined together. The study area is outlined by the black line.

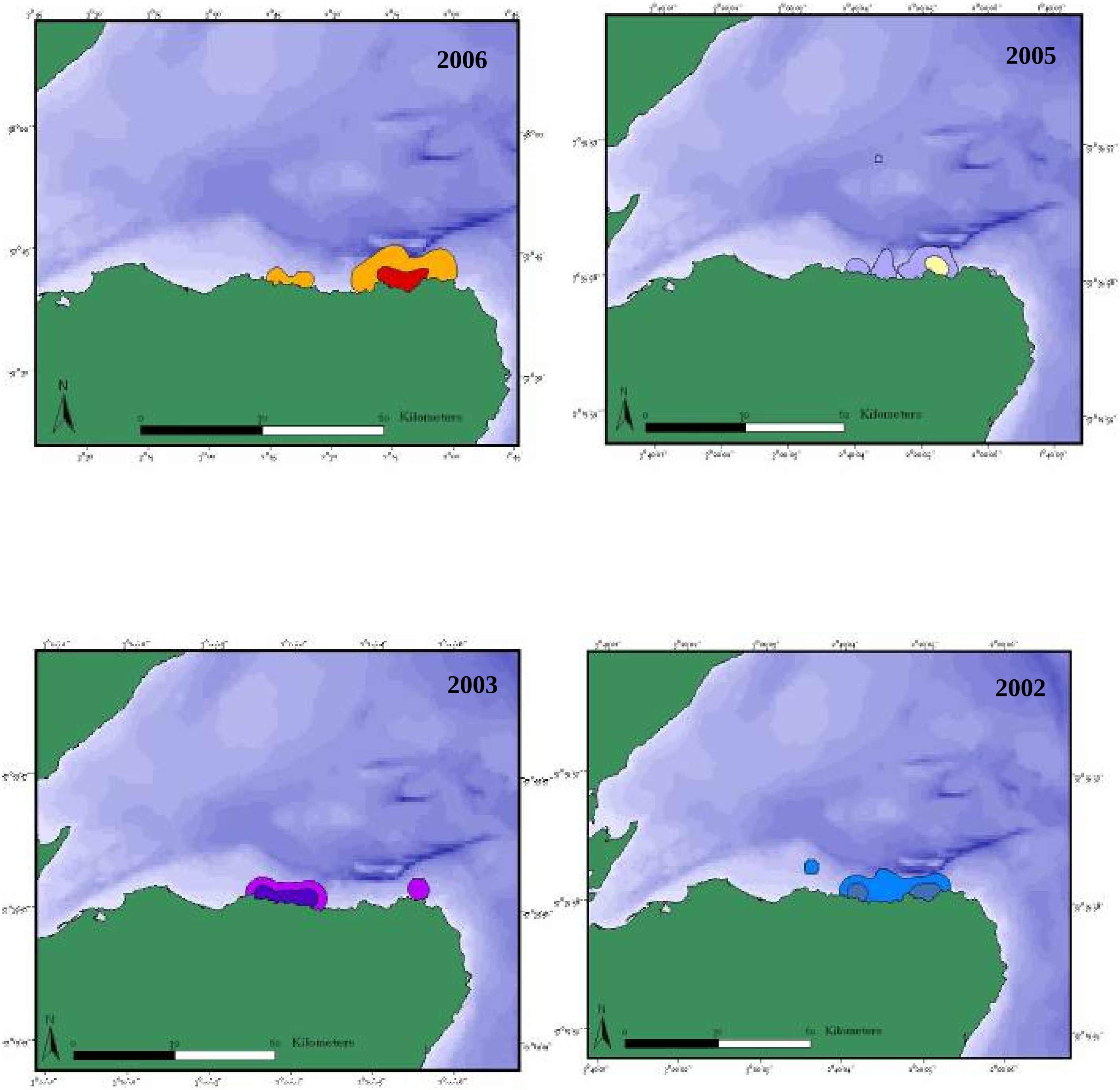

Fig. 4.4. Minke whale range by year (core areas - 50% contours - are represented by smaller areas). 2001, 2004 and 2007 are not plotted due to the low encounter rates of those years. Surface feeding behaviour occurred for the majority of the years in the core areas.

4.4.2 GAMs - Environmental predictors

'Latitude' and 'sediment type' variables were excluded following exploration of multivariate correlations, due to their VIF values above 5.0 (i.e. these variables were highly correlated with the set of remaining variables). After a forward stepwise selection, the best-fitting GAM for minke whale presence included all the explanatory variables considered, except for time (AIC=986.99, adjusted r^2= 0.382, Table 4.1.). The deviance explained by the final model was 39.3%. The forms of the relationships between minke whale presence and the significant explanatory variables are represented in Figure 4.5.

The highest occurrence of whales in the study area occurs during the month of July, in 2005 and 2006, at water depths of 20-50m, on a rising tide, at tidal stream speed of ≥0.4 m/s, when the current comes from west, where the slope descends gently and the seabed faces east. Time effect was not significant. Although sediment does not figure in the final GAM model, its effect is potentially confounded with effects of several other explanatory variables especially depth, slope and longitude. If the effect of sediment is analysed separately, without taking into account effects of other variables, a chi-squared test suggests that whale presence is significantly related to sediment type, being particularly associated with sandy gravel (Pearson Chi-Square = 30.556, DF = 3, P < 0.001).

Table 4.1. Results of GAM showing the levels of significance attributed to each covariate in determining whale presence or absence for parametric coefficients and smoothers.

Parametric coefficients:

	Estimate	Std. error	P
Intercept	-3.94091	0.59063	2.52e-11 ***
Eastern current	0.93795	0.63208	0.1378
Southern current	-0.07041	0.70278	0.9202
Western current	1.44022	0.58437	0.0137 *

Approximate significance of smooth term:

	edf	X^2	*P*
Longitude	2.967	56.250	<0.0001 ***
Month/Year	18.225	167.200	<0.0001 ***
Tide height	2.839	9.408	0.0243 *
Tide speed	2.268	33.739	<0.0001***
Depth	2.772	21.668	<0.0001***
Slope	2.670	10.668	0.0137 *
West-East aspect	1.000	17.567	<0.0001***

- P <0.05; (UBRE score = -0.40327)

