PROCEEDINGS OF THE WORKSHOP

AN INTEGRATED APPROACH TO NON-LETHAL RESEARCH ON MINKE WHALES IN EUROPEAN WATERS

Held at the
21st Annual Meeting of the European Cetacean Society
Donostia - San Sebastián, Spain, 22 April 2007

Editors:

Kevin P. Robinson[1], Peter T. Stevick[2] and Colin D. MacLeod[3]

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EUROPEAN CETACEAN SOCIETY

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CONTENTS

1. INTRODUCTION

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Minke whales (*Balaenoptera acutorostrata* Lacépède) are the smallest and most abundant of the baleen whales in European waters and a significant component of the marine ecosystem. This truly cosmopolitan species is found throughout the world's oceans and seas – from the Poles to the tropics – but shows an apparent fondness for inshore, coastal waters. Due to their extensive distribution and preference for coastal waters, however, minke whales are subject to a range of detrimental anthropogenic impacts including direct and indirect interaction with fisheries, exposure to anthropogenic noise, ingestion of contaminants and debris and commercial whaling which is the most direct and contentious current concern. As such, a better knowledge of the behaviour and biology of this species, as well as its role in the marine environment, is considered vital for its effective protection.

The main objective for this workshop was to bring together research groups and individuals currently studying minke whales in European waters, to share experiences and discuss present and future research priorities, opportunities for collaboration, and the current conservation issues that are driving focal studies being carried out at this time. Given the widespread distribution of minke whales, and their presence in many areas that are subject to ongoing cetacean research, remarkably little is known about the ecology of this small rorqual species. They have been the subject of a limited amount of directed research, and were considered to have been under-represented in the main ECS conference proceedings in former and recent years. This meeting was established to present new and recent results from field studies and proposals for novel non-lethal research methods targeted at resolving gaps in our current knowledge. It presented an opportunity for those working on different aspects of minke whale biology or in different parts of the world to meet and compare observations, ideas and results.

The workshop was convened on Sunday 22 April 2007 (from 09:00 to 13:30 hrs) at the Aquarium in Donostia - San Sebastián, Spain, in association with the 21st Annual Conference of the European Cetacean Society, and was attended by 24 participants from 7 countries (listed at the end of this volume). The majority of attendees were already studying minke whales in the field. Seven presentations were made on topics, including large and fine-scale distribution and abundance, site fidelity, feeding strategies and behaviour, genetics, stock structure, and habitat selection, along with a closing discussion session on future research priorities and collaboration. Participants agreed to pursue development of a European Working Group for the species. The following proceedings provide an overview of the work presented at this workshop.

2. ABUNDANCE AND LARGE-SCALE DISTRIBUTION PATTERNS OF MINKE WHALES IN THE EUROPEAN ATLANTIC: SCANS-II

Phillip S. Hammond

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Estimates of abundance were one of the three main outputs of the SCANS-II Project. They add to the estimates from the SCANS survey in 1994 and form two points at the beginning of a hopefully long-term time series. These surveys are a major exercise and many people contributed to the success of the surveys and the subsequent analysis of the data.

All European Atlantic continental shelf waters were surveyed with seven ships and three aircraft. (figure 2.1). Good coverage was obtained. Minke whales were found in the North Sea and round most of Britain and Ireland. This was a similar pattern to that seen in 1994, but there were fewer sightings in the north in 2005. The total estimate of minke whale abundance for the North Sea of 10,500 animals was not significantly different from the figure of 7,300 obtained in 1994. However, new information was obtained for the west of Britain and Ireland. Unlike for harbour porpoises, there was no evidence of white-beaked or minke whales moving out of the northern North Sea area.

In 2005, the highest concentrations of minke whales were predicted to be in the central North Sea, off Norway, around NE Scotland, off southern Ireland and off of SW England. In 1994, the highest densities were predicted off of SE Scotland. However, because the survey area was at the southern extreme of the summer range, we might expect minke whale distribution and abundance in the area to vary from year to year as a result of variation in the respective distribution and availability of their targeted prey.

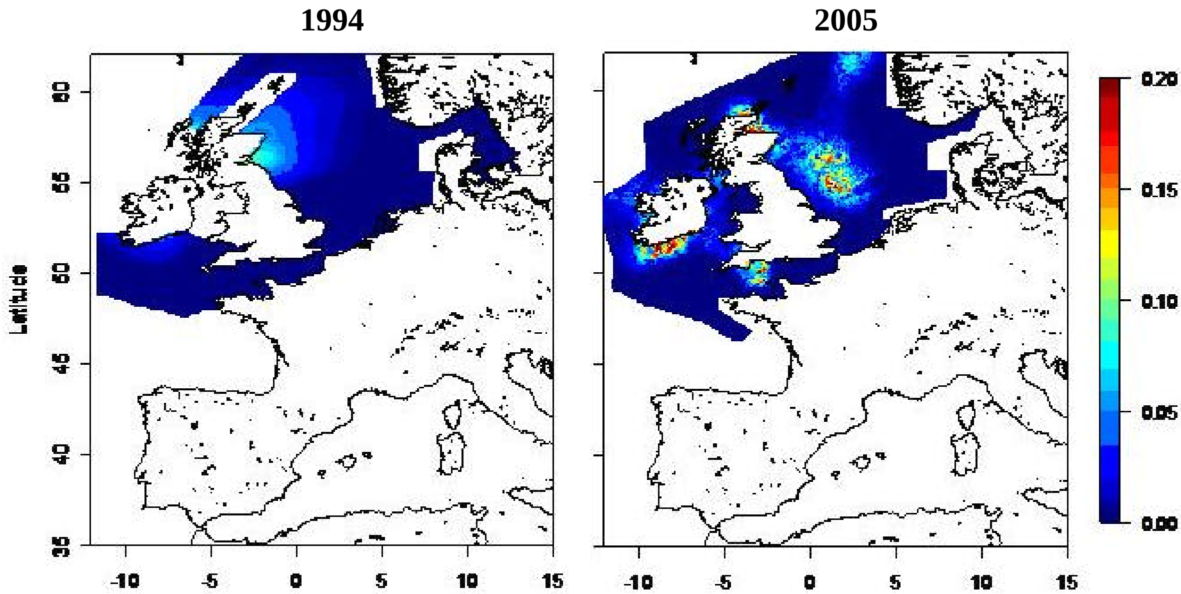

Fig. 2.1: GIS Plots showing the density of minke whale sightings obtained from SCANS surveys in 1994 and 2005 respectively.

3. MINKE WHALE POPULATIONS IN THE NORTH ATLANTIC: AN OVERVIEW WITH SPECIAL REFERENCE TO UK WATERS

Pia Anderwald[1,2] and Peter G.H. Evans[2]

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NORTH ATLANTIC

Distribution & Movements

North Atlantic minke whales (*Balaenoptera acutorostrata acutorostrata*) are widely distributed mainly in continental shelf waters from Baffin Bay to the West Indies, and from Svalbard to the Azores. Like many other balaenopterids, minkes are thought to undergo seasonal migrations between summer feeding grounds in high latitudes and temperate winter breeding grounds (Stewart & Leatherwood, 1985).

Population Structure

Clearly separated genetically from both North Pacific (*Balaenoptera acutorostrata scammoni*) and Antarctic minkes (*Balaenoptera bonaerensis*), investigations into the fine-scale population structure of the North Atlantic sub-species have resulted in different sub-divisions, depending on the nature of genetic markers used. Some differentiation between animals from West Greenland, the Central and Northeast Atlantic was detected using allozymes, DNA-fingerprinting, RAPD-typing and microsatellites (Daníelsdóttir *et al.*, 1992, 1995; Árnason & Spilliaert, 1991; Martinez & Pastene, 1999; Andersen *et al.*, 2003), whereas mitochondrial DNA analyses (Palsbøll, 1990; Bakke *et al.*, 1996) and a recent microsatellite study (Anderwald *et al.*, in prep.) found no or very little sub-division between regions. A general consensus from these studies is that, if population differentiation between North Atlantic minke whales from different regions does exist, it seems to be present only at low levels. Representative sampling for genetic analysis in this species is hindered by the lack of understanding about its winter distribution / breeding grounds and the added difficulty of spatial and temporal segregation by both sex and age in at least parts of its range: e.g. adult females generally appear to migrate further north than adult males and juveniles during the summer months, and females migrate closer to the coast than males in coastal Norway (e.g. Jonsgård, 1951, 1962; Mitchell, 1974; Christensen, 1975).

Diet

Regional differences exist with respect to diet. In general, krill and capelin form an important part of minke whale diet in the northern range of the species' distribution, whereas clupeids are taken around the coast of Norway and western UK, and sandeel in the North Sea, and (in addition to krill and capelin) Iceland and West Greenland (e.g. Lindstrøm *et al.*, 1997; Neve, 2000; Sigurjønsson *et al.*, 2000; Olsen & Holst, 2001; Haug *et al.*, 2002; Pierce *et al.*, 2004; pers. obs.). In the UK sample (n=10; Pierce *et al.*, 2004), sandeels predominated, followed by clupeids and, to a lesser extent, mackerel.

Group Sizes

The species is usually solitary, but aggregations of 5 to 15 individuals may sometimes occur in areas with high prey densities.

BRITISH & IRISH WATERS

Distribution & Movements

In UK waters, minke whales are distributed mainly around Scotland and in the northern and central North Sea regularly south to the Yorkshire coast, with small numbers also in the Irish Sea and western English Channel (Evans *et al.*, 2003; Reid *et al.*, 2003). By far the most sightings within continental shelf waters occur between May and September, with peak numbers from July to September, depending on the region (Evans *et al.*, 2003).

It is not clear yet whether minkes around the UK and Ireland undergo similar latitudinal migrations to animals that spend the summer further north, or if they merely move further offshore during the winter months. The Sea Watch Database holds 165 winter sighting records of the species, collected by volunteer observers between November and March for the UK and Ireland since the mid-1990s, with no obvious latitudinal trend in distribution (Fig. 1). Although the sample size is small, this suggests that at least some individuals spend the winter close to Britain and Ireland. Occasional records of young calves in spring and summer leave the possibility open that some females may give birth in these latitudes, although this remains speculative until more data are available.

Population Trends

Sighting rates of minke whales have increased dramatically in west, north and east Scotland since the early 1990s (Evans *et al.*, 2003), most likely due to an increase in prey availability. On the west coast, however, minke whale numbers were unusually low in 2005 and 2006 (Fig. 2a).

Foraging Ecology

It can be difficult to explain sudden increases or decreases in numbers of a cetacean species, especially within a small area and over a short period of time. However, in some cases it is possible to infer to some extent the status of one taxon from the status of another which may be easier to observe. Interactions between minkes and seabirds feeding on the same prey (mostly schooling fish such as sandeels or clupeids like sprat and herring) are well documented both for the UK (Evans, 1990; Gill *et al.*, 1999; Anderwald *et al.*, 2002) and other parts of the world (e.g. Hoelzel *et al.*, 1989).

In UK waters, the most common seabird species associated with feeding minke whales are auks (mainly razorbills and common guillemots), kittiwakes, large gulls (herring gulls, great and lesser black-backed gulls), Manx shearwaters and shags, depending on the time of year and distance from breeding colonies. Both taxa can also benefit from predatory fish, such as mackerel and herring, trapping small schooling fish against the surface and thus making them more accessible to the whales and especially to the seabirds.

On the west coast of Scotland, Manx shearwaters are often observed following minke whales in the earlier part of the season (May to July), taking advantage of the activity of the whales, which are believed to feed mainly on sandeels during that time of year (Gill *et al.*, 1999; Macleod *et al.*, 2004). During the second half of the season (July to September), however, when sprat are more important in their diet (Anderwald *et al.*, 2006), minkes are mainly associated with mixed-species flocks of seabirds. During this part of the season, the whales appear to mainly take advantage of the seabirds for finding prey, often joining active multi-species feeding groups of birds, although associations with shearwaters or lunges without any seabirds associated can still be observed on occasions (pers. obs.). As expected, the exceptionally low sighting rates of minke whales in August and September during 2005 and 2006 coincided with equally low numbers of those species (auks, kittiwakes and large gulls) usually encountered in multi-species seabird flocks during that time of year and lower seabird species diversity (Figs. 2a-c) as compared to "good" years (2003 and 2004). The only exception was Manx shearwaters, which were often observed in large aggregations in both years (Fig. 2b). This is not surprising, since Manx shearwaters are the only species amongst those commonly found in association with minke whales that is also capable of feeding on macro-plankton when no fish is available. Furthermore, shearwaters can travel over longer distances on a single daily foraging flight than either minke whales or other seabird species, and are therefore likely to be less affected by local prey shortage.

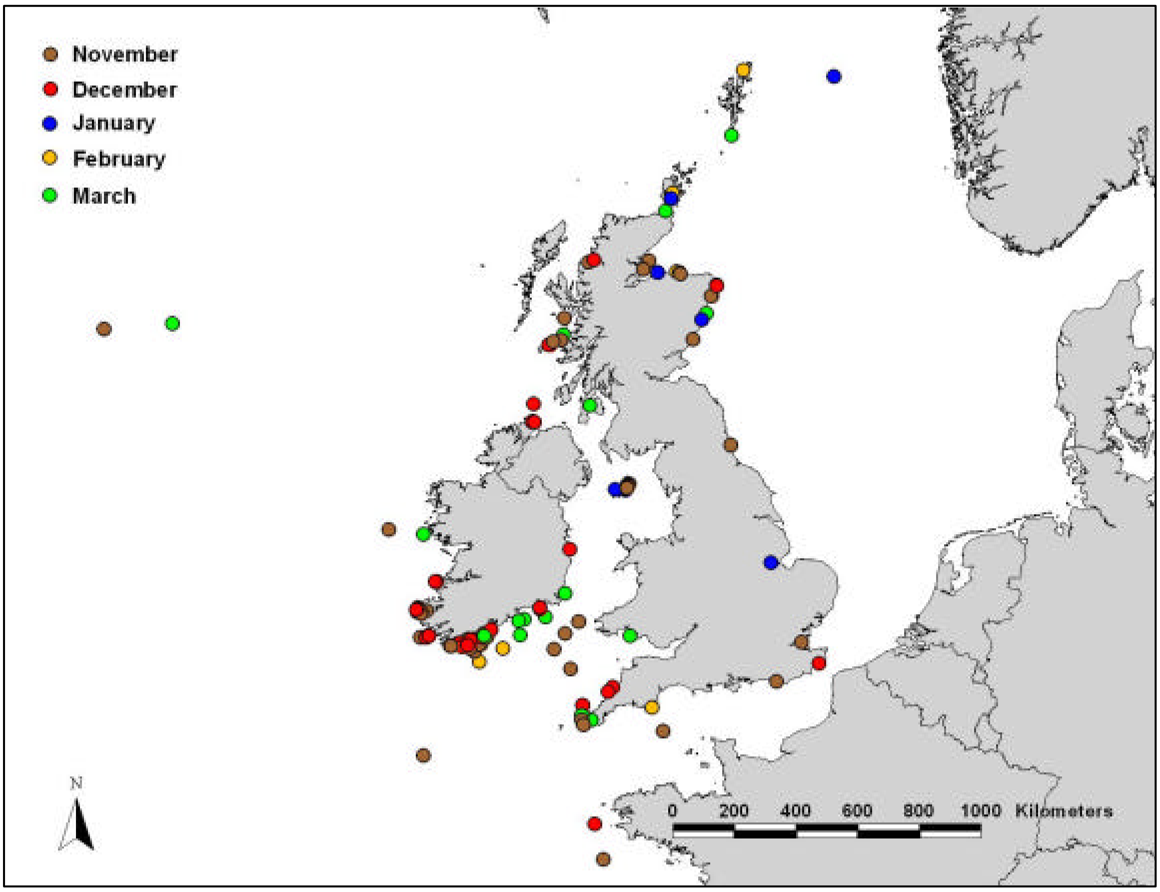

Fig. 1. Distribution of minke whale sightings around the UK and Ireland in winter.

