Photo-identification rate and wide-scale movement of common minke whales (*Balaenoptera acutorostrata*) in the coastal waters of Faxaflói and Skjálfandi Bays, Iceland

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ABSTRACT

Information on movement and site fidelity is important for conservation and management. Photo-ID of common minke whales (*Balaenoptera acutorostrata*) was conducted from whalewatching vessels within the coastal waters of Faxaflói (a bay on the southwest coast of Iceland) and Skjálfandi (a bay on the northeast coast) between 2007–10 and 2001–10 respectively, to examine fidelity to the sampling locations and movement between them. Images of 292 individual minke whales were obtained in Faxaflói and 61 in Skjálfandi, with an overall 'annual re-capture proportion' of 23.3% in the former and 16.4% in the latter. Most (about 80%) of the resighted animals in each bay were re-sighted in one year only. The total number of identified whales has increased in both Faxaflói and Skjálfandi Bays since 2007 and 2001 respectively, suggesting the existence of an open population in both bays. One match was found between the two bays, eight years apart; the distance was approximately 600km between southwest and northeast Iceland. This study shows the value of photo-ID studies from platforms of opportunity such as whalewatching vessels. More data are required from broader geographic areas before firm conclusions can be drawn about movements and site fidelity within Icelandic waters.

KEYWORDS: MINKE WHALE; PHOTO-ID; SITE FIDELITY; MOVEMENTS; NORTH ATLANTIC; NORTHERN HEMISPHERE; SURVEY-VESSEL; DISTRIBUTION

INTRODUCTION

The common minke whale (*Balaenoptera acutorostrata*) has a worldwide distribution, with sightings recorded in all oceans (Perrin *et al.*, 2002). In Iceland, it is the most abundant baleen whale (Borchers *et al.*, 2009; Hauksson *et al.*, 2011; Pike *et al.*, 2009a; Pike *et al.*, 2009b; Pike *et al.*, 2011).

Common minke whales are thought to follow the same general balaenopterid life history strategy of seasonal migration between summer feeding grounds and winter breeding grounds (Jonsgård, 1966; Stewart and Leatherwood, 1985; Christensen *et al.*, 1990; Víkingsson and Heide-Jørgensen, 2005). Details of the seasonal movements of these animals to and from Icelandic waters remain unclear. Common minke whale sightings in Faxaflói generally increase around the end of March and peak during the months of July and August (Bertulli, 2010; Salo, 2004). However, at least from 2009 until the 2011 winter (November to March), whalewatching tours organised on the southwest coast found that not all individuals leave the area at the end of the summer (C. Bertulli, pers. obs.).

The summer feeding areas of the bays of Faxaflói (64°24'N, 23°00'W) in the southwest and Skjálfandi (66°05'N, 17°33'W) in the northeast (hereafter Faxaflói and Skjálfandi) were chosen for whalewatching operations from small vessels because of the predictable seasonal occurrence of whales close to shore in relatively high numbers. Common minke whales are more frequently sighted on the southwest coast of Iceland, in Faxaflói, than on the northeast coast, in Skjálfandi (Pike *et al.*, 2009b). Faxaflói is about 50km long and 90km wide (Stefansson and Guðmundsson, 1978; Stéfánsson *et al.*, 1987) and is larger than Skjálfandi, which is about 25km long and extends at its base for 10km (Gíslason, 2004).

The objectives of the present study were to highlight specific findings for common minke whales on photo-ID rate, smaller scale distribution (inter-annual site fidelity) and the potential movement of individuals between Faxaflói and Skjálfandi.

MATERIAL AND METHODS

From April to September, 2007–10, effort, sightings and photo-ID data were collected in the southwestern coastal waters of Faxaflói from a whalewatching operation based in Reykjavík within a maximum of 22km off shore (Fig. 1; Table 1). Similar data from a whalewatching operation based in Husavík were collected from 2003 to 2010 in Skjálfandi from May to October (although no photo-ID data were collected in 2003). In addition, photo-ID images only were collected in 2001 and 2002.

Observations were generally conducted between the hours of 07:00 and 22:00 and distributed across all seasons, although most tours occurred during the summer. The whalewatching companies in both areas conducted morning, afternoon and evening trips lasting approximately three hours each. Cetacean sightings data were collected every day, weather permitting. Fieldwork was carried out in wind speeds of 7 ms^{-1} (13 knots) or less and Beaufort sea state of 0 to 4 (majority below 3). Observations were performed on the roof of the wheelhouse of two vessels (vessels 25–26m in length, wheelhouse 6–8m above sea level) in Faxaflói and

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three within Skjálfandi (vessels 20–25m in length, wheelhouse 2–5m). One to a maximum of four observers, usually the principle investigator and three assistants, were stationed to watch 360° around the survey vessel in Faxaflói. In Skjálfandi, surveys were conducted by one or two investigator teams at a time, with a total of six different investigators being involved on rotation in data collection.