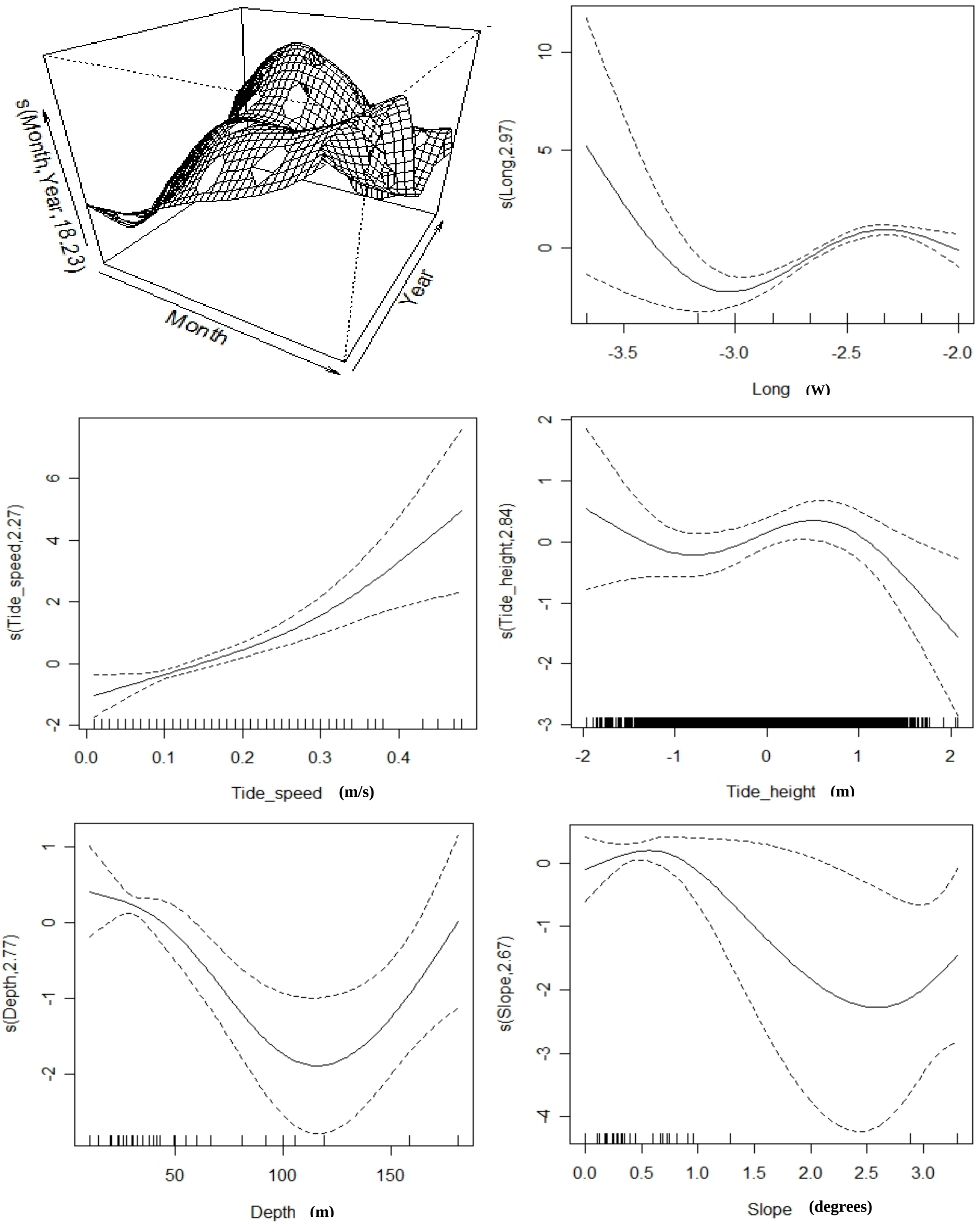

Fig. 4.5. Fitted smoothing curves for partial effects (solid line) of explanatory variables and standard error bands (dashed lines) from GAMs fitted to whale occurrence. Plots show the marginal effect of each significant variable once effects of all other variables in the model have been taken into account: effects of month/year (2-d smoother), longitude, tidal speed, tidal height, depth and slope on the presence of minke whales. Units in the y correspond to the scaled fitted presences. Dashes along the X axis (the "rugplot") indicate the amount of data available.

4.4.3 GAMs – Intra-annual variability

As seen in Figure 4.2, there was evidence that minke whale distribution changed over the course of the summer and separate models were therefore fitted to data for each month.

4.4.3.1 May and June

In May only depth appears to be a significant predictor: the whales are distributed both in coastal (0 to 50m) and offshore (50 to 100m) waters. After 100m depth there are too few data points to describe a trend. The deviance explained by the model is 21.6%. The results are shown in Table 4.2. and Fig y.

Table 4.2. Approximate significance of smooth terms.

	edf	Est.rank	χ^2	p-value
Depth	2.817	3	22.41	5.36e-05 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

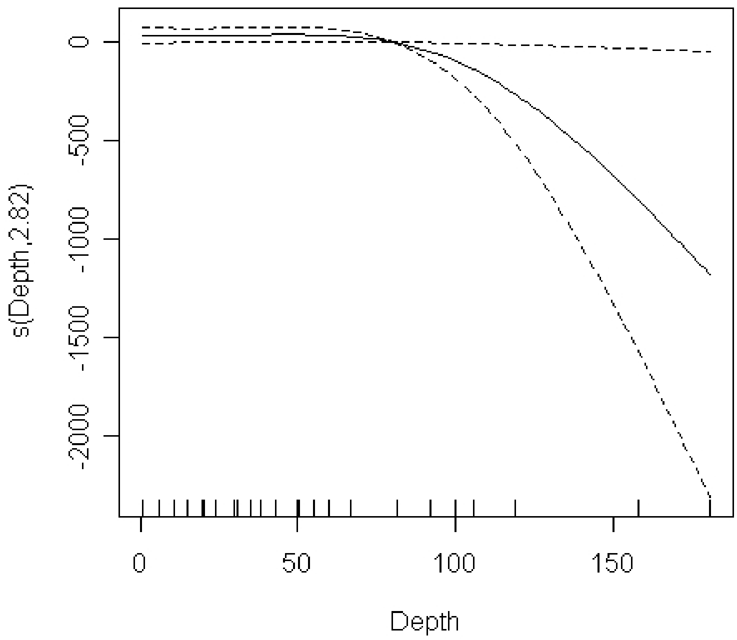

Fig. 4.6."Partial plots" of smoothing functions (solid line) and standard error bands (dashed lines) from GAMs fitted to whale occurrence. Plot shows the marginal effect of depth on the presence of minke whales in May and June. Units in the y correspond to the scaled fitted presences.

4.4.3.2 July

In July depth, tidal speed, seabed aspect and time appear to be significant predictors; it was more likely to find a whale from 0 to 50m water depth, where the seabed faces east, at fast current speeds, throughout the whole day. The deviance explained by the model is 20.8%. The results are shown in Table 4.3. and Figure 4.7.