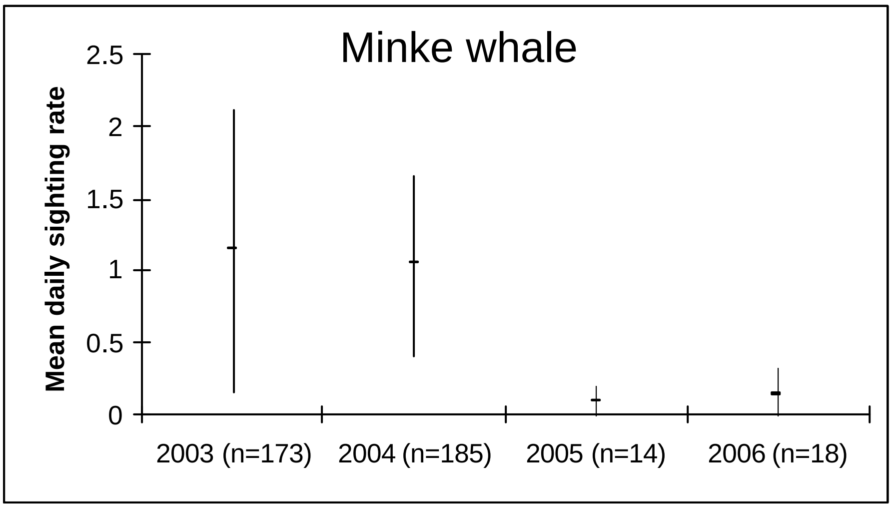

Fig. 2a. Sighting rates of minke whales around the Small Isles during August and September from 2003 to 2006.

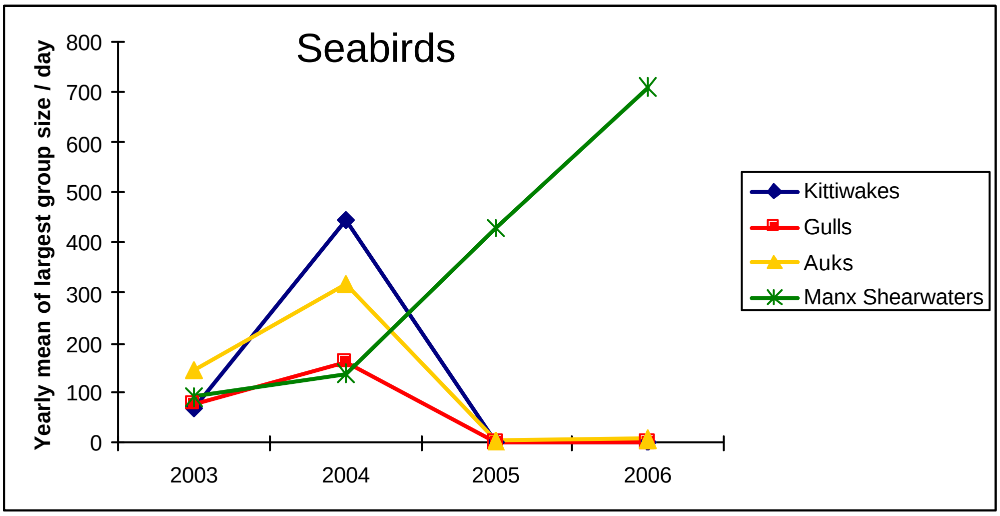

Fig. 2b. Yearly average of largest group size / day for seabird aggregations around the Small Isles during August and September from 2003 to 2006.

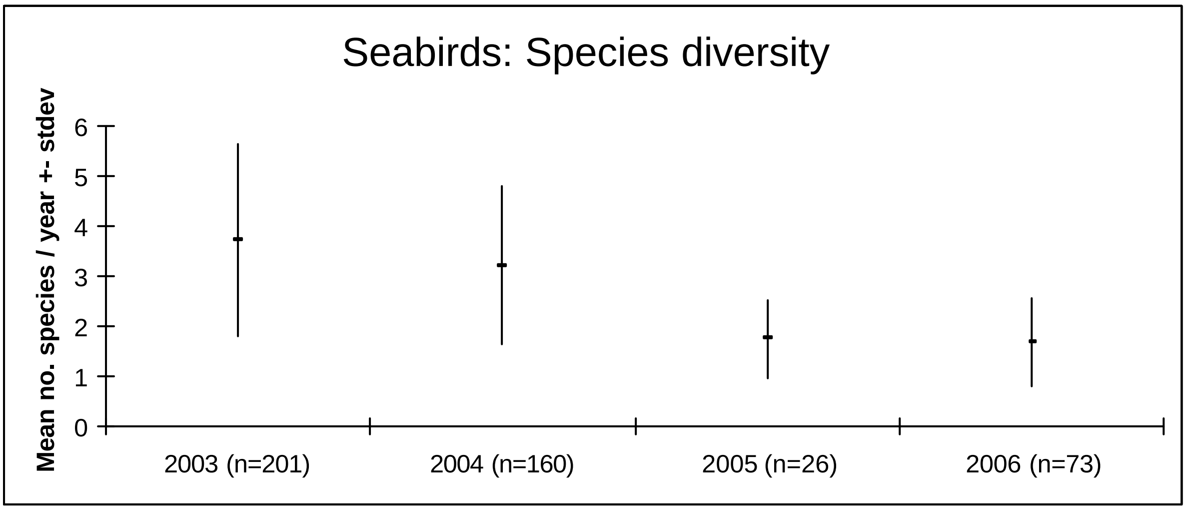

Fig. 2c. Species diversity for seabird aggregations, as mean number of species per seabird group per year, around the Small Isles during August and September from 2003 to 2006.

Low numbers of both minke whales and seabird species normally congregating in multi-species feeding aggregations thus point towards a local shortage of sprat at least in our study area around the Small Isles during 2005 and 2006. Preliminary results suggest that numbers of both minkes and seabirds have increased again in 2007, and information on the possible reasons for the short-term sprat shortage in the last two years is currently being processed.

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4. INDIVIDUAL SITE FIDELITY AND NOVEL FEEDING STRATEGIES OF MINKE WHALES: A SUMMARY OF RESEARCH RESULTS

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INTRODUCTION

Since 1995, the Ocean Research & Education Society (ORES) has conducted long-term and focal studies on minke whales (*Balaenoptera acutorostrata*) migrating into a main summer feeding ground in the St. Lawrence Estuary in Canada, where they concentrate daily in high numbers. Extended photo-identification has revealed a high inter- and intra-annual resighting rate of individuals. ORES currently maintains probably the most extensive photo-identification catalogue of minke whales worldwide, containing more than 250 individual animals with many life histories going back to the mid-nineties (the oldest sighting from 1978). Between June and October, dedicated surveys and opportunistic data collection are typically carried out using rigid-hulled inflatable boats within the boundary of the Saguenay - St. Lawrence Marine Park of the St. Lawrence estuary in Canada, which is home to a major whale-watching industry. Here, we present an overview and summary of our study results on the spatial and temporal distribution, site fidelity, breathing and feeding ecology and photo-identification of the species in these waters.

The St. Lawrence Estuary lies at the head of a deep underwater channel, the Laurentian Channel (LC), which stretches throughout the St. Lawrence Gulf and connects with the Atlantic Ocean (figure 4.1). From here, nutrient-rich, cold water continuously flows at depth into the Gulf and eventually reaches the Estuary more than 1,000 km away. Throughout the channel, water depth decreases only slowly from 450 m at the Cabot Strait, between Newfoundland and Nova Scotia, to about 300 m near the channel head (Lavoie *et al.*, 2000). There, however, the channel shoals rapidly within 20 km, to less than 40 m in depth. Barriers created by banks, islands, shallow sills (Simard and Lavoie, 1999), and the steep slopes along

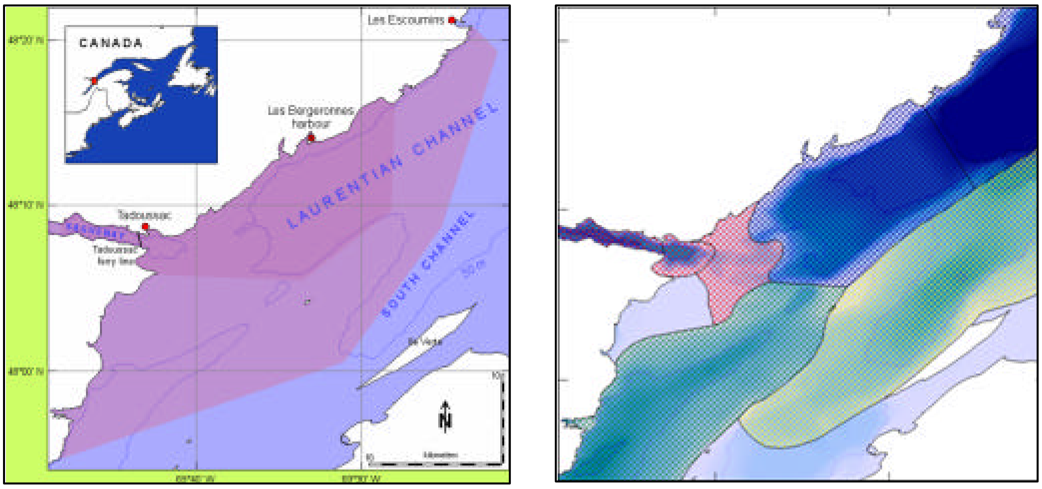


Fig. 4.1: The St. Lawrence Estuary in Canada. The study area at the head of the Laurentian Channel measures approximately 600 km^2 and is divided into 4 general areas: i) the channel head (blue), ii) the Saguenay mouth and fjord (red), iii) the upriver shallows (green), and iv) the south channel (yellow).

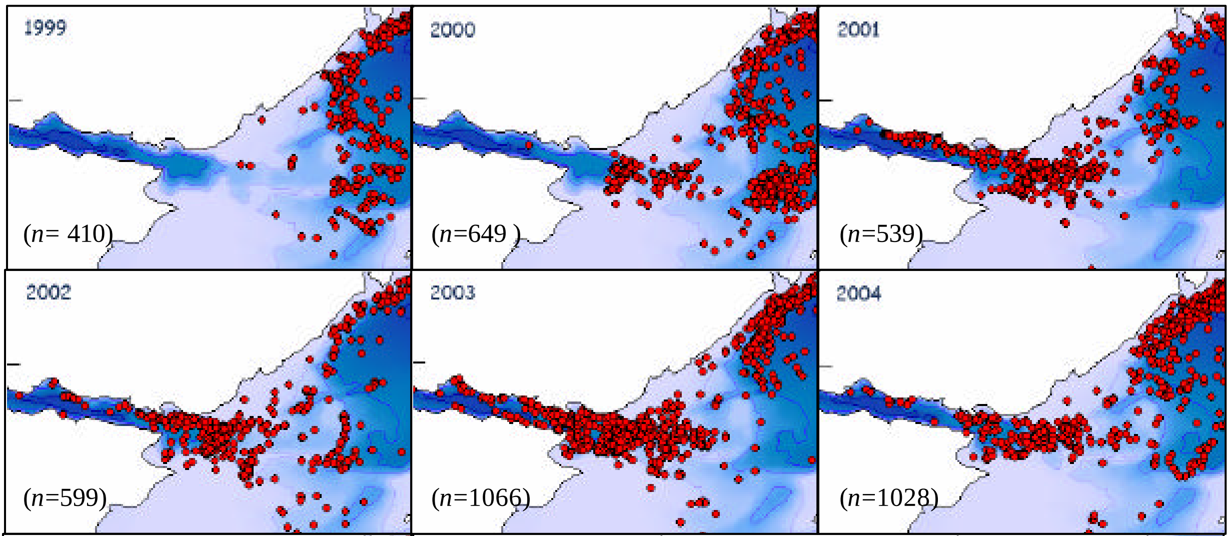
the North shore and along the southern edge of the channel (about mid-river), create strong upwellings where prey is concentrated near the surface. From the Gulf to the Estuary, the St. Lawrence is divided into a three-water-layer system, which appears seasonally. The surface layer is formed due to freshwater run-off into the estuary and freshwater outflow from the Saguenay Fjord (Rainville and Marcotte, 1985). Below, a cold intermediate layer (CIL) is present, consisting of a denser and heavier water mass than the surface layer above. The third water mass stretches throughout the Estuary and Gulf along the sea floor, and is partially fed by the Labrador Current. Twice a day, strong flooding tides, which hit the LC head, create strong upwellings of the CIL, and bottom waters flow over the sills (Gratton *et al*., 1988; Lavoie *et al*., 2000) resulting in cold, surface waters between 2 and 7°C (Ingram and El-Sabh, 1990). These forces – the strong estuarine two-layer circulation, intense tidally driven upwellings and other complex physical oceanographic processes and very complex tidal current dynamics, closely linked to local topographic features – lead to a site of 'quasi-permanent rich krill aggregation' on a semi-diurnal time frame at the head of the LC, creating probably one of the richest and persistent krill aggregations yet documented in the northwest Atlantic. This leads to a high concentration of shoaling fish species such as capelin, which is one of the main predators of krill in this area (Simard and Lavoie, 1999). In response to this aggregation of prey, minke whales also concentrate along the slopes of the LC head in those areas of densest krill and/or capelin occurrence.