Standardised data forms were used to record the vessel position every 5min (Global Positioning System, *Garmin 60CSx*) and environmental data (Beaufort sea state, swell, and visibility) at 15min intervals. Survey effort was determined by calculating the time spent in actively searching for whales during each survey. Encounter duration was ultimately dependant on the captain's decision to stay with the animals or leave the area (adapted from Gill *et al.*, 2000).

In order to obtain an unbiased estimation of the number of animals with re-identifiable marks in each mark class, whales were photographed without making any distinction of their mark status (Currey *et al.*, 2008; Gormley *et al.*, 2005; Williams *et al.*, 1993). A range of digital cameras were used with zoom lenses ranging from 55–200mm to 70–300mm (Faxaflói) and from 28–135mm to 40–150mm (Skjálfandi). All images were viewed using Adobe *Photoshop CS2/CS3* imaging software. Photos were graded for closeness and sharpness, only photographs accorded as good and average quality were used in the analyses (Bertulli *et al.*, 2012; Van Bressem and Gaspar, 2003). Identification to individuals was undertaken using the classification system developed by Tscherter and Morris (2005). Initial sorting of acceptable quality photographs involved searching for the presence of indentations or 'nicks' on the dorsal fin, usually on the trailing edge; these are known as dorsal fin edge marks or DEMs. The position of these markings on the fin was further compared with the general fin shape and any additional body marks and scars to further reduce the likelihood that two different whales were identified as one. If no nicks were obvious from the photographs, individuals were classified using remaining distinctive fin shapes and body marks where available.

The following analyses were carried out:

(1) estimation of minimum relative abundance based on identified individuals;

(2) estimation of the 'interannual resighting proportion', i.e. the proportion of individual whales identified in more than one year among all years of study; and

(3) the matching of individual whales between the two study areas.

A 're-sighting proportion' is defined as the number of animals re-sighted in both bays divided by the total number of individuals identified in them.

The total distance between bays of the re-sighted minke whale identified in the analysis was determined using the 'ruler' tool provided by *Garmin MapSource* (version 6.14) as the direct route by sea (avoiding land) between Reykjavik and Húsavík.

RESULTS

Common minke whale sightings

During the study period, minke whales were observed on 760 (75.8%) days in both study areas (Table 1), with a total of 1,333 sightings in Faxaflói and 994 in Skjálfandi. Within Faxaflói, the majority of photographed individuals were west of Kollafjörður (a branch of Faxaflói incorporating only the most northeastern part of Kolla bay is named this way), whilst in Skjálfandi, whales were normally captured within the coastal zone of the bay (Fig. 1).

Data relative to monthly and total mean survey effort show that the months with most effort for all years were June, July and August in Faxaflói, and May, June and July in Skjálfandi (Table 1).

Minimum relative abundance and identification rate

A total of 292 individuals were identified in Faxaflói and 61 in Skjálfandi, with just over half from both Faxaflói (54.5%, n = 159) and Skjálfandi (55.7%, n = 34) identified by the presence of DEMs.

The 'discovery curve' (Fig. 2) using either cumulative numbers of all mark class individuals or only those with DEMs from one year to the next is large and characterised by sharper increases in Faxaflói than in Skjálfandi Bay.

Site fidelity

The estimated annual resighting proportion for Faxaflói between April and September 2007 to 2010 was 23.3% (i.e. 68 animals resighted at least once between years out of the 292 identified there over the whole period). Thus over three-quarters of identified whales were observed only in a single year (n = 224, 76.7%). Of those resighted, 53 individuals were observed in two of the years (18.2%), nine were observed in three years (3.1%) and six were observed in four years (2.1%). In Skjálfandi, the annual resighting proportion was 16.4% between 2001 and 2010 (no photo-ID effort in 2003). Again therefore the vast majority (83.6%, n = 51) were seen only in a single year, followed by individuals observed in two years (6.6%, n = 4) and six in three or more years (9.8%, n = 6). See Table 2.

Resightings between Faxaflói and Skjálfandi

Resightings within Faxaflói and Skjálfandi were relatively uncommon and in fact there was only one animal (DEM162 in Faxaflói, DEM24 in Skjálfandi) of the total number of 353 individuals from both catalogues that was sighted in both areas, i.e. 0.3%. This individual was first photographed on 16 July 2002 in Skjálfandi and re-sighted in Faxaflói Bay on 29 April 2010, then photographed again on 10 August 2011 in Skjálfandi, on 5 May 2012 in Faxaflói and on 6 July 2012 in Skjálfandi (the latter showing intra-annual movement between bays). The mark on the trailing edge of the dorsal fin and a large scar on the back were both used to identify this individual in both areas (Fig. 3).