Table 4.3. Approximate significance of smooth terms:

	edf	χ^2	p-value
Tidal speed	1.000	36.40	1.25e-08 ***
Depth	2.833	14.66	0.002132 **
Aspect facing east	1.851	24.21	2.26e-05 ***
Time	2.851	20.22	0.000153 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

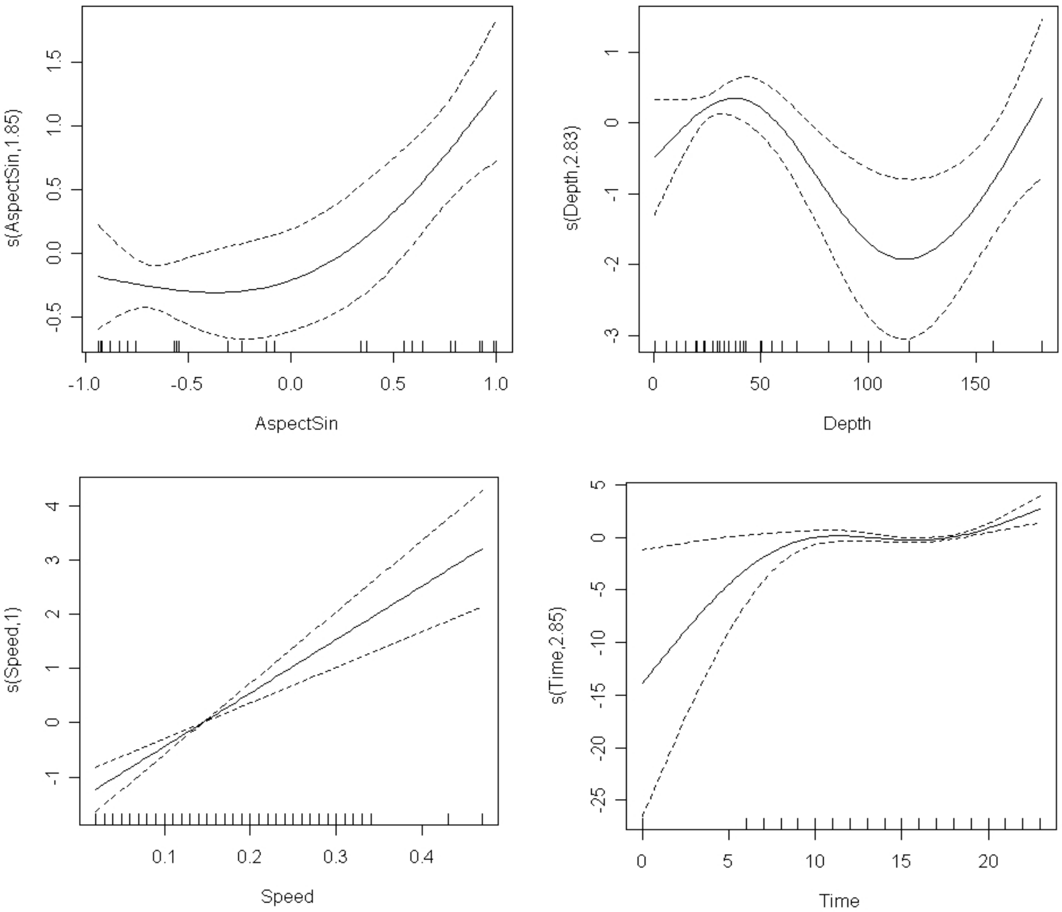

Fig. 4.7.“Partial plots” of smoothing functions (solid line) and standard error bands (dashed lines) from GAMs fitted to whale occurrence. Plot shows the marginal effect of sign. variables on the presence of minke whales in July.

4.4.3.3 August

In August depth, tidal speed, seabed aspect and time appear to be significant predictors; it was more likely to find a whale from 0 to 50m water depth, at fast current speeds, mainly from 12pm to 4pm. The deviance explained by the model is 20.8%. The results are shown in Table 4.4. and Figure 4.8.

Table 4.4. Approximate significance of smooth terms.

	edf	χ^2	p-value
Tidal speed	2.759	19.08	0.000263 ***
Depth	2.850	16.86	0.000754 ***
Time	2.183	11.32	0.010128 *

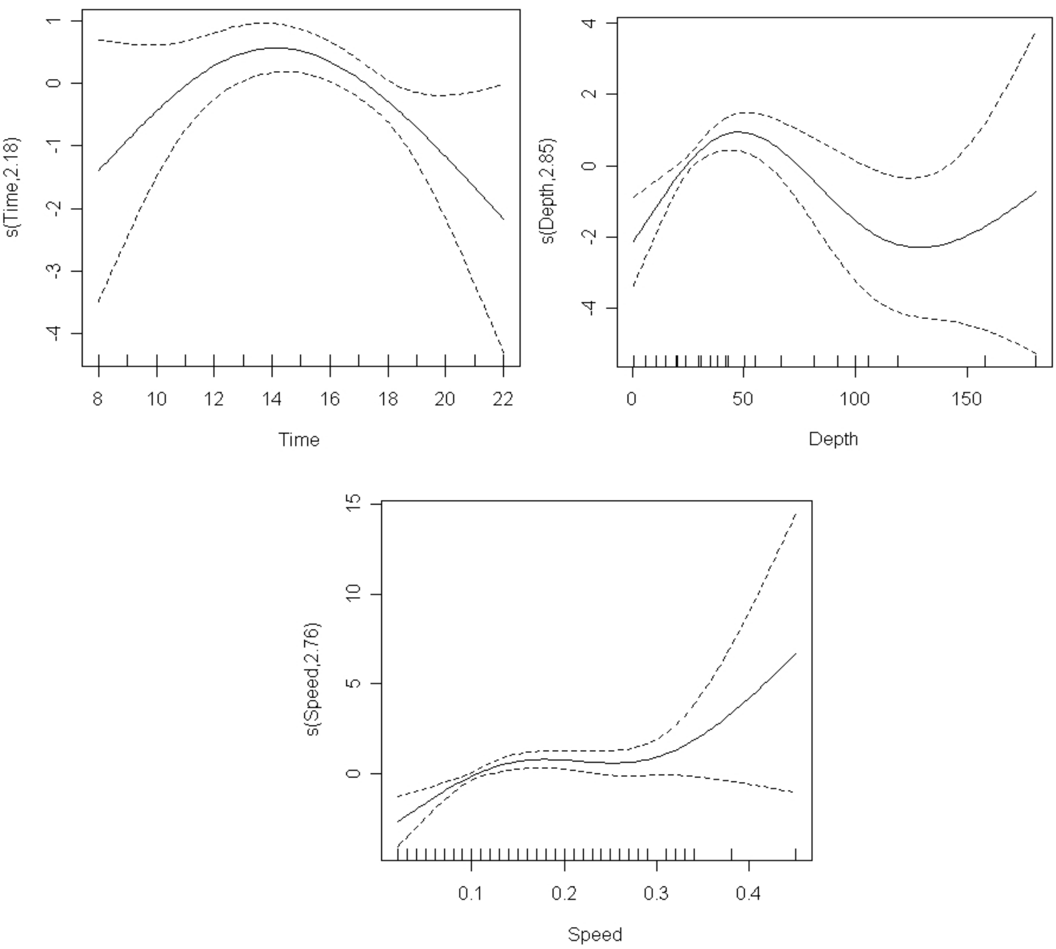

Fig. 4.8. "Partial plots" of smoothing functions (solid line) and standard error bands (dashed lines) from GAMs fitted to whale occurrence. Plot shows the marginal effect of significant variables on the presence of minke whales in August.

4.4.3.4 September and October

In September and October tidal speed, seabed aspect and time appear to be significant predictors; it was more likely to find a whale where the seabed faces east, at fast current speeds, towards the end of the afternoon. The deviance explained by the model is 14.2%.