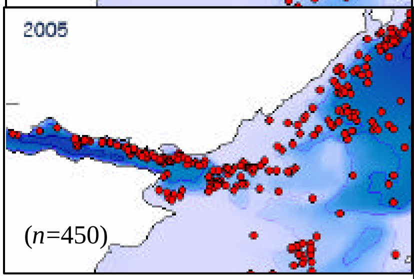
RESULTS

Distribution and Site Fidelity

The photo-identification of individual minke whales in the St. Lawrence Estuary between 1999 and 2006 inclusive, revealed a high variability in spatial and temporal distribution of whales within the study area. Starting in 2000, the number of identified whales and their day-sightings showed a general decrease, accompanied by a general distributional shift towards and into the area of the Saguenay Fjord (Tscherter and Weilemann, 2003), as well as further up the estuary. The highest number of whale day-sightings (n=1922), was recorded in 2006, with most of the sightings occurring within the LC head (figure 4.2). Analyses of the number of individuals identified during this period revealed a strong site fidelity by the animals in this region for two specific feeding areas, i.e. the Laurentian Channel, and the fjord and mouth of the Saguenay River respectively (Zeppelin, 1998; Morris and Tscherter, 2006). Approx 17% (35 out of 209) of the whales identified during the study period were classed as regulars. On average, they were seen on 72.2 ±25 days in 5.7 ±0.6 years, with 81% of the sightings being recorded within an individuals' primary region. Twelve of these animals were seen in the LC in over 75% of the sightings, and thirteen showed a similar preference for the Saguenay Region. Only five generalists were identified, with less than 60% of the total sightings being counted within a single region (figure 4.3). The sightings for two individuals from each group are illustrated in figure 4.4. Although the 35 regulars represent only 17% of all whales identified during the study period, they were responsible for 59% of all the day-sightings recorded.

These results show striking differences in the habitat use by individual minke whales in this location. Apparently, most individuals that regularly forage within the study area exhibit a definite fidelity for specific feeding areas. Spatial fidelity is correspondingly observed to result in individual specialisation of foraging techniques, which are adapted to prevailing environmental conditions or are the result of such specialisation itself. Individually-





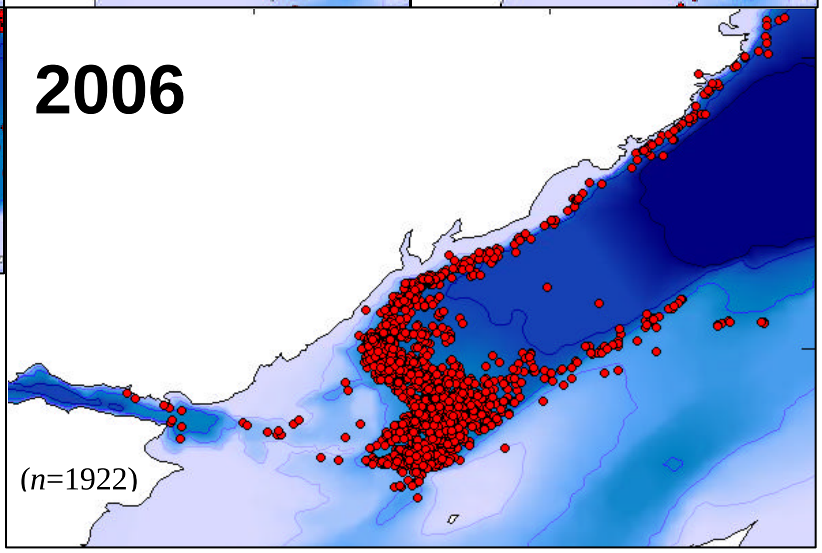


Fig. 4.2: Showing the spatial distribution of minke whales encounters from 1999 to 2006. Note the shift in animals towards/into the Saguenay Fjord and back into the LC. Each dot represents one day-sighting. Note also that the plot for 2006 shows a bigger area due to the expansion of area use.

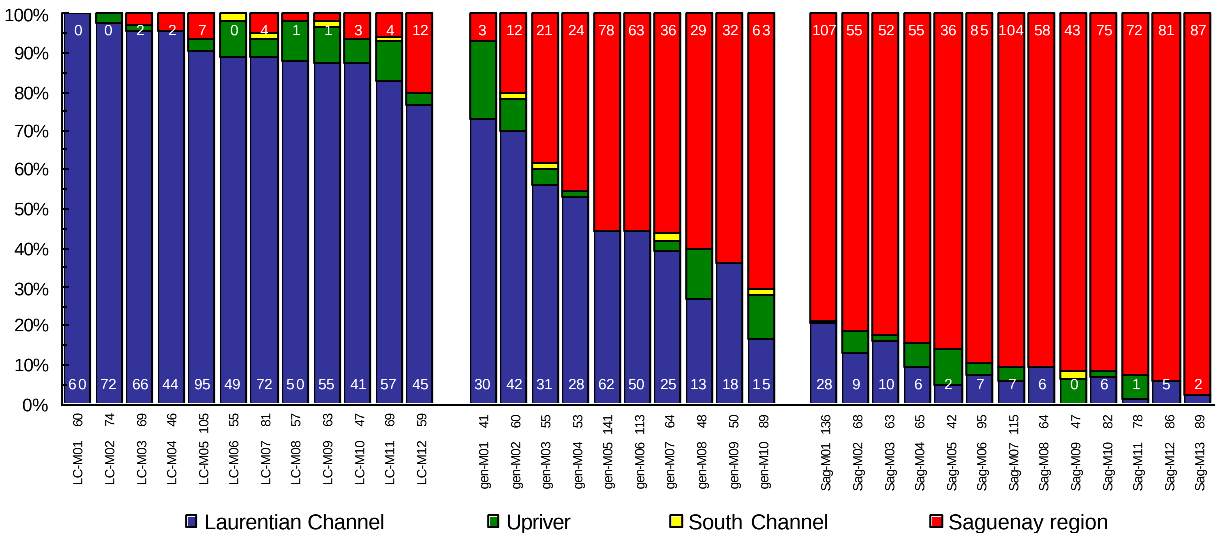


Fig. 4.3: The proportion of sightings counted per region for 35 regulars. Individuals with over 75% of sightings in the LC are plotted on the left (12 LC-whales), and animals with over 75% of sightings in the Saguenay region are plotted to the right (13 Sag-whales). The remaining 10 'generalists' are plotted in the middle. The white values in the graph indicate the number of day-sightings in the LC (bottom) and the Saguenay Region (top) respectively.

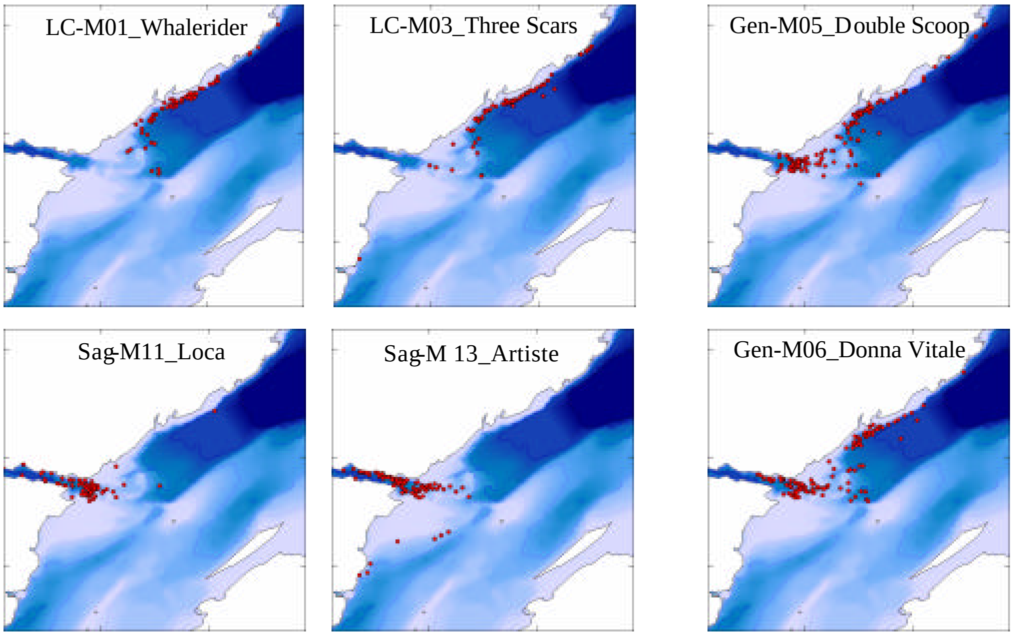


Fig. 4.4: Plots of day-sighting of 6 individuals showing site-fidelity in a) the LC (top), b) the Saguenay region (bottom), and c) to both areas (right). Numbers refer to figure 4.3.

characteristic foraging behaviour has been described for many whales that frequently feed in the Saguenay Region (Kuker *et al.*, 2005). However, since this study was completed, all but two individual animals (Sag-M 13 and Sag-M 06) appear to have left the Saguenay region and have been seen in the LC area in 2005 and 2006.

Whereas site fidelity and specialised feeding techniques might increase foraging efficiency in a specific environment, the question arises whether such specialisation may increase sensitivity towards environmental changes or human activities like whale-watching for example? Ongoing, focal studies of individual whales will ultimately lead to a better understanding of their habitat use and their adaptability to present environmental parameters.

Breathing Ecology

Non-intrusive research of cetaceans is hugely constrained by their aquatic and largely submerged life-style that restricts observations to the short periods when they appear at the surface. As whales are mammals, which spend their entire life in an aquatic environment, they are required to swim to the surface in order to breath. For other activities, such as feeding, travelling and socialising, they remain for the most part submerged. These two contrary situations determine all their activities and define their ventilation patterns more profoundly than for any terrestrial mammal species (Dolphin, 1987). Based on theories of the late Ned Lynas, breathing data of minke whales were collected from the early nineties to investigate differences of ventilation characteristics of different behaviours. Subsequently, Curnier (2005) analysed a total of 376 focal follows =25 mins (collected between 1995 to 2005), and these were categorized into the following behavioural states: i) travelling (TRV, n=50), ii) surface feeding (SF, n=192), and iii) depth feeding. For the latter, profiles of prey scattering layers were used to further subdivide the samples into near-surface feeding (10 to 50 m) (NS, n=59) and deep feeding (>50 m) (DF, n=75) respectively. This analysis highlighted the significant differences in mean surfacing intervals across this range of behaviours (H_3=744.411, p=0.000) (figure 4.5). The mean surfacing intervals for NS and DF were found to be remarkably similar, with 52.034 secs (range 5 to 449) and 52.495 secs (range 6 to 588), whilst the mean interval for a travelling whale was longer than for any other behaviour at 71.162 secs (range 6 to 749). SF animals were found to have the lowest surfacing interval of 43.452 secs (range 1 to 543).

Besides surfacing intervals, other ventilation characteristics were calculated and statistically assessed such as the dive duration, interval between surfaces, surface duration and the number of blows per surfacing cycle. All of these characteristics were also found to be significantly different across the range of behaviours investigated (Curnier, 2005).

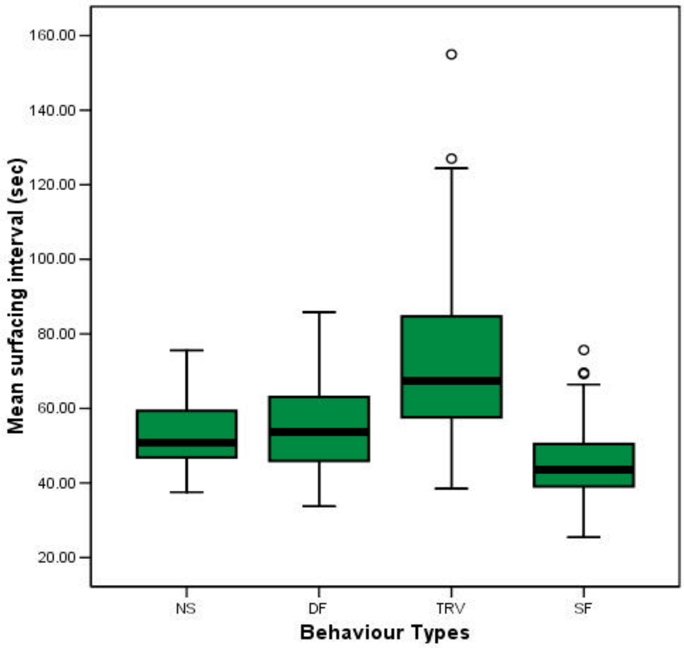


Fig. 4.5: Box plot showing the mean surfacing intervals across the four different behaviours: NS (near-surface feeding), DF (deep feeding), TRV (travelling), and SF (surface feeding).

Feeding ecology

Due to the concentration of prey near the surface, minke whales can regularly be seen feeding near or at the surface allowing focal studies on their strategies and techniques to herd, corral and engulf target prey to be carried out. Minkes in the St. Lawrence might feed on euphausiids (*Thysanoessa raschi* and *Meganyctiphanes norvegica*) when super abundant and in sufficient densities, applying rather slow and low angle feeding strikes. Their major prey, however, consists of capelin (*Mallotus villosus*) which is reported to be the most predominant shoaling fish species in the Saguenay and neighbouring areas of the St. Lawrence (Simard *et al*., 2002).

A number of studies have suggested that minke whales apply different feeding strategies and techniques according to the density and type of prey available (Lynas and Sylvestre, 1988; Hoelzel *et al*., 1989). These applications are thought to be related to predominant environmental factors such as upwellings, fronts, tidal currents and topography, for example (Macleod *et al*., 2004), and in some areas the presence of other predators (e.g. piscivorous fish species, seabirds) (Robinson and Tetley, 2007). While minke whales in Scotland may apply bird associated feeding strategies (Gill *et al*., 2000; Robinson and Tetley, 2007), such interspecies interaction is extremely rare in the St. Lawrence. In fact, if such interaction occurs, it is the birds that follow the hunting whale to profit from the prey being pushed to the surface by the whale itself. Instead, minke whales in this region show a large variety of "active" entrapment and engulfing behaviours, which may include fast and powerful lunges (breaking the surface), and arcs (within the water-air interface) in different body planes (dorso-ventral, lateral, and ventro-dorsal angles) (Lynas and Sylvestre, 1988; Thomson *et al*., 2003) (as shown in figure 4.6). Since 2000, when minke whales were largely concentrated in the Saguenay fjord, novel feeding behaviours never seen before in the St. Lawrence waters or described elsewhere were observed - corralling and entrapment of prey with head slaps, underwater blows, underwater blows right after a surfacing (with exhalation on the dive), lateral rolls, and swimming in tight circles (as described by Kuker *et al.*, 2005). Several of these behaviours are illustrated in figure 4.7 below.

Fig. 4.6: Photographs illustrating the repertoire feeding manoeuvres utilised by minke whales in the St. Lawrence estuary study area. Top left to bottom right: oblique lunge (OL), vertical lunge (VertL), ventral lunge (VL), lateral lunge (LL), lateral arc (LA) and ventral arc (VA). (Photographs by Ursula Tscherter/ORES).

Fig. 4.7: Photographs showing some of the entrapment manoeuvres used by *B. acutorostrata* in the St. Lawrence. Left to right: head slap (also applied laterally), lateral chin-up blow (also applied in dorsal-ventral plane) and exhale on the dive (Photographs by Ursula Tscherter/ORES).

Surface feeding minke whales have also been observed to utilise different foraging strategies between the LC and the Saguenay Fjord. In the LC, where physical factors concentrate prey dense enough for efficient feeding, corralling or entrapment manoeuvres are very rarely seen, and 68% of all feeding manoeuvres are performed in the dorsal-ventral plane (Thomson *et al.*, 2003). In the fjord, however, 2.67 entrapment manoeuvres per strike were used and approximately 99% of all feeding strikes were observed in the lateral or ventro-dorsal plane (Thomson *et al.*, 2003) (figure 4.5).

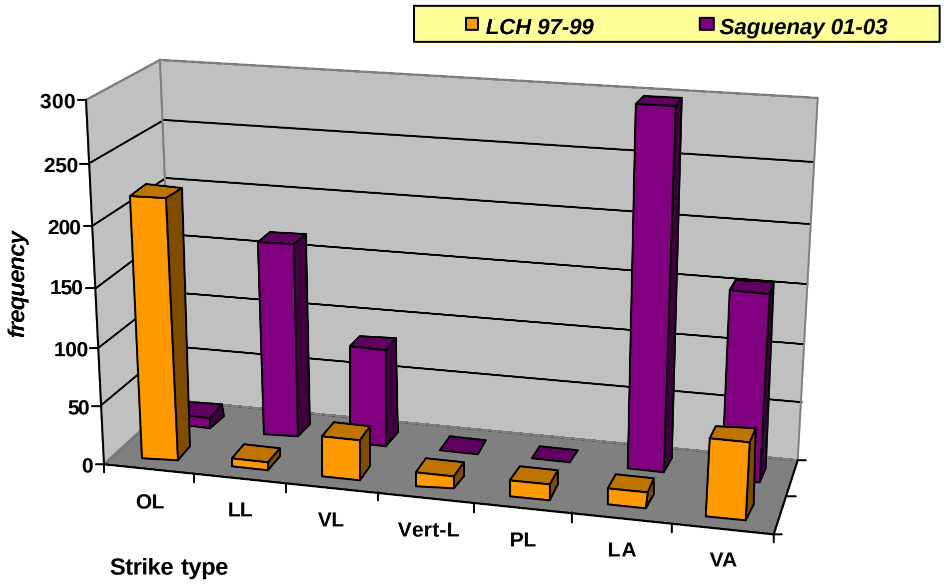


Fig. 4.5: Histogram showing the frequency of feeding strike types utilised by minke whales in two unique feeding environments: the LC and the Saguenay Fjord respectively.

A comparison of the surface feeding techniques of five recognisable minke whales further showed individual differences in their respective feeding techniques (Kuker *et al.*, 2005) (Table 4.1). Some individuals could even be identified based on their unique surface feeding behaviours. In both the LC and Saguenay Fjord, minke whales are found to exhibit a strong preference for the right side for both lateral engulfing and entrapment manoeuvres (97.6%) and dorsal-ventral rolling following a vertical strike (96.9%) (Koster and Tscherter, 2005).

Table 4.1: Showing the pre-strike surface manoeuvres of five minke whales showing strong site fidelity for the Saguenay mouth and fjord in 2003.

	Surface Manoeuvre		
Individual	**Chin-up blow**	**Head slap**	**Exhale on dive**
Sag-M13	53	0	14
Sag-M06	58	0	0
Sag-M03	180	2	0
Sag-M12	19	154	0
Sag-M11	185	180	42
Total	495	336	56

Photo-identification

The identification of individual cetaceans from natural markings is a common tool to study distribution, habitat use, population dynamics and behaviour of these animals that has been applied to minke whales since at least the 1980s (Dorsey, 1983; Dorsey *et al.*, 1990; Gill, 1995). More intensively since the mid-nineties, natural markings such as dorsal edge marks (DEMs), dorsal shapes, body pigmentation and body scars have been used to identify minke whales in the St. Lawrence study area. DEMs, such as nicks, dents and cut-off tips, are found to be the most useful feature used for individual identification, as their presence can be photographically documented irrespective of most environmental and lighting conditions.

Between 1999 and 2004 inclusive, photography has been used to calculate the ratio of those animals carrying dorsal edge marks (DEMs) versus those who do not. From 475 study days, a mean of 10.5 ±8.1 individuals (range 1 to 46) were photographed on any given day. Of these, 73% were identified by DEMs. Between 2000 and 2006, a mean of 89 ±22 individual animals were identified with DEMs each year (range 62 to 118). Throughout the study period, the percentage of animals identified by DEMs remained similar, between 66 to 76% (Tscherter and Morris, 2005). The cause of these marks is not yet fully understood, however, and only a few can be directly linked to anthropogenic causes such as rope entanglement or boat collisions. The same set of photographs has further been used to analyse the temporal stability of the DEMs recorded. The mean number of whale-years documented for all 115 minke whales was 3.35 ±1.63 years (range 1 to 5), giving a total of 385 whale-years (Morris and Tscherter, 2005). A change occurred in only 6 (1.6%) whale-years, which suggested that DEMs in this species were in fact very highly stable. For some animals included in this analysis, however, sightings histories going back ten years or more were used, with the longest documented period of unchanged DEMs lasting an impressive 23 years. The high percentage and stability of DEMs therefore suggest that it is possible to study general changes in distribution and numbers of whales in the study area by analysing the sightings rates for those animals with distinctive DEMs. The use of a digital camera for the first time in 2006 has furthermore significantly increased the identification success rate to more than 90% during the previous research year, and has included the identification of animals without DEMs. As of 2006, 265 individual minke whales are included in the ORES identification minke whale catalogue to date.

CONCLUSIONS

The St. Lawrence estuary is a marine environment where minke whales concentrate in high numbers during the summer and fall months. High re-sightings rates and extended residence periods subsequently allow fine-scale and long-term studies of this species in these waters and their inter-individual distribution, habitat use, site fidelity feeding and breathing ecology. Knowledge gained from the long-term and on-going studies being conducted in this region lead to a better understanding of the lives of these small, balaenopterid whales and have direct implications for their respective conservation and management within the Saguenay - St. Lawrence Marine Park.

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5. FINE-SCALE STUDIES OF COASTAL MINKE WHALES IN NORTHEAST SCOTLAND

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The Moray Firth in northeast Scotland (57º 41'N, 3º 15'W) is a large, triangular embayment measuring approximately 5,230 km^2. Bound 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 5.1). Sharing large-scale environmental determinants such as water circulation and climate patterns, this embayment forms an integral part of the northwest North Sea and Atlantic Ocean beyond (Wright *et al*., 1998). The area to the west of a line drawn from Helmsdale to Lossiemouth comprises the "inner" Moray Firth Special Area of Conservation (SAC), whilst the remaining sea to the east of this limit is referred to as the "outer" Moray Firth. The waters within the Moray Firth are a combination of mixed and coastal waters. The main marine input is provided by the Dooley current, which circulates cold waters from the north in a clockwise direction (Wilson, 1995; Tetley, 2004). This is met by a warm-water plume feature (Tetley, 2004) which extends out from the inner Firth into the wider embayment to produce frontal zones with strong horizontal gradients in surface and/or bottom temperatures (Reid *et al*., 2003). The resulting environment is highly

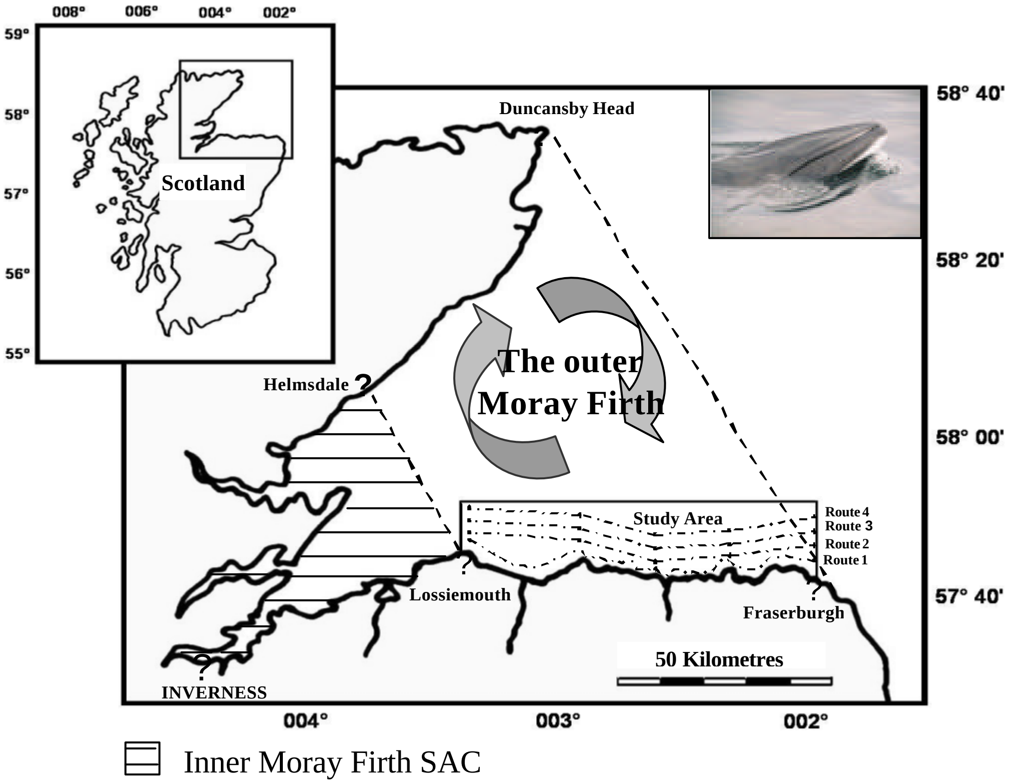

Fig. 5.1: Map of the Moray Firth in northeast Scotland. The arrows indicate the direction of the Dooley Current. The Special Area of Conservation is also highlighted by the shaded area, and the 880 km^2 study area is shown along with the survey routes covered during dedicated boat surveys.

productive and attracts numerous prey species that provide rich feeding for a wide range of marine megafauna, including cetaceans, pinnipeds, turtles, basking sharks and oceanic sunfish (Robinson, personal observation).

From 2001 to 2006 inclusive, dedicated boat surveys were conducted for minke whales along an 83 km length of the southern coastline of the outer firth (lying between the ports of Lossiemouth and Fraserburgh) using four dedicated survey routes positioned parallel to the shore: three outer routes, approximately 1.5 km apart in latitude, and an inner coastal route, covering a total survey area of approximately 880 km^2 (figures 5.1 and 5.2). All surveys were carried out using 5.4 m rigid inflatable boats equipped with observation frames to give an eye height of approximately 3.5 m above the water. The systematic surveys were conducted at mean vessel speeds of 7 knots in visibility =1 km and Beaufort Sea States =3 with a crew of up to 6 observers. Observers searched the water for whales using a continuous scanning method (after Mann, 1999), from directly in front of the boat to 90 degrees left and right of the track line. To ensure the animals were sighted before they reacted to the presence of the survey vessel, binoculars were used from the observation frame to scan far from the boat, whilst the remaining crew searched closer to the vessel with the naked eye.

Cues used to locate whales whilst surveying included the presence of bird feeding rafts and direct observation of animals from their long dark backs and falcate dorsal fins when surfacing. Once an animal 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 travelling in a predictable manner. The time and GPS position of the encounter were recorded for each individual sighted, and additional notes on the age-class and behaviour of the subject, identification features (using traditional mark-recapture methods), and environmental parameters such as the water depth and temperature were recorded. Only the most recognisable animals, with distinctive dorsal edge markings (DEMs), were chosen for 30-minute ventilation samples (typically referred to as a focal follow). Samples where surfaces may have been missed were excluded from any subsequent analysis of diving behaviour.

Between May and October 2001 to 2006, surveys were carried out on 314 days covering a total distance of 12,571.6 km (table 5.1). During this time, 305 encounters were recorded with 323 whales. The whales were encountered throughout the survey area, but were more generally distributed towards the central and eastern area of the study site, with a notable absence to the far west (figure 5.2). A larger number of whales were also sighted on the innermost survey route, but once corrections for survey effort had been made, a considerably higher abundance of animals was shown for each of the outer survey routes, 2 to 4 respectively (table 5.2). Whilst minke whales were recorded during all survey months (May to October inclusive) (figure 5.3a), the animals were typically encountered in this region from mid June onwards, showing a peak in occurrence during July and August. In addition, the temporal distribution of whales suggested an inshore movement of animals across the summer months, with the whales being recorded in deeper, offshore waters in May and June followed by increasing numbers of encounters of animals in more shallow, inshore waters from July onwards (as illustrated in figure 5.4). Throughout the study period, however, considerable variation was observed in the number of encounters from one year to the next (table 5.1 and figure 5.3b). In 2004, for example, the whales were found to be completely absent from the study area, whilst 2005 and 2006 saw the highest abundance of whales across the study period (figure 5.3b).

Sightings of minke whales in the outer Moray Firth were also found to be significantly higher during warm water plume events (Mann-Whitney U, W=24.5, p=0.0167) (when phyto-

Table 5.1: Showing the survey effort for systematic boat surveys conducted between May and October 2001 to 2006 inclusive. From Robinson *et al*. (in prep).