Table 4.5. Approximate significance of smooth terms.

	edf	χ^2	p-value
Time	2.322	16.190	0.001037 **
Tidal speed	2.790	18.614	0.000329 ***
Aspect West-East	1.000	8.432	0.003686 **

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

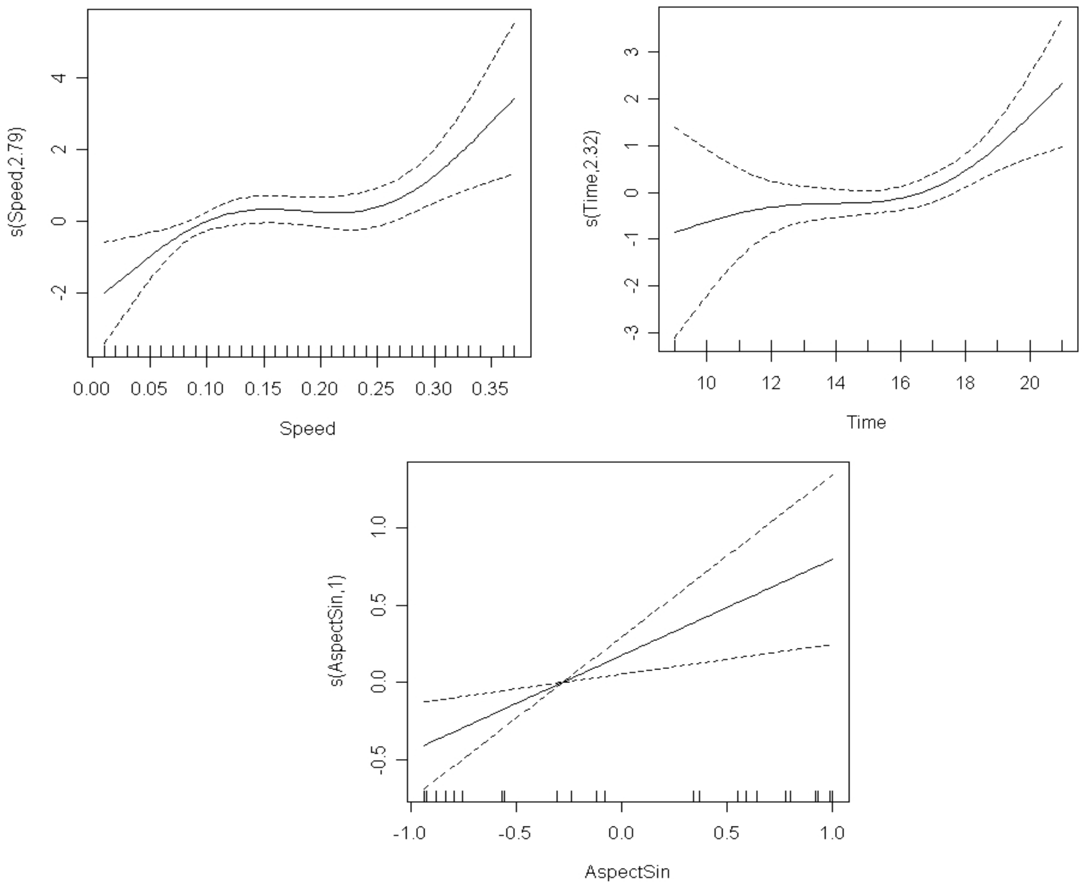

Fig. 4.9. "Partial plots" of smoothing functions (solid line) and standard error bands (dashed lines) from GAMs fitted to whale occurrence. Plot shows the marginal effect of significant variables on the presence of minke whales in September and October.

In summary, the monthly results show that:

- In early summer (May and June) the whales are distributed both in coastal (0 to 50m) and offshore (50 to 100m) waters.

- In July the whale are likely to be found from 0 to 50m of water depth, where the seabed faces east, at fast current speeds, throughout the whole day.

- In August they are still found in coastal waters, where the current speed is faster than 0.3m/s, however they mainly occur from 12pm to 4pm.

- In September and October the effect of “depth” is not significant anymore, as the whales are more dispersed throughout the research area. The fast tidal speed is still significant, although now the whales mainly occur towards the end of the afternoon.

4.4.4 Inter-annual variability

It is not easy to give an explanation to the monthly and annual variations in minke whales distribution and occurrence in the study area. Seasonality is a phenomenon that affects most of the living creatures through environmental and habitat changes, and so the presence of the minke whale in Scottish nearshore waters could depend upon the changing availability of resources, as much as upon periodic fluctuations of oceanographic conditions.
Monthly series of sandeel and herring abundance, SST and Chlorophyll-a data for the specific research area were not available for comparison with minke whale sighting data. The small number of years in the study limits the possibility of statistical analysis of inter-annual trends. However, it was decided to plot yearly trends of SST data and Chl-a concentrations, in order to identify potential anomalies in poor minke whale years - 2004 and 2007 (Figure 4.10.) and sandeel spawning stock biomass versus whale sightings (Figure 4.11) to assess the typology of fluctuations. Although summer SST drops from 2003 to 2005, and also Chl-a decreases slightly from 2004 to 2005, no conclusion can be drawn from this graph.