Year	**No. survey days**	**Survey effort (km travelled)**	**Total no. encounters**
2001	45	1514.20	16
2002	67	2518.55	52
2003	60	1946.00	53
2004	35	1886.80	0
2005	43	1797.55	79
2006	64	2908.50	123
Total	**314**	**12571.6**	**323**

Table 5.2: Showing the number of minke whale encounters in the study area with respect to the cumulative effort for each of the survey routes, 1 to 4 respectively.

Survey Route	**Route 1**	**Route 2**	**Route 3**	**Route 4**
Total Effort (km)	7371.35	2486.60	1916.65	797.20
No. of minke encounters	131	94	65	33
No. of animals per km	**0.018**	**0.038**	**0.036**	**0.039**

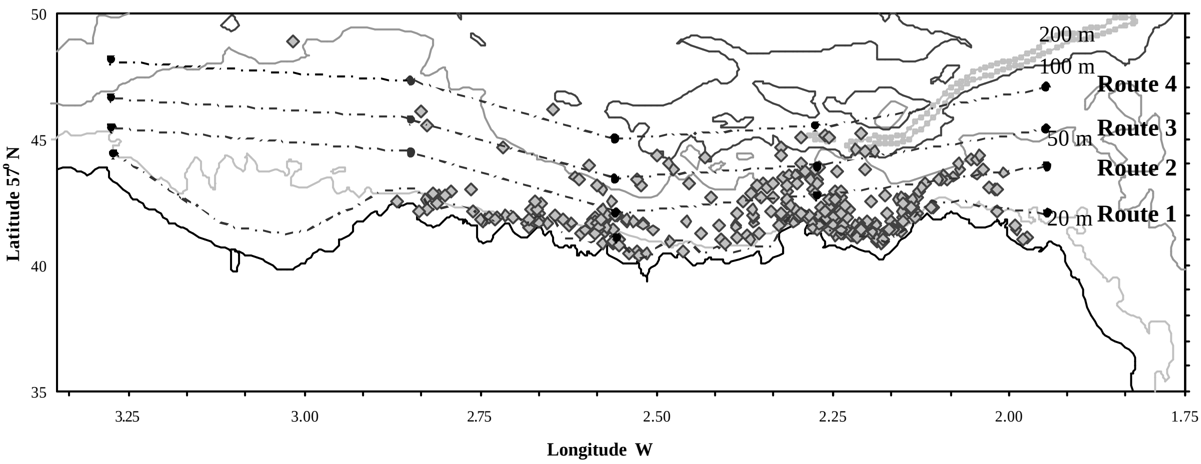

Fig. 5.2: Sightings map showing the spatial distribution of minke whales encountered in the outer southern Moray Firth study area between May and October 2001 to 2006 inclusive (n=323). The boat survey routes used are labelled 1 to 4 respectively.

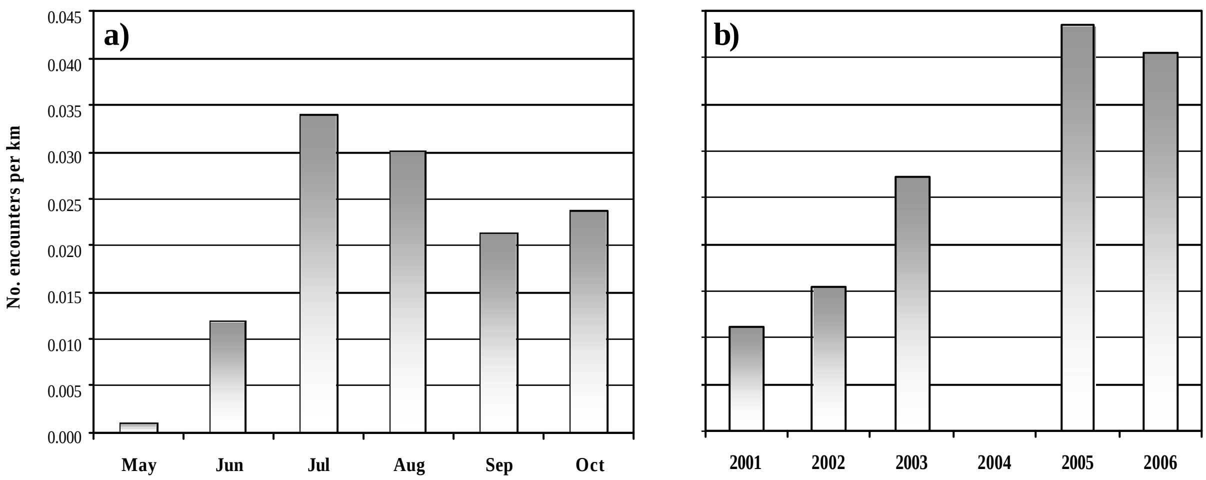

Fig. 5.3: Histograms showing the cumulative number of minke whales (per km of survey effort) from 2001 to 2006 inclusive for (a) survey month and (b) survey year, respectively. Adapted from Robinson *et al*. (2007).

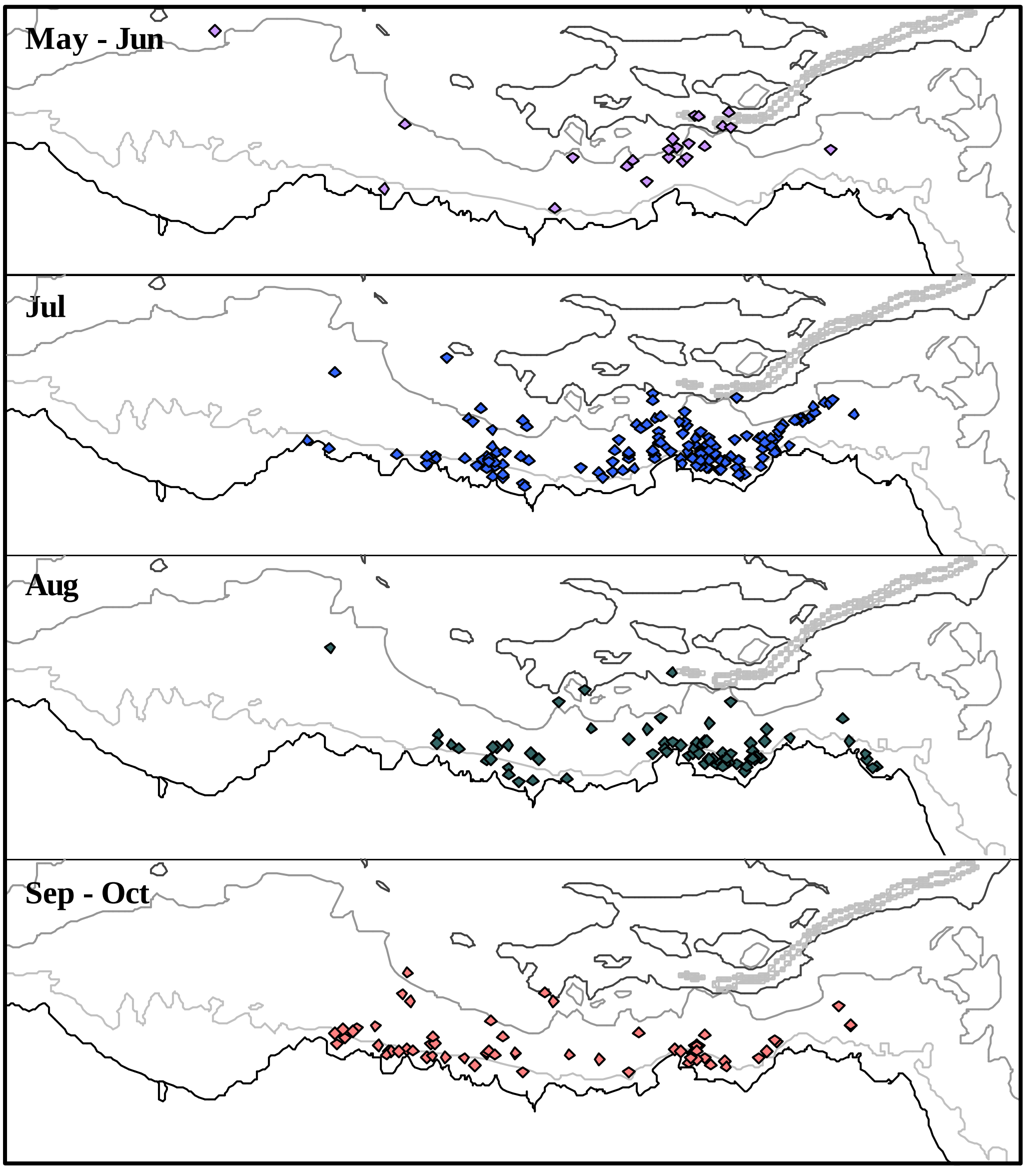

Fig. 5.4: Sightings maps showing the temporal changes in minke whale distribution in the outer southern Moray Firth study area.

plankton biomass was greater) than when the colder water Dooley current was prevailing (figure 5.5). In addition, GIS plots of the physiography of the coastal study site revealed a strong preference by the species for areas with steep, northerly-facing slopes, mean water depths of 38 metres and sandy gravel sediment type (figure 5.6). Sandy gravel sediments showed the strongest positive correlation with minke distribution, and this type of substrate is seen to be the optimal habitat utilised by burrowing sandeels (*Ammodytes marinus*).

In the North Sea, sandeels are found to comprise the principal prey item for minke whales, constituting approximately 70% by weight of their diet (Pierce *et al*., 2004), and in the Moray Firth, piscivorous mackerel (*Scomber scombrus*) are believed to perform a significant role in compacting the targeted sandeel prey into ephemeral bait balls which are subsequently

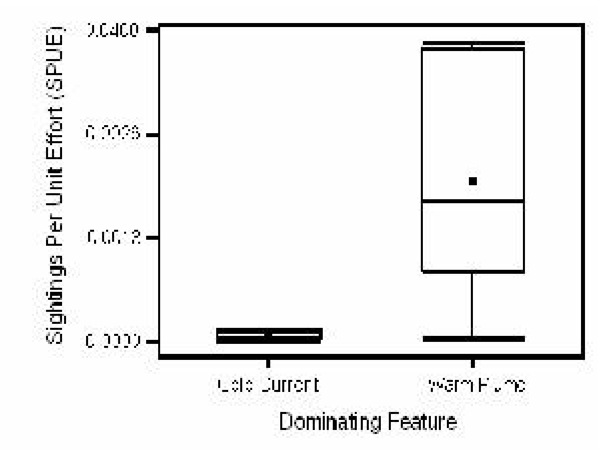

Fig. 5.5: Box plot showing the differences in *B. acutorostrata* sightings between months when either the cold water current or warm water plume was in dominance. From Tetley *et al*. (2007).

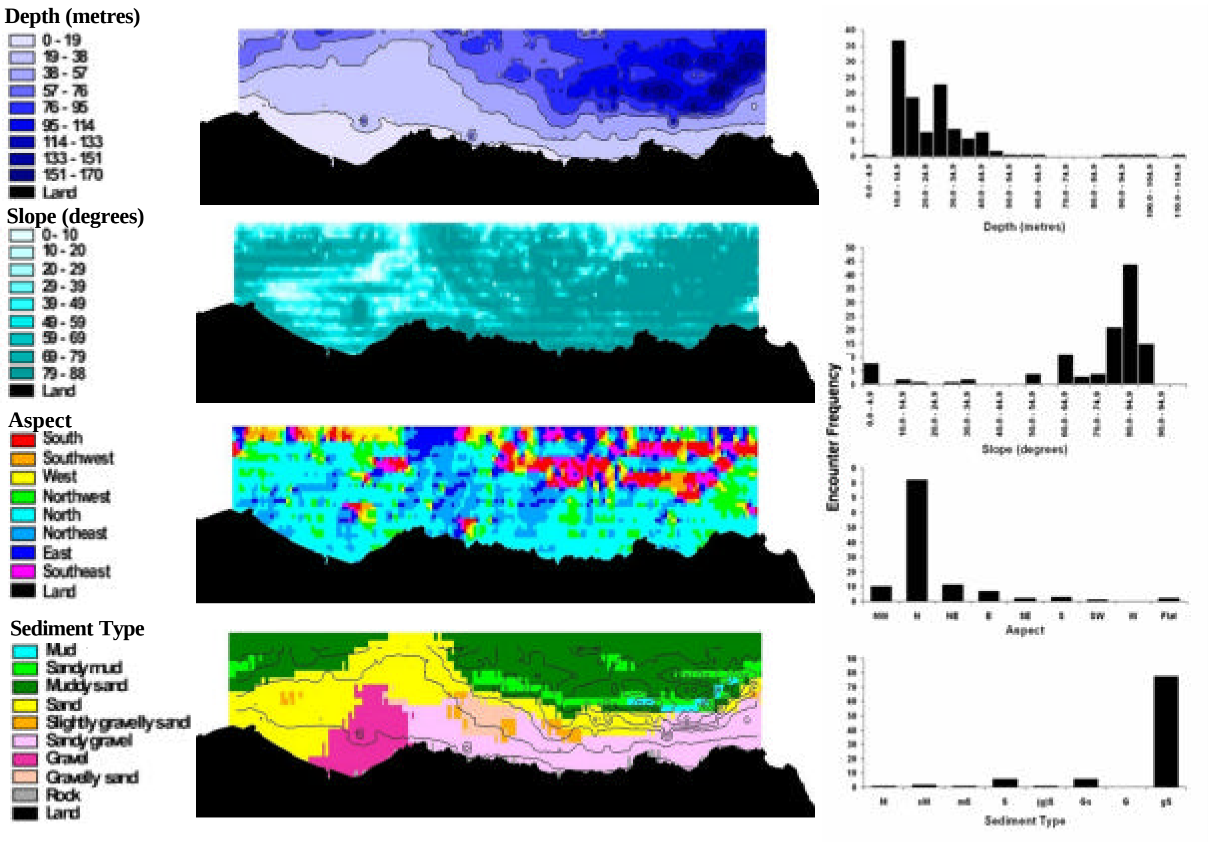

Fig. 5.6: GIS plots of the outer southern Moray Firth study area for the fixed physiographic variables of depth, slope, aspect and sediment type respectively (created using ArcView 3.3). The encounter frequencies for minke whales respective to each are shown in the histograms to the right. From Tetley (2004).

exploited by foraging minkes in the shallow coastal waters. The concentration of sandeels at the water's surface is revealed by the accompanied formation of successive rafts of feeding birds (figure 5.7), such as kittiwakes, auks and shearwaters, which are also thought to play a role in bait ball creation. In a recent study by Robinson and Tetley (2007), bird-associated feeding by minke whales was observed in 76% of the encounters recorded over a 5-year period; the whales opportunistically utilising these bird rafts, rather than expending unnecessary energy corralling their sandeel prey themselves.

Fig. 5.7: Photo montage showing: A) the sandeels primarily targeted by minke whales in northeast Scotland during the summer months; B) the piscivorous mackerel which are responsible for corralling the sandeel prey at the water's surface; C) showing the formation of a bird-feeding raft at the surface; and D) the opportunistic minke whale taking advantage of this ephemeral, aggregated food source.

In 2006, a total of 20 focal follows (= 30 min), equivalent to 603 surfacing/diving sequences, were collected between the months of May and October (N. Baumgartner, unpublished data). This total number of sequences gave a mean surfacing interval of 71.5 ±81.9 sec when pooled, but could be separated by behaviour into the following intervals: 61.3 ±50.9 sec when feeding, 67.2 ±59.6 sec when foraging, and 81.4 ±79.1 sec when travelling (figure 5.8). The frequencies of dive durations across the different behaviours showed that feeding whales typically performed more surfaces with shorter intervals (greater oxygen uptake) than travelling animals (Kruskal-Wallis test, p=0.02). Further studies at this time aim to compare the surfacing rates of these coastally occurring minkes with animals from other geographical locations, with additional analyses considering differences due to age class, feeding depth, and the time of day and year, for example.

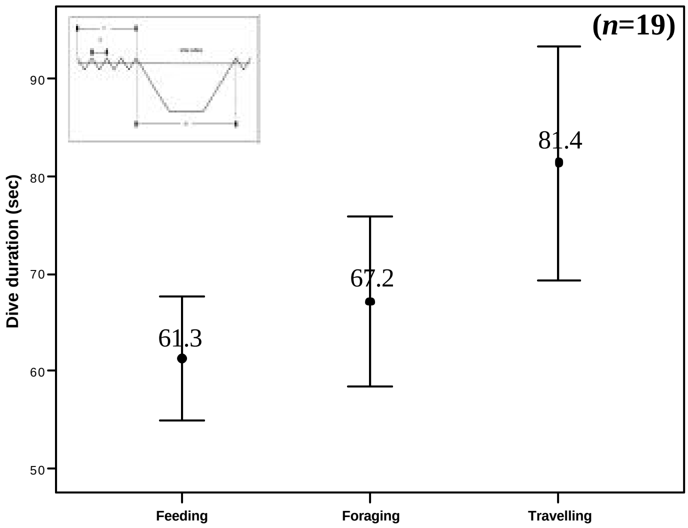

Fig. 5.8: Graph showing the mean surfacing intervals across the 3 different behaviours, feeding, foraging and travelling (Kruskal-Wallis test, p=0.02). Note: the large error bars are due to the very low sample numbers recorded at this time.

Between 2001 and 2006, “marked” whales were also opportunistically photographed during dedicated surveys and whilst conducting focal follows. A large percentage of the animals encountered (approx. 60%) were found to be juveniles without any useful identifying features. However, high-quality identification shots have been successfully recorded for 32 “marked” individuals to date. Four categories of markings have been resolved from the processed images, which are broadly categorised as: whales with (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%) (Baumgartner *et al.*, 2007). 41% of the animals photo-identified in the study area between 2001 and 2006 have been recaptured on at least one or more occasions, and 19% have been captured in at least 2 or more different survey years. The resulting compilation of a progressive photo-archive for recognisable minke whales in northeast Scotland is believed to be an important first step towards a more integrated east-west coast approach to minke studies in Scottish waters.

CONCLUSIONS

Fine-scale studies can be used to better understand the distribution, site fidelity and behaviour of coastally-occurring cetaceans such as minke whales in our inshore coastal waters. Such an understanding is necessary for the focus of conservation measures, to mitigate detrimental human impacts such as over-fishing, disturbance by shipping and by-catch, for example, in these areas, and to identify times and areas of special significance for these animals and measure the effectiveness of existing management actions.

On-going studies aim to achieve additional coverage of the outer Moray Firth region, integrating broader scale survey data and directing more detailed work in focal areas of particular interest or concern. Such a multi-scale approach is believed to be important for the identification of those oceanographic, biological and anthropogenic determinants that are thought to underlie the distinctive patterns of distribution seen in this coastal North Sea area, and these objectives are believed to be fundamental to local management directives for the protection of this and other coastal minke whale communities in UK and European waters.

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6. USING PASSENGER FERRIES TO STUDY SEASONAL PATTERNS OF MINKE WHALE OCCURRENCE IN NW EUROPE

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INTRODUCTION

Understanding seasonal changes in the distribution of minke whales is essential for their conservation. Only once it is known which areas are critical for minke whales and how these change across the year will it be possible to construct an appropriate conservation strategy that takes these seasonal changes into account. Minke whale seasonal occurrence has been relatively well studied at a number of discrete locations in northwest Europe (e.g. the Sea of Hebrides – K. MacLeod *et al*., 2004; the outer Moray Firth – Robinson, pers. comm.). Information on the wider scale distribution of minke whales is also available from surveys such as SCANS and SCANS II (see Hammond *et al*., 2002; http://biology.st-andrews.ac.uk/scans2). However, this information is limited to a single month of two years (July 1994 and July 2005). Little is known about how representative seasonal information from local studies is of seasonal changes in the wider distribution, nor how representative the region wide distribution in July is of other times of the year. This study aimed to fill in the gaps between these sources of information and provide a broader description of seasonal patterns in the occurrence of minke whales over a substantial part of western Europe

One of the best ways to study seasonal changes in the occurrence of a species is to undertake repeated surveys along a fixed transect as this reduces the potential impact of spatial variations in survey effort on any identified seasonal changes. Undertaking a number of such transect surveys over a large area using a dedicated research vessel is logistically difficult and very costly. However, the waters around northwest Europe are regularly crossed by a large network of passenger ferries. These ferries repeatedly travel along the same route and, therefore, provide the opportunity to conduct regular surveys along the same transect. In addition, ferries tend to be large, stable, have a good eye height above the water for observers and are relatively cheap to access. As a result, passenger ferries provide excellent research platforms for conducting studies of seasonal changes in species occurrence. By using comparable data collection methods, patterns in seasonal occurrence can be studied not just in one location, but compared across a number of different ferry routes to provide a regional picture of seasonal changes and how they compare in different areas.

METHODS

Data were collected by four research groups along 11 ferry routes (table 6.1). These routes covered waters from 43ºN to 60ºN and included both shelf and oceanic waters. The surveys were conducted using standard cetacean surveying protocols involving observers situated on the bridge of the ferry scanning an area ahead and to the sides of the vessel as it travelled along its normal route. When any cetaceans were recorded, the vessel's position was recorded along with information on the species and group size. For this analysis, only data on minke whales were examined. The data were grouped into four regions: The northern North Sea, western Scotland, the Irish Sea and the English Channel/Bay of Biscay. To examine the seasonal pattern in occurrence, the number of minke whale sightings in each month for each region was plotted on a histogram. To investigate seasonal patterns in habitat use, the sightings were grouped into two or four seasons depending on temporal coverage of surveys (table 6.1) and plotted in a geographic information system (GIS). Temporal variations in spatial distribution and monthly occurrence were then compared between each of the four regions.

Table 6.1: Details of specific routes surveyed by each research group, and inter and intra-time period of data collection.

Region	Ferry Route (company)	Research Group	Inter-annual Coverage	Intra-annual Coverage
Northern North Sea	Aberdeen-Shetland (Northlink Ferries)	NORCET (Northern North Sea Cetacean Ferry Surveys)	2002-2006	April-September
Northern North Sea	Aberdeen-Orkney (Northlink Ferries)	NORCET (Northern North Sea Cetacean Ferry Surveys)	2002-2006	April-September
Western Scotland	Ullapool- Stornoway (Caledonian MacBrayne Clyde and Hebridean Ferries)	Sarah Bannon, Aberdeen University	2001-2006	May-September 2001-2005, year round 2005-2006)
Western Scotland	Uig-Tarbet (Caledonian MacBrayne Clyde and Hebridean Ferries)	Sarah Bannon, Aberdeen University	2003-2006	May-September 2003-2005, year round 2005-2006)
Western Scotland	Uig-Lochmaddy (Caledonian MacBrayne Clyde and Hebridean Ferries)	Sarah Bannon, Aberdeen University	2003-2006	May-September 2003-2005, year round 2005-2006)
Western Scotland	Oban-Lochboisedale (Caledonian MacBrayne Clyde and Hebridean Ferries)	Sarah Bannon, Aberdeen University	2003-2006	May-September
Western Scotland	Tiree-Oban-Colonsay (Caledonian MacBrayne Clyde and Hebridean Ferries)	Sarah Bannon, Aberdeen University	2003-2006	May-August
Irish Sea	Dublin-Hollyhead / Mostyn (Irish Ferries and P&O Ferries)	Irish Whale and Dolphin Group (IWDG)	2001-2006	Year Round

Irish Sea	Rosslare-Pembroke (Irish Ferries)	Irish Whale and Dolphin Group (IWDG)	2004-2006	Year Round
Irish Sea/English Channel	Dublin/Rosslare – Cherbourg (P&O Ferries)	Irish Whale and Dolphin Group (IWDG)	2002-2004	Year Round
English Channel/Bay of Biscay	Portsmouth-Bilbao (P&O Ferries)	Biscay Dolphin Research Programme (BDRP)	1995-2006	Year Round

RESULTS

The Northern North Sea

Data were available for the northern North Sea from April to September from 2002 to 2006. Sightings of minke whales increased from April to July before dropping quickly in August and September (figure 6.1). In April to June, sightings were primarily in more open waters away from the coast while in July to September they were restricted to more coastal waters. This movement into more coastal waters over the summer may explain why the number of minke whale sightings drops rapidly between July and August as this ferry route does not survey the most coastal waters as its usually route is usually at least 8km away from the coast.

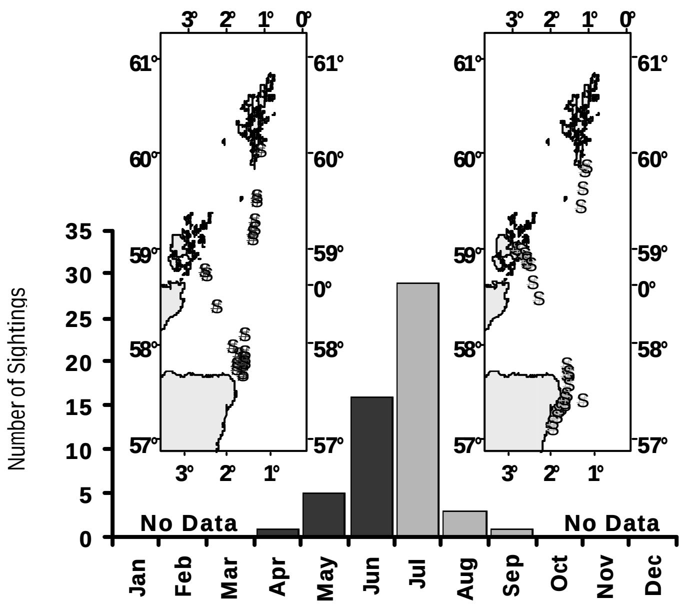

Fig. 6.1: Seasonal pattern of minke whale occurrence in the northern North Sea (data from NORCET).

Western Scotland

Data were available year round for western Scotland from 2001 to 2006 (although data for October to April was only available from September 2005 onwards). No sightings were recorded before May and sightings peaked in July before decreasing again to zero by October (figure 6.2). In May and June, sightings were primarily recorded close to the coast and in narrow coastal sounds. In contrast, in July-September, sightings were more widespread in this area and minke whales were also recorded in more open waters away from the coast.

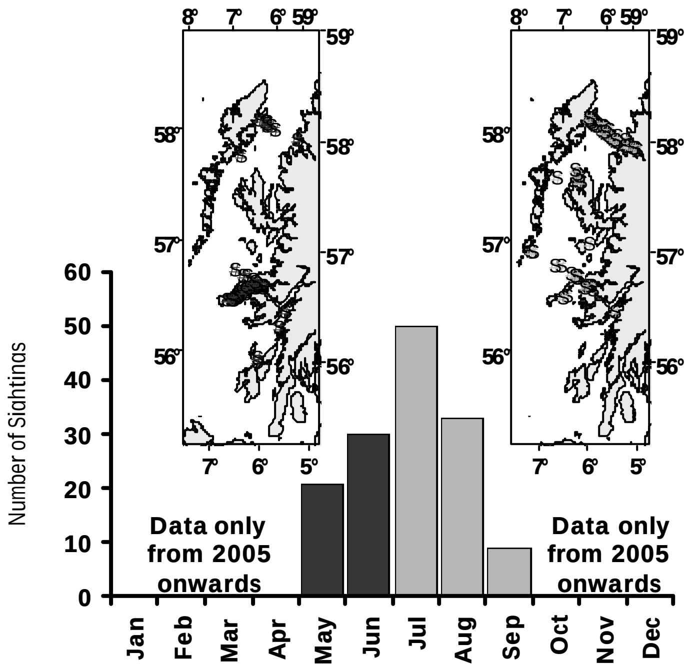

Fig. 6.2: Seasonal occurrence of minke whales in western Scotland (data from Sarah Bannon).

Irish Sea

Data were available year round for the Irish Sea from 2001 to 2006, however fewer minke whales were recorded in this region than in the others making it harder to interpret patterns in seasonal occurrence. No sightings were recorded before April and sightings peaked in June before decreasing again to zero by September (figure 6.3). A single sighting in November was

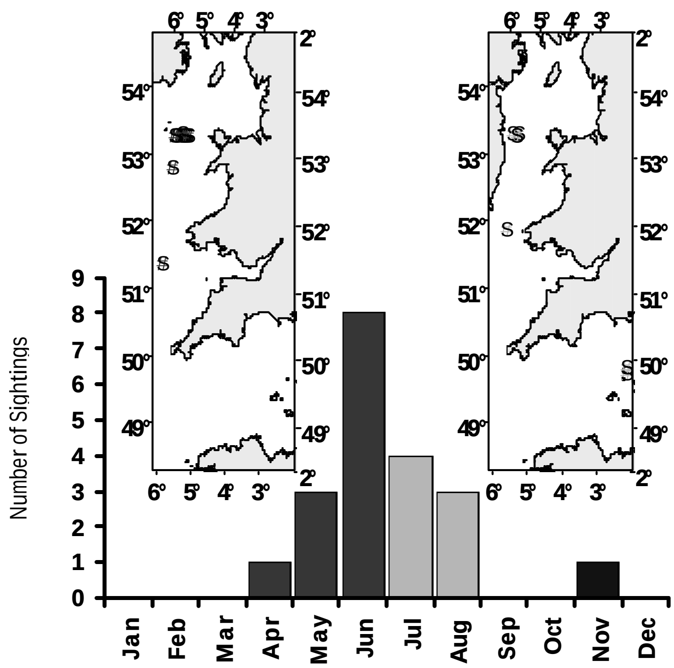

Fig. 6.3: Seasonal occurrence of minke whales in the Irish Sea (data from IWDG).

the only sighting for winter months. There were insufficient sightings to analyse changes in spatial distribution, although sightings were potentially more coastal in July-September than in April to June.