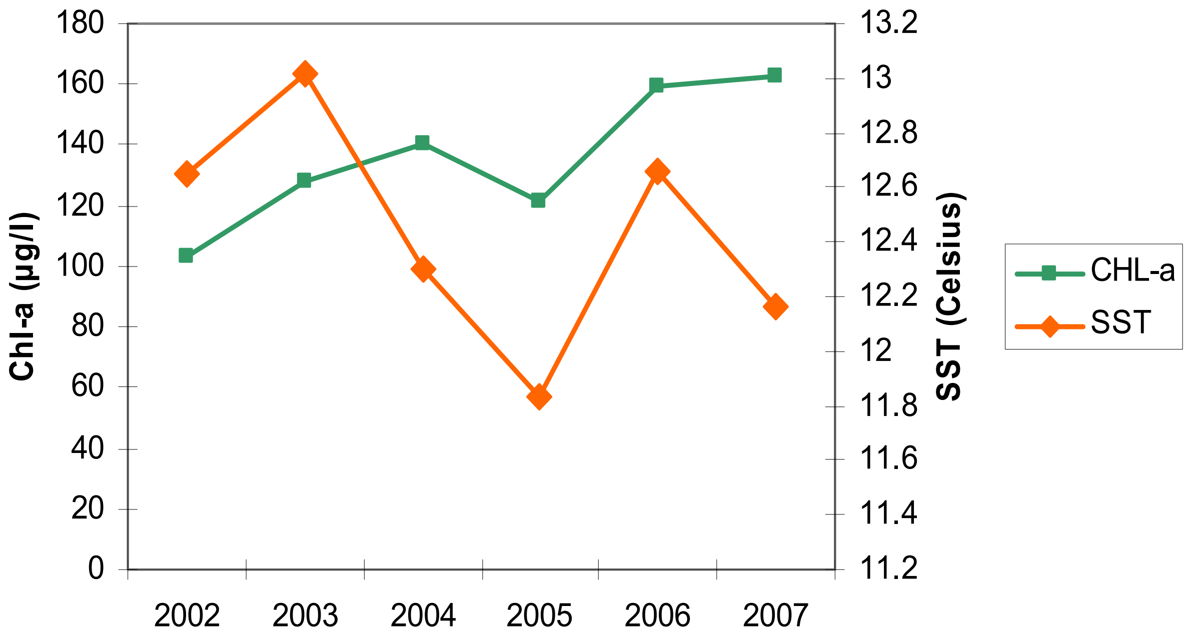

Fig. 4.10. Average summer sea surface temperature and Chl-a for the study area

The lesser sandeel (*Ammodytes marinus*) is one of the known minke whale prey species in the area. In Figure 4.11. the annual North Sea sandeel spawning stock biomass (SSB) is plotted against the summer minke whale encounter rate. The two trends increase and decrease together for the first 4 years, but diverge when the sandeel SSB falls to a low level in 2004. Assuming that the sandeel population occurring in the Southern Outer Moray Firth is part of the North Sea population this graph could give a superficial and indirect indication of a predator-prey relationship. However, as Pedersen *et al.* (1999) point out, there might be regional differences within the North Sea sandeel stock which may invalidate this type of relationship (minke whale occurrence data gathered at a small scale versus sandeel spawning stock biomass data collected at a major scale).

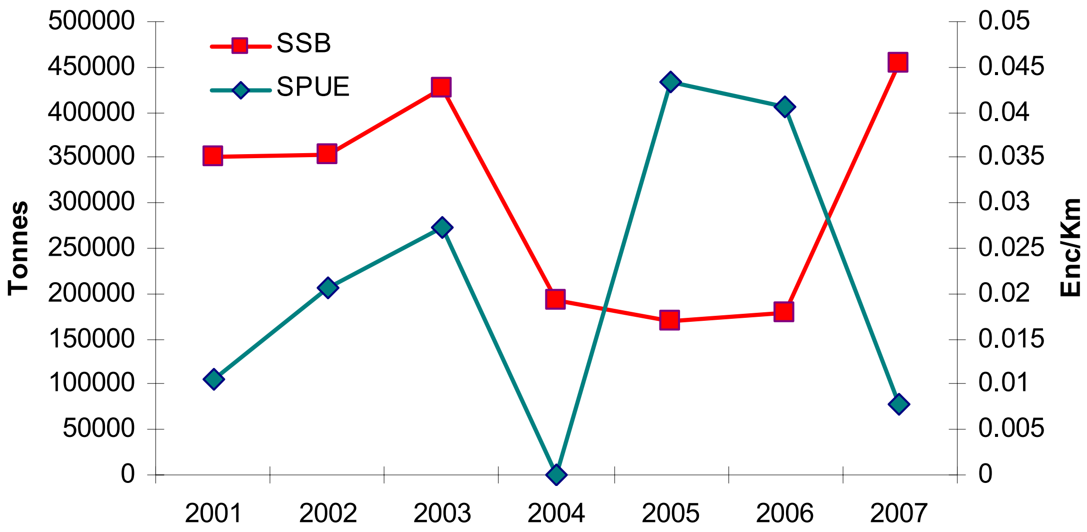

Fig. 4.11. Sandeel spawning stock biomass in tonnes (SSB) against sightings per unit effort (SPUE=number of animals per km). The SPUE trend follows the SSB until 2004. From 2005 the two patterns are inverted.

Another potential minke prey is represented by zooplankton. In this case we found that the yearly summer concentration of Euphausiids (Northern krill – *Meganyctiphanes norvegica)* caught in the study area follow a more similar pattern to minke whale relative abundance.

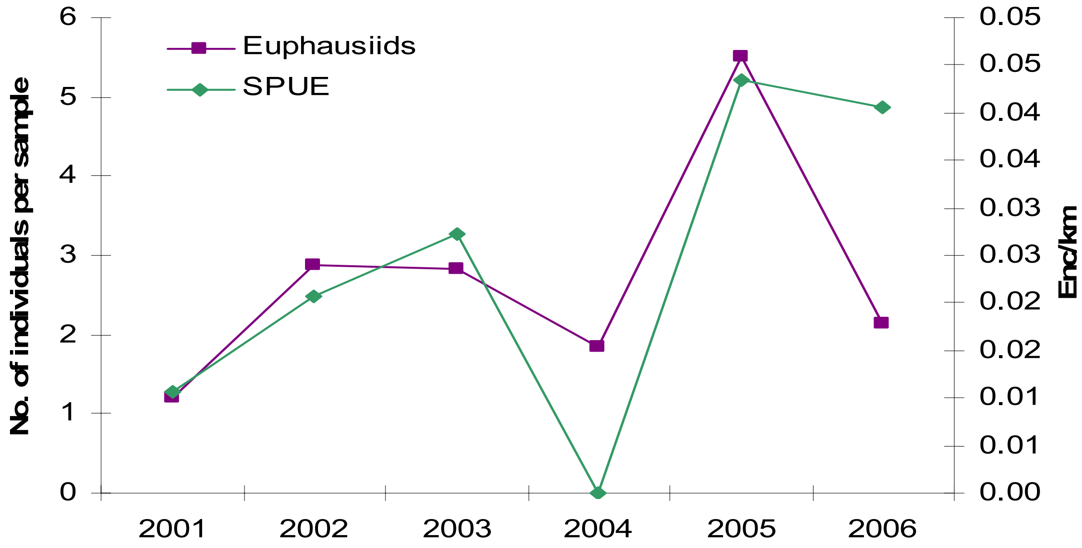

Fig. 4.12. Average number of individual Euphausiids caught in the Moray Firth versus minke whale sightings per unit effort (SPUE=number of animals per km).

In this case the spatial coverage of the zooplankton and minke whale datasets correspond. Despite the fact it is not possible to evaluate this relationship statistically, the two quantities seem directly proportional.

4.5 DISCUSSION

Generally speaking, although direct evidence has not always been found, a correlation is likely to occur between local prey distribution and minke whale diet (Tamura & Fujise 2002; Haug *et al.*, 2002; Macleod *et al.*, 2004; Anderwald *et al.*, 2006). However Torres *et al.* (2008) point out how cetacean habitat selection is better predicted by environmental variables used as proxies of prey distributions, rather than relying on direct prey distribution data, reflecting the difficulty of accurately measuring the latter at an appropriate scale.

In fact, minke whales habitat use has been linked in previous studies to various physiographic and oceanographic features such as water depth (Hooker, 1999), seabed sediment type (Naud *et al.*, 2003; Macleod *et al.*, 2004), oceanographic fronts, the extent of sea ice, SST (Kasamatsu *et al.*, 2000) and a warm water plume (Tetley *et al.*, 2008). In the case of tidal variables, their effect on cetacean aggregations have been analysed in several studies (e.g. Irvine *et al.*, 1980; Borges & Evans, 1996; Harzen. 1998; Mendes et al 2002; Marubini, in press), which illustrate cases of positive relationships between cetacean presence and tide-induced fronts, presumed to relate to food availability.

The most significant findings of the present study are that the highest incidence of minke whales occurs in coastal waters of the Moray Firth, especially during the month of July (inshore summer shift also observed by MacLeod *et al.*, 2007) and when the tidal stream velocity is at its highest, during the rising tide, above sandy gravel sediment type. However, the importance of two particular variables varies throughout the summer season; these are depth and time of day. In May a few minke whales occur mainly in offshore waters; in July whales are in coastal waters and presumably feed all day; in August they are still in coastal waters, but feed mainly from 12pm to 4pm; in September and October the effect of 'depth' is not significant and the whales occur mainly in late afternoon. This subtle intra-annual variability should not be overinterpreted, as sample sizes are small. However, it can be speculated that fine-scale minke whale distribution may vary according to prey movement patterns.

The depth range, tidal speed and sediment type identified as being associated with minke whales are thought to characterize a suitable habitat and optimal feeding conditions for juvenile Ammodytidae (Wright *et al.*, 2000) and clupeids, which in summer feed on the burst of zooplankton triggered by the phytoplankton bloom (Last, 1989). Ammodytidae, in fact, prefer depths of 30 to 70 m (Wright *et al.*, 1998), sediment consisting of medium and coarse sand with the lowest silt concentration in which they bury (Holland *et al.*, 2005; Wright *et al.*, 2000), and rippled seabed or tidally active areas with strong bottom currents and intense wave actions, as evident from both laboratory choice experiments and field observations (Pinto *et al.*, 1984; Wright *et al.*, 2000; Holland *et al.*, 2005). In these tidally active areas the advective oxygen transport into the sediment is high (Beherens & Steffensen, 2007), creating favourable breathing conditions for this fish and conveying the zooplankton on the overlying water column. Similar results were shown by Wolansky & Hamner (1998) and Zamon (2003) in which feeding activity in piscivorous predators was strongly coupled to the daily tidal cycle.
The diet of other immature fish present in the study area such as clupeids (herring and sprat), upon which minke whales are also known to feed (Haug *et al.*, 1995; Pierce *et al.* 2004), is based on zooplankton blooms (Last, 1989; Möllmann *et al.*, 2004), and the visual comparison of year-to-year variation in minke whale SPUE and euphausiid abundance in the Moray Firth

suggests that minke whale presence is indeed, directly or indirectly, related to zooplankton blooms.

In a study conducted on the west coast of Scotland also MacLeod *et al.* (2004) concluded that the spatial distribution of whale sightings appears to correlate with the likely Ammodytidae distribution in June and the pre-spawning herring habitat in August and that during July, many prey species are abundant in the water column and therefore minke whales are present in high numbers.

Although the local whale abundance peak seems to be in mid summer for most of the years considered, this was highly variable from year to year. It has been shown that the predator consumption rate can vary significantly with the availability of suitable prey. This happens for example on the North Sea scale at least for haddock, whose predation rate depends on the availability of Ammodytidae (Adlerstein *et al.* 2002). The authors attributed the inter-annual variations in sandeel availability to the seasonal timing of the appearance of the 0-group. As for other marine mammals, predatory fish and sea birds minke whales appear to feed mainly on 0-group fish (Pierce, unpublished data), and minke whale occurrence may thus represent an indication of spatiotemporal overlap with juvenile Ammodytidae. However, in years with low sandeel recruitment, minke whales may switch to other prey species, such as clupeid, gadoids and/or Northern krill. This opportunistic behaviour has been already documented in other northern hemisphere regions (i.e. Haug *et al.*, 1995; MacLeod *et al.*, 2004), hence the strong inter-annual variability in minke whale occurrence observed from 2001 to 2007 in the southern outer Moray Firth may represent a predator response to variation in prey abundance and/or distribution.

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CHAPTER 5

General Discussion

5.1 SUMMARY OF RESULTS

A number of observations and conclusions were made from this research, which are listed below:

- The use of digital photo-identification during focal follows has revealed to be a useful tool to pursue the same individual.
- The minke whales utilising the southern outer Moray Firth may be part of an open population.
- To date, there is no certain interchange of individuals between the east coast of Scotland, the west coast of Scotland and western Iceland.
- Breathing intervals are significantly different according to surface feeding, foraging (or milling) and travelling behaviours, in which intervals during feeding are the shortest and the most numerous.
- The minke whale enclosed in the harbour performed very short (~60 sec) breathing intervals, probably due to the low depth (5 to10m) and/or stress.
- Minke whales mostly occurred in July 2005 and 2006, in coastal waters (up to 50m depth) and shallow seabed slopes, when the tidal stream velocity was at its highest, on a rising tide, in the eastern side of the study area (where the sediment type is sandy gravel).
- The encounter frequency corrected by effort (number of sightings per effort) is highly variable within and between years.

5.1.1 Limits of this research

It is acknowledged that the present study has a number of limitations which could introduce errors into results and subsequent interpretations. To start with, the spatial distribution of the animals could be explained in part by a biased and inconstant survey effort, mainly due to the extremely high variability of weather and sea conditions of the North Sea. Secondly, the Cetacean Research & Rescue Unit aims to teach while collecting data, therefore it is not to be excluded that, at times, unconscious searching behaviour (in which the boat tends to search areas where cetaceans have been encountered before) could have represented a potential source of bias. Moreover, potential autocorrelation has been detected in this dataset.

Other limits of the present study are mainly due to the generally elusive and unpredictable behaviour of minke whales. One initial objective of comparing the diving behaviour in different types of habitat and different months/years was abandoned due to lack of data. Secondly, the low number of animals in the second field season (2007) precluded the plan of tagging the whales with suction cupped time-depth recorders in order to validate the visual observations (used to measure the diving intervals).

After a short training period it was feasible to get high quality, perpendicular shots of the dorsal fins for photo-identification. However, in the study area this baleen species showed quite a low number of recognisable nicks, marks and scars; this could be due to the solitary nature of the species, which is not as interactive as for example Odontocetes (toothed whales) and/or to the possibility that the individuals frequenting the area are for the majority juveniles. Thus, the established CRRU Photo-ID catalogue will require a longer effort for its implementation and a standardisation with other catalogues for its future comparison.

5.2 GENERAL DISCUSSION

Although focusing on a fine-scale investigation, the findings of the present work suggest that an inter-annual and intra-annual variability in minke whale occurrence exist in the southern outer Moray Firth for the time period considered. However, sighting data across years combined together showed that minke whales spent most of their time foraging in the eastern part of the study area, without using Spey Bay, a shallow sandy area in the western side. As all the other mammals, cetaceans practice their ‘normal activities of foraging, mating, and caring for young’ in an area defined by Burt (1943) as home range. Subjective interpretations of ‘normal’activities and the lack of a temporal component induced White (1990) to give a probabilistic definition of home range, intended as ‘the probability of finding an animal at a particular location’. The new concept of home range was then associated with the notion of ‘utilization distribution’ (UD) by Kernohan and colleagues (2001) in which the extent of the area was defined by the probability of occurrence of an animal during a specific time period. The information about the level of use of the various parts of the home range (Kernohan *et al.*, 2001) and the identification of core areas (‘centre of activity’; Hayne, 1949) are required for an ecological understanding of the species distribution.