Bay of Biscay/English Channel

Data were available year round for the English Channel and the Bay of Biscay from 1995 to 2006. Only one sighting was recorded between January and March. After this time, sightings increased to a peak in July before declining to a low in November and December (figure 6.4). In terms of spatial distribution, the only sighting in January to March occurred close to the shelf in the southern Bay of Biscay in March. In contrast in April to June, sightings were restricted to the northern shelf of the Bay of Biscay and the English Channel. From July to September, sightings where more widespread in these shelf waters, with a greater penetration into the English Channel. In addition, there were a small number of sightings in non-shelf waters. Finally, in October to December, sightings were again restricted to the northern shelf of the Bay of Biscay and the English Channel and did not penetrate as far into the English Channel mirroring the pattern in April to June.

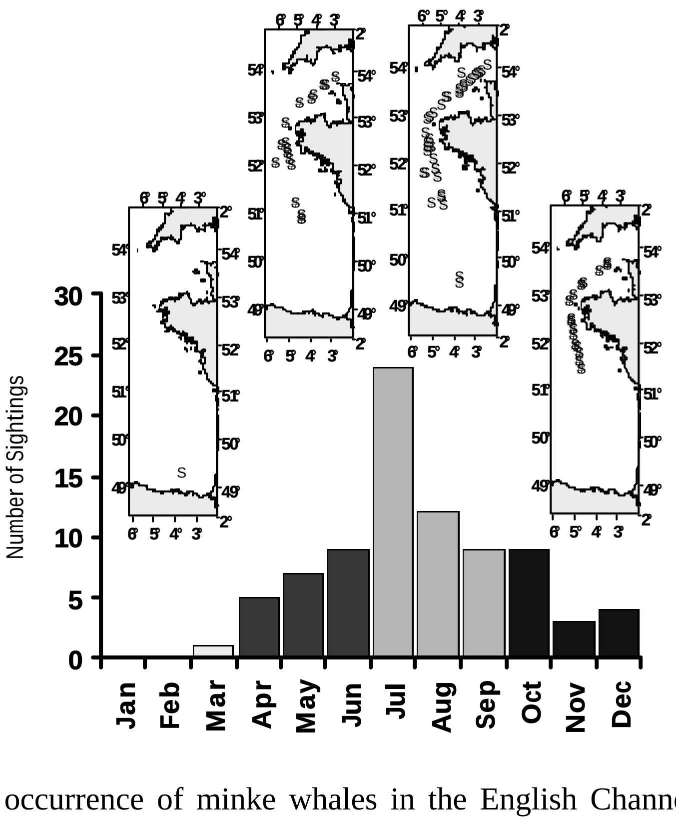

Fig. 6.4: Seasonal occurrence of minke whales in the English Channel and Bay of Biscay (data from BDRP).

DISCUSSION

Minke whales are known to show seasonal patterns in occurrence in waters of northwest Europe. However, this is one of the first attempts to compare these patterns across a number of different areas over a broad latitudinal range (43-60ºN). In all four regions examined, the main peak of occurrence was in the summer months (June or July), suggesting that this is a common feature of minke whale occurrence throughout shelf waters of northwest Europe.

This similarity in the peak time of occurrence between the different regions and the fact the sightings in southern areas do not decline as sightings in more northern areas increase (or vice versa) suggests that the seasonal patterns in minke whale occurrence are not just simple north-south seasonal movements in study area, with a single aggregation of individuals moving northward as the summer progresses and then moving southward again at the end of the summer. It may be that such north-south movements occur, but if they do, they must involve multiple aggregations with new individuals replacing others as they move out of more southern waters.

There was also a general pattern towards a greater use of more coastal areas in July to September than in April to June. The exception to this appears to be western Scotland. However, this area consists almost entirely of coastal-type habitat and the apparent difference may reflect the lack of more offshore habitat within the study area rather than a true difference from other regions. This general pattern towards increased use of coastal areas in late summer may reflect common dietary preferences or dietary switches across all shelf waters of northwest Europe as the summer progresses. However, more research is required to investigate why minke whales use more coastal waters in late summer than earlier in the year.

While there are similarities between the regions in terms of peak occurrence and shifts in distribution, there are also differences between them. In particular, the main timeframe of occurrence is May to September in the north but April to December in the south. One possible reason for this is that seasonal movements are linked to changes in water temperature with a certain threshold having to be crossed before minke whales commonly occur in shelf waters. However, it is unclear why this might be the case and further research into this possibility is required.

One notable result of this study is that there is only one record from the whole study area between January and March and this was at in the most southerly portion of the most southerly region. This suggests that minke whales are almost completely absent from shelf waters of northwest Europe at this time. The lack of sightings from the deeper water regions of the Bay of Biscay in January and February suggests that minke whales are not simply moving into neighbouring deeper waters, but may instead be leaving northwest European water entirely. This raises two questions. Firstly, does this absence from the shelf waters of northwest Europe coincide with key life history events such as mating and/or calving, suggesting that minke whales from northwest Europe breed else where? Secondly, where do the minke whales that spend much of the rest of the year in the waters of northwest Europe go between January and March? Finding the answers to both of these questions will be essential for the development of any conservation strategies for minke whales in northwest Europe. In particular, this study highlights the fact that any measures to conserve minke whales around western Europe must not simply consist of implementing conservation strategies based on habitat use at a few limited locations or distribution in a few summer months as this may overlook issues that are important at other times of the years and in other places.

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7. UNDERSTANDING MINKE WHALE HABITAT ECOLOGY: IMPLEMENTATION OF META-ANALYSIS

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The minke whale (*Balaenoptera acutorostrata*) is one of the most cosmopolitan and numerous species of mysticete cetacean within the Northern Hemisphere. However, due to its distribution, the species is also impacted by (and has impacts upon) a range of direct and indirect anthropogenic activities. The three primary examples include whaling, whale watching and fisheries. Thus, to adequately manage the deleterious impacts and long-term economic stability of these industries, a clear understanding of the abundance and spatio-temporal distribution of the species needs to be appreciated. The recent use and development of environmental niche modelling (ENM) techniques for a variety of different species (e.g. Fiaboe *et al.,* 2006; Kaschner *et al.*, 2006) indicates a good potential for spatially predicting current and future minke whale distributions. However, ENM techniques should be used carefully when dealing with species which have high variances in regional adaptation (Murphy and Lovett-Doust, 2007), their community interactions (Austin, 2006), migrational shifts (Martinez-Meyer *et al.,* 2005) and associations with non-fixed oceanographic parameters (Hamazaki, 2004).

In this presentation, a proposal aiming to successfully predict and gain a greater understanding of the distribution of minke whales within the northern hemisphere. This will be achieved by comparing new, archived and published data for spatial and temporal occurrence of the species in coastal waters within five geographically distinct locations (shown in figure 1). It was hypothesised, that across this wide, geographic range, regional adaptations in the whale's foraging ecology and behaviour would exist (as described by Robinson and Tetley, 2007; Thomson *et al.,* 2003) due to suspected differences in the oceanography and community within each region. Therefore, a comparison of whale distributions in each of these areas could be used to provide a greater understanding of the species' coastal ecology.

Whale associations and their environmental parameters will be examined (within the framework of a PhD study) for each area in isolation, whilst developing a variety of comparative ENM approach matrices aimed at determining the most accurate combination of model parameters. These are to include: area datasets incorporated for ENM approaches; those for ENM approach validation; and the choice, or combination of, ENM techniques used for prediction approaches (e.g. PCA, Maxent, ENFA, GARP analyses). With respects to ENM techniques, it is presumed that the majority of data available for each location will provide the presence only of whale sightings. Therefore, the four techniques mentioned above seemed most suitable for use in a meta-analysis framework. After this process of ENM approach comparison, that which is deemed most functional in successfully predicting spatial distribution between the five locations will be used to generate a habitat suitability map (HSM) for foraging minke whales within the northern hemisphere. Validation of the produced HSM will be potentially tested against minke whale sightings data available through the on-line GIS database of the OBIS-SEAMAP project.

With respects to the temporal prediction of minke whales, the proposed study intends to relate distribution to the presence and interactions of co-occurring meso-scale oceanographic

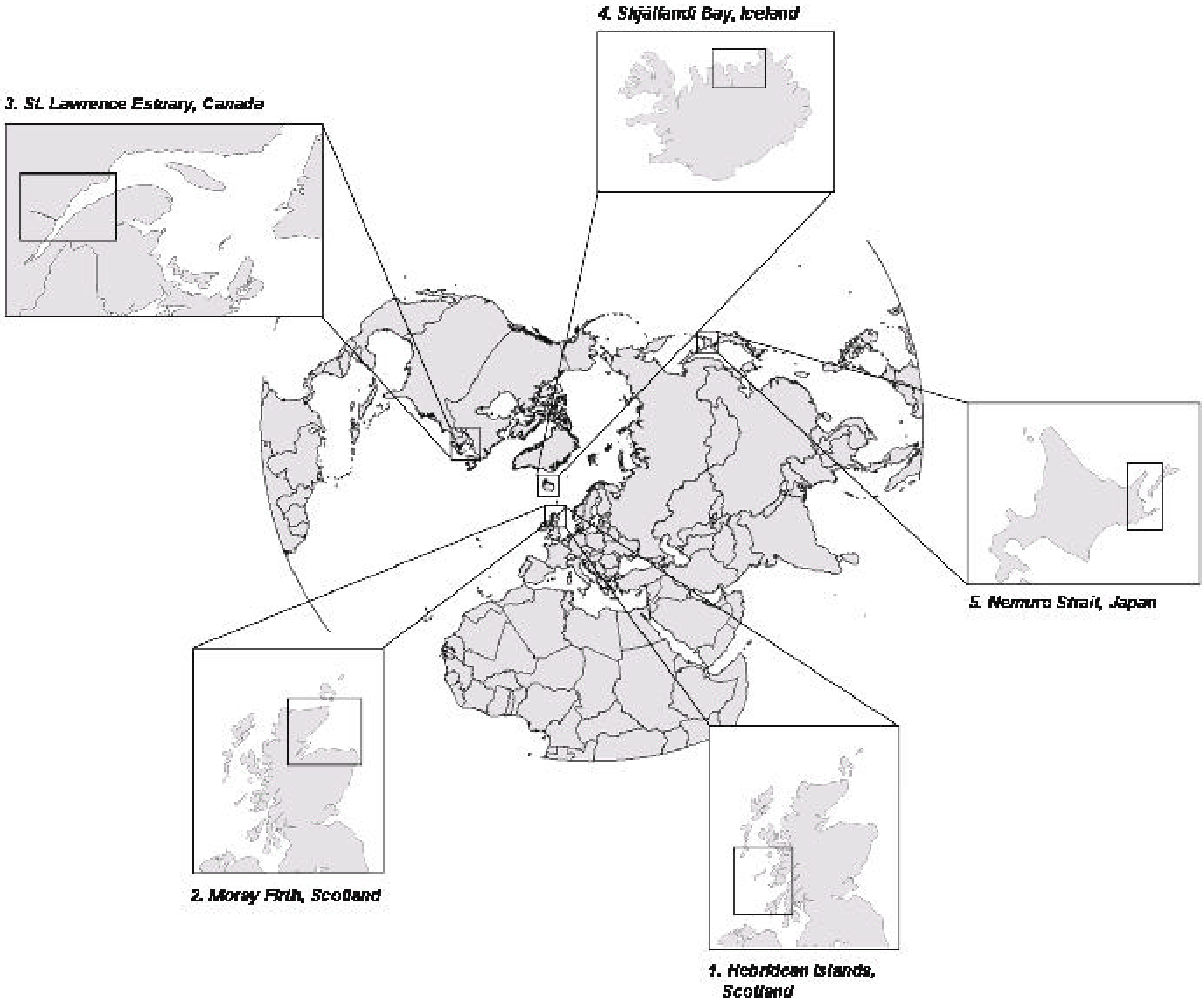

Fig. 7.1: Geographical spread of distinct project areas located within the northern hemisphere including the Moray Firth and Inner Hebrides, Scotland, St. Lawrence Estuary, Canada, Skjálfandi Bay, Iceland and the Nemuro Strait, Japan.

features which may be present in the locations studied. The temporal occurrence of minke whales has been found to relate to the presence of these oceanographic features (Kasamatsu, 2000; Tetley *et al*., 2007). Once any patterns or trends have been determined within the areas studied, satellite based ocean forecasting systems (SOFTs) will be used to make predictions on the likely future occurrence of whales within these localities. SOFTs have proven highly useful for many areas for predicting species distributions and changes in oceanographic features and variables (e.g. Alvarez *et al.,* 2006; Le Foust *et al.,* 2006). Once this is successfully completed, a selection of currently existing marine protected areas – where the species is known to occur but no detail research has been conducted – will be used to test the reliability of SOFTs. This objective aims to incorporate whale occurrence trend data in order to make predictions on the temporal distributions of the species. The findings of this study will be made available for use in further monitoring, protection and for the management of these and other coastal whale populations within such MPA's.

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8. EVIDENCE FOR CHANGES IN MINKE WHALE PREY OFF SCOTLAND: WHY COLLABORATION MATTERS

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During the course of this workshop, many excellent examples were presented of minke whale studies conducted at different scales and in different geographical regions and addressing different questions or academic disciplines. However, a number of similar and intersecting themes have recurred in presentations of disparate datasets. Such overlap can prove instructive, and may be essential to interpreting the observations made during a study.