Animals generally do not use their home range with equal intensity, and a concentration in certain areas over time is expected (Samuel *et al.*, 1985). With the purpose of investigating the intensity of use of the study area across the years, the kernel home range probabilistic technique (Silverman, 1986) was applied in this study to represent the ranging patterns of minke whales from 2001 to 2007: the 95% and 50% (core area) contour probability of the total space used by the whales across the years has been illustrated in Chapter 4.

As mentioned before, of the many factors influencing directly and indirectly cetacean distribution and thus their home range, the environmental variables play a fundamental role (Hastie *et al.*, 2005; Tyan *et al.*, 2005; Torres *et al.*, 2008). Bentic or demersal prey species can be limited depending on particular substrate characteristics (Hastie *et al.*, 2005), whereas high productivity can be associated with areas of upwelling in steep regions (Mann & Lazier, 1996). Thus, features that have been found in association with cetacean distribution include for example depth (i.e. Baumgartner *et al.*, 2001; Cañadas *et al.*, 2002; Moore *et al.,* 2002; MacLeod *et al.,* 2004), sea floor gradient or slope (Cañadas *et al.*, 2002; Ingram & Rogan, 2002; MacLeod *et al.*, 2004; Walker, 2005) and sea surface temperature (Tynan *et al.*, 2005; Tetley *et al.*, 2008).

Also in this study a number of correlations between minke whales occurrence and environmental variables were found, in which minke whales were more numerous within the 50m isobath, shallow seabed slopes (although this may be because seabed slope is positively related to depth), mostly during the month of July and when the tidal stream velocity is at its highest, during the rising tide. These environmental parameters are likely to offer a suitable and food rich habitat for minke whales prey species. However, these (and other) favourable conditions may not occur each year. In fact, the sighting data presented not only a spatial but also a temporal distribution which was highly variable between and within years. This variability suggests that other variables, and interactions, not considered in this study played a role in determining predator's and, quite possibly, prey's distribution. In the research area direct fine scale fishery data was not available and environmental predictors were used as proxies of prey distribution. Torres *et al.* (2008) have concluded that using environmental variables as a proxy for fish distribution usually results in a better prediction of the distribution of piscivorous predators than making direct use of fish distribution data (e.g. because the latter are less accurately measured and much more expensive to measure). Nonetheless, the predictors included in the research model were not able to explain years of almost absolute lack of whales, like in 2004 (as also Tetley (2005) concluded) and in 2007. The sandeel spawning stock biomass graph in chapter 4 suggests that minke whales may have preyed upon Ammodytidae until their collapse in 2004 and switched prey in 2005. However, the lack of fishery data in the study area does not allow answering the question on whether Ammodytidae are the most important minke whale prey species in this region, as it is thought to be.

Two other variables, sea surface temperature (NASA dataset - Appendix 1) and zooplankton (SAHFOS data), were analysed separately in a time series analysis. However, because of the missing values and the short time period considered, it was decided not to include the results.

5.2.1 Future work

Defining minke whales' distribution, diving behaviour and identification is complicated task due to their highly mobile and elusive nature, to the difficulty to interpret their underwater behaviour, and to the endless research effort required. However, a few propositions for future research can be made.

- The spatial coverage of the search area could be more even, and absence data could also be collected, along with presence data, if the aim is to investigate the distribution and habitat use of this species.

- Double platform line transects and distance sampling could be applied once each year to estimate the cetacean abundance in the study area.

- A simulation model to determine the probability of sighting a whale (g*(0)*), according to its behaviour could be made; by 1) determining the proportion of time a minke whale performing different behaviours is available at the surface, and by 2) running simulation models from these values, with random distributions of feeding, foraging and travelling whales in the specific survey area.

- Having identified a set of important habitat variables, the next step would be to develop predictions of the distribution patterns throughout the study area.

- A fine scale study on the availability, competition, and ecological niches occupied by Ammodytidae and clupeids in the study area, could facilitate the interpretation of minke whale feeding behaviour, habitat use and inter-annual variability in occurrence.

- The collaboration between study centres and opportunistic platforms in Scotland (e.g CRRU, HWDT, NORCET Ferries) and Iceland will favour a more integrated minke whale study approach.

5.3 CONCLUSIONS

Whales, seals and other marine mammals have long been a significant part of the life and culture of coastal people all over the globe. However, the human relationship with these animals differs greatly from country to country and from culture to culture, as indeed does the human/nature relationship and the concept of nature conservation in general. Thus, in the northeast Atlantic, countries like the Faroe Islands, Greenland, Iceland and Norway, members of the North Atlantic Marine Mammal Commission (NAMMCO) which consider marine mammals an 'important renewable resource that can be utilised sustainably' (NAMMCO, Anon. date), live alongside countries like the United Kingdom which is a Member State of the EU Habitat Directive (Edwards, 2006) set up to help maintaining the biodiversity through the establishment of Special Areas of Conservation (SAC). The research area considered in this study, the southern outer Moray Firth, lies just outside an established SAC which includes only the inner Moray Firth. The development and implementation of conservation strategies, such as for instance the expansion of the Moray Firth SAC, involves the full understanding of the nature of the animals under review and the environment in which they live (Martien *et al.*, 1999; Barros & Wells, 1998; Ingram & Rogan, 2002). As well as the majority of the research produced in the last 30 years, also the ultimate goal of the present work was to contribute in getting an insight into the species ecology for conservation purposes.

Although minke whales are not considered in danger of extinction due the global high population estimates, the environmental changes documented worldwide put all species under pressure. In the North Sea dramatic changes in abundance, community composition and phenology of plankton at lower trophic levels have been documented and linked to climate change (Edwards *et al.*, 2002; Beaugrand, 2004; Edwards & Richardson, 2004). It is therefore reasonable to think that also the Moray Firth, as part of the North Sea, is undergoing a transition phase, in which changes, more or less detectable, are occurring. With this study observations are only being made of short-term small-scale fluctuations and of a highly variable environment which could strongly depend on key mid-trophic fish species. However, as climate change continues, a collective effort and further research in this area should focus on the relationships between oceanographic features and the different trophic levels. Lastly, an interdisciplinary approach between social and biological sciences would be advisable in order to integrate the precious local fishermen knowledge with the biological time series.

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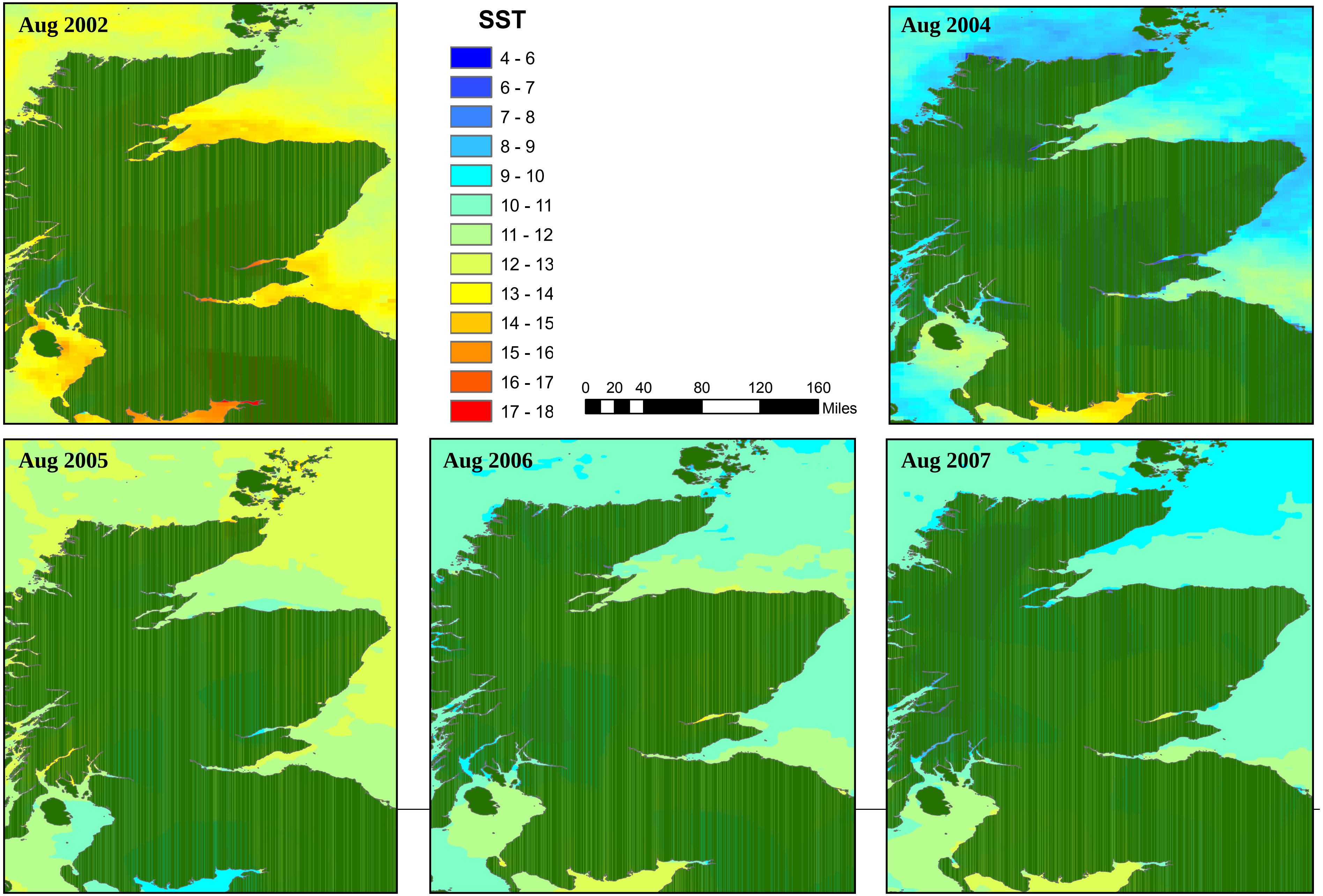
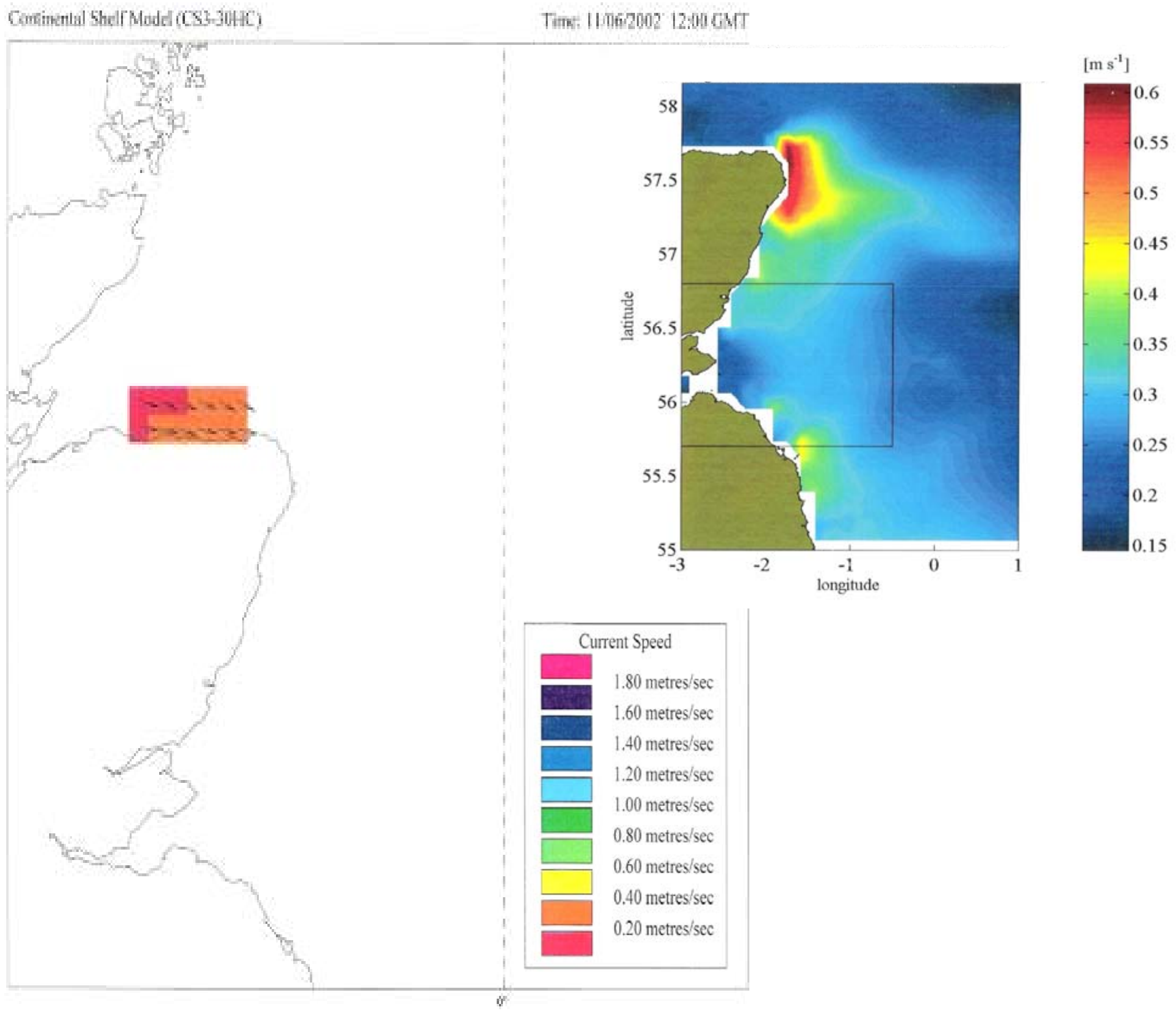
APPENDICES

Appendix 1 Example of sea surface temperature (SST) maps extracted with ArcView 9.2 from NASA dataset.



Appendix 2



Example of graphic output from Polpred software, showing current speed and direction for the study area. Top right: daily average of tidal current strength (m/s) in summer for the east coast of Scotland. Note the fastest currents form Fraserburgh to Aberdeen. (Courtesy of Beth Scott).