Since 2003, the Hebridean Whale & Dolphin Trust (HWDT) has conducted dedicated distance-sampling surveys off the west coast of Scotland during the summer months. The most regular and intensive sampling is conducted in the waters around the Inner Hebrides, extending from South Skye to the Kintyre Peninsula, with additional, though more limited, survey effort further to the north and west (figure 8.1). These surveys were designed to establish patterns of cetacean habitat use in the area and to monitor changes in cetacean distribution and relative abundance.

Fig. 8.1: HWDT survey area. Dedicated vessel-based sampling surveys are conducted over much of the west coast (left). The highest density of dedicated effort is within the Inner Hebrides (right).

Over the first four years of these surveys, a steady and startling decline was observed in the number of minke whales (*Balaenoptera acutorostrata*) sighted in the core survey area (figure 8.2). The result was not subtle; the number of minke whales sighted per hour of survey effort in 2006 was a third of that in 2003. Coupled with the qualitative observation that visible surface feeding was nearly absent after 2003, this decline in numbers would seem likely to reflect patterns of prey distribution, abundance or concentration. However, even with so unambiguous a signal in these data, this single observation is able to explain little when presented in isolation.

Even with a high intensity of survey effort each year, there are only four years (and therefore four data points) in the trend. Thus, the possibility that the observed pattern is artefactual cannot be dismissed. It is possible to support a single observation with data from other projects in the region. HWDT conducted shore-based surveys from the lighthouse at Ardnamurchan Point from 2001 to 2005. These data are subject to different biases than are the vessel-based surveys. Specifically, because the area visible from the shore station is so small, the availability of animals to the surveys is dependent on fine-scale distribution. Changes of only a few km in distribution patterns can place animals out of range of the observers. None-the-less, sightings data from the Ardnamurchan project showed a decline of two orders of magnitude in minke sightings per unit of search effort between 2003 and 2004 (F. Quarmby (HWDT), unpublished data), with so few sightings in 2004 and 2005 that the project was discontinued in 2006. A declining trend was also reported at this workshop from the Small Isles (Anderwald, 2007). This is just north of the region visible from Ardnamurchan and a section of the HWDT survey area. These data strengthen the case that the trend observed in the HWDT vessel survey represents minke whale distribution rather than being a sampling artefact. However it does not necessarily add to the explanatory power of the observation.

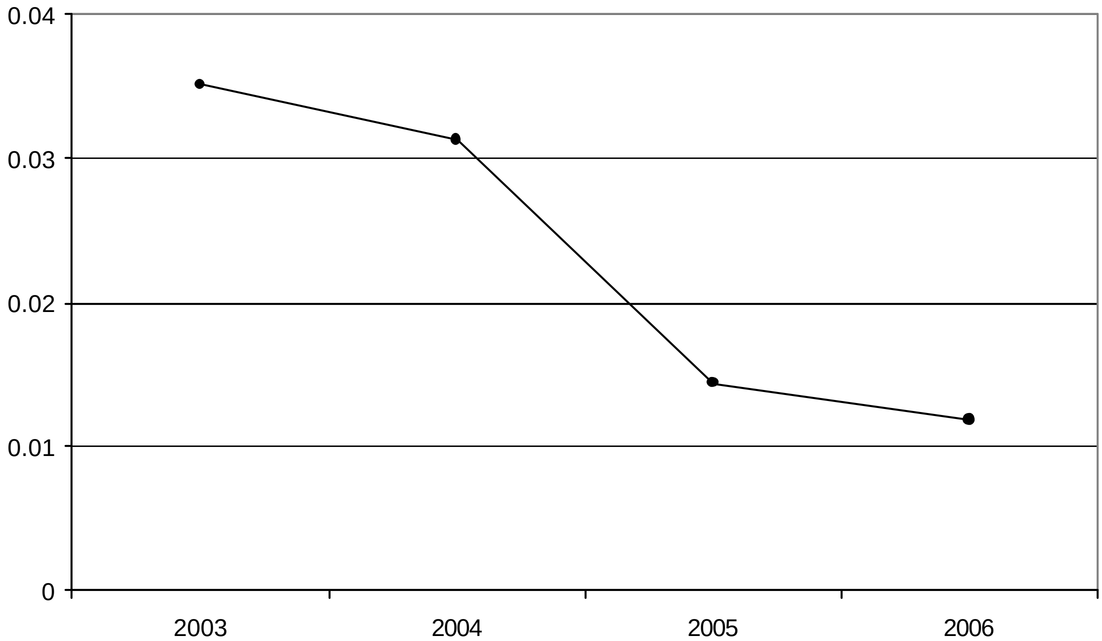

Fig. 8.2: Minke whale sightings per unit time from surveys conducted June-September in the waters of the Inner Hebrides, west Scotland.

Long-term data on cetacean distribution in the area has been collected collaboratively by HWDT and the commercial whale watch operator Sea Life Surveys (SLS). This coverage is intensive in the waters north of Mull and through the Small Isles. It includes the Ardnamurchan survey area and is part of the broader survey area covered by the dedicated HWDT surveys. While commercial ventures are optimizing the opportunities for their customers to view whales rather than operating systematic surveys, effort data are collected on board all SLS trips using GPS-linked computer data logging software. This allows some effort-based analyses to be conducted. Minke whale distribution data collected by this project from 1992-1999 were modelled using habitat variables (MacLeod *et al.*, 2004; see also Tetley, 2007 for another physiographical habitat study). These data indicate that the key minke whale habitats in the region are associated with physiographic characteristics consistent with lesser sandeel (*Ammodytes marinus*) distribution and abundance, early in the season, and with pre-spawning Atlantic herring (*Clupea harengus*) later in the season (MacLeod *et al.*, 2004). Abandonment of these habitats in the past four years, then, would seem likely to represent minke response to a decline in these prey species. This additional data source supports the anecdotal observation of reduced surface feeding in the area and begins to suggest an ecological mechanism for the observed minke whale decline.

A steep reduction in at least two species of locally important small pelagic fish is likely to have broad trophic implications. Since 2002, systematic surveys for basking sharks (*Cetorhinus maximus*) have been conducted over the south Skye to Kintyre region through the Scottish Wildlife Trust's Basking Shark Project (SWT-BSP). These data indicate a pattern quite the reverse of that seen in minke whales; no basking sharks were observed in the area in 2002 despite substantial survey effort, while by 2004 the region had the highest densities of basking sharks on the west coast of the United Kingdom (C. Speedie, unpublished data). Both sandeels and herring predate heavily on large zooplankton (Collette and Klein-MacPhee, 2002). When such planktivorous fish populations decline, substantial ecological changes may occur (Sissenwine, 1986); zooplankton populations are likely to increase due to reduced predation pressure, and ichthophagous predators may be replaced by planktivores (Payne *et al.*, 1990). From a statistical perspective, opposing trends, even very substantial ones, have little power. However, in this case, the ecological relationship between trophically-connected species helps to support the contention that the decline in minke whale abundance resulted from a decrease in local prey availability.

In a few steps then, by progressively adding data from additional sources, the initial observation has been strengthened, and more importantly built into (I hope) an ecologically compelling story. There are a great many additional ways in which this case could be strengthened or expanded even further through involvement of other studies. I will touch on a small number of these and, in some cases, the limitations of these data and the reasons why they have not been included above.

Where changes in trophic structure occur, numerous species across many taxa are likely to be involved. Anecdotal reports suggested that reproductive success by local seabird colonies was dramatically low during this period, and that adult birds were seen returning to nests with low-value prey rather than the typical diet. This clearly supports the premise that prey stocks have declined, at least within the foraging radius of the birds. Ringing studies are ongoing at the large breeding colonies at the Treshnish Isles in the heart of the survey area. However, the objective of this study is to count and ring large numbers of birds during a restricted field season each year. Reproductive success and chick foraging studies are not conducted. Thus, these data show large numbers of adult birds on the colonies throughout the period, and no clear or consistent trend (Ward, 2006). They do not reflect the response of nesting seabirds to prey at suitable temporal scales (the signal will only become evident if the decline goes on long enough to cause abandonment of the colony, or after the young from the years of catastrophic nest failure would normally be recruiting to the breeding population).

The information presented here linking whales to prey stocks are entirely indirect. It is self-evident that the inclusion of data on the distribution and abundance of prey species occurring locally would be far more powerful. Most fisheries research is, by its very nature, directed towards species and areas with commercial fisheries, and therefore data are frequently not collected on the species of interest, or in a spatial or temporal pattern, that are conducive to cetacean applications. For these reasons, data on sandeel distribution and abundance on the west coast of Scotland are essentially non-existent, while data on herring stocks are only available at very large scales and are limited to offshore waters (ICES, 2006).

Even when it is not possible to sample prey directly, it may still be possible to obtain more direct information on prey consumption and shifts. For example, stable isotope studies have illustrated that changes occur in the type of prey consumed by baleen whales between seasons (S. Todd (COA), unpublished data). Studies of this type require tissue sampling programs that are not currently taking place in Scotland, except on stranded animals.

Physical and biological oceanographic features may influence cetacean movements both directly and through their prey (see Stevick *et al*., 2002). However, oceanographic data are rarely collected in a manner or on a temporal and spatial scale that make them readily applicable to cetacean studies.

The examples above all require the cooperation of those in specialised taxonomic or academic disciplines. In most cases, obtaining and analyzing these data requires equipment and expertise that most cetacean biologists do not readily have access to. Obtaining suitable data will therefore require establishing working relationships with oceanographers, fisheries researchers and other specialists, to develop studies of mutual interest and for direct sampling and analysis at these concerns. Simply accessing existing data sets will frequently not be adequate.

Working within the cetacean research community, collaboration between minke whale studies conducted in adjacent or nearby regions may help to indicate the extent of movement and perhaps identify the destination of those movements. Local changes in prey patterns may result in the movement of whales into adjacent regions, while correlations in relative abundance trends at more distant sites may indicate that large-scale changes in distribution have occurred. Data collected by dedicated HWDT surveys in waters to the north and west of the core area *and* ferry-based surveys conducted in these same waters (MacLeod, 2007), could determine if the pattern of decline extends across all of the west coast. Minke whale sightings have increased in the outer Moray Firth by approximately a factor of four from 2001 to 2005-2006 (Robinson *et al*., 2007), the same interval during which they decreased in the Inner Hebrides. This raises the possibility that minke whales formerly foraging on the west coast have shifted to foraging areas in the east.

Very large-scale surveys can identify changes in the abundance (Schweder *et al*., 1997) and distribution (Hammond *et al*., 2002; Hammond, 2007) of whales across extremely large areas. If available, they help to place local observations into a larger context. As the objective of these surveys is to obtain information on large-scale patterns, the spatial intensity of sampling is often quite course, and may not integrate well with local studies. One of the SCANS surveys covered the west coast of Scotland (Hammond, 2007), for example, while the other did not (Hammond *et al*., 2002). Thus, these shed little light on the question at hand. Additionally, such surveys are resource intensive and so are likely to be conducted at infrequent intervals. As such, they may not have the necessary temporal resolution for a given concern and distribution changes that span a few years would not be evident from these data.

Finally, data on the movements of individual animals identified in the area could support the proposed distribution shift, especially if those movement patterns were shown to change over time (e.g. Stevick *et al*., 2006). Small-scale foraging-related shifts by individual minke whales have been documented in Canadian waters using individually-distinctive natural makings (Tscherter, 2007). A long time series of identification photographs of natural markings has been collected in the Inner Hebrides as a collaborative project with HWDT and SLS. Comparisons of these photographs with those collected in other areas may contribute substantially to this work. For example, comparison of photographs with the collection from the outer Moray Firth (Baumgartner *et al.*, 2007) could be used to document any exchange of individuals that might occur between eastern and western Scotland as postulated above.

A single observation, pattern or trend in data may pose intriguing questions – even suggest potential answers – yet by itself is able to demonstrate very little. Frequently, however, such an observation is all that we are able to glean from the data we collect. This is especially likely when the observation is unexpected and therefore the study has not been designed to address it, or when the observation involves a species that is observed opportunistically during studies directed on other species. We may use these observations to refine data collection and initiate studies to address these specific matters in future. However it may also be possible that, through communication and collaboration with colleagues in other areas or disciplines, disparate datasets may combine to produce a biologically meaningful picture, thereby strengthening the support for the observation and suggesting a mechanism to explain it. Actual or potential relationships have been explored here between my initial observation drawn from the HWDT minke whale data and each of the other presentations made at this workshop, with potential for additional strengthening or expansion of the findings at each point. Thus, it is in the interest of all of us to investigate the linkages between projects within our own geographic areas, taxonomic specialties and academic disciplines, and especially with projects outside of them.

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9. CONCLUDING REMARKS

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Minke whales are ubiquitous in coastal waters of temperate regions and thus are a familiar sight to cetacean researchers around the globe. However, much remains unknown about the biology and ecology of the species. It may be a straightforward task to sight and recognise minke whales, but conducting directed studies on them frequently proves to be a substantial challenge. Their relatively small size, generally solitary habits, infrequent vocalizations, inconspicuous surface behaviour and often evasive behaviour towards vessels, make many of the most common cetacean research techniques difficult to apply. Even obtaining high quality photographs for identification of individuals can prove daunting. Thus they are frequently bypassed in preference for species that are more straightforward to study. As a result, minke whale biology lags behind that of many other cetacean species.

This workshop brought together representatives of a number of organisations that have overcome some of these challenges to succeed in conducting field research on minke whales. An impressive array of expertise – representing a wide array of disciplines – was demonstrated at the meeting. This diverse group comprised researchers studying many disparate aspects of minke whale biology in a number of discrete habitats across the northern hemisphere. The combined knowledge base of participants at the workshop, the advances in understanding represented, the overall calibre of the research presented and the enthusiasm for the future of this field, were both enlightening and encouraging.

Participants at the workshop considered a greater degree of communication and collaboration between research groups to be a vital initial step towards the enhancement and development of current and future studies of the species in European waters. The workshop was an opportunity to begin this process, and provided a forum for dialogue within this diverse research community. The group agreed to work towards instituting a European Minke Whale Working Group (perhaps within the ECS framework) to formalise, encourage and facilitate future minke whale studies. Additionally the Working Group could provide a vehicle for accessing and incorporating expert and applied knowledge from other relevant fields (such as oceanography, fisheries biology, avian ecology etc), as well as adopting a more integrated approach to collaboration between existing minke whale studies and those conducted on other rorqual whale species. It was therefore concluded that this Working Group should be instrumental to development of on-going and future research objectives and for interpretations of current results.

The organisers agreed that this workshop had been extremely beneficial and enthusiastically received by all parties. The organizers are extremely grateful to all of the contributors and participants for their valuable input and insightful exchange.

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