DISCUSSION

In conducting cetacean research, photo-identification is an effective technique (e.g. Hammond *et al.*, 1990; Whitehead *et al.*, 2000). Common minke whales, although considered more difficult than some of the other baleen whale species such as the humpback, blue and right whales, have been successfully studied and photo-identified since 1980 (Anderwald, 2009; Dorsey, 1983; Dorsey *et al.*, 1990; Gill

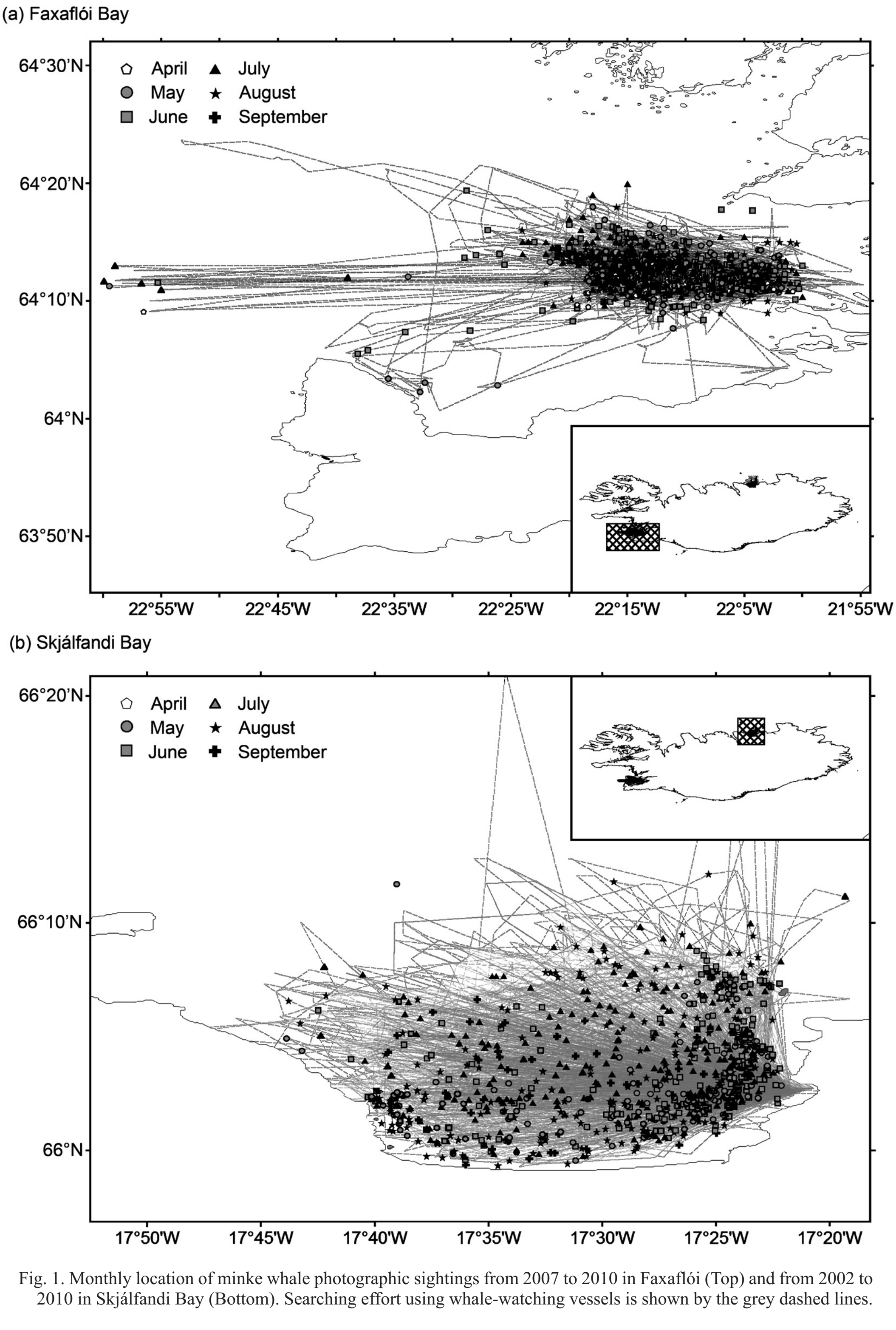

Fig. 1. Monthly location of minke whale photographic sightings from 2007 to 2010 in Faxaflói (Top) and from 2002 to 2010 in Skjálfandi Bay (Bottom). Searching effort using whale-watching vessels is shown by the grey dashed lines.

et al., 2000; Stern *et al.*, 1990; Tscherter and Morris, 2005). The present study is consistent with several previous studies in which the successful identification of individuals was based upon the presence of large and small DEMs. Body scars such as lesions, anthropogenic scars and marks supposedly left by parasites are thought to be less reliable than DEMs in recapturing individuals, except in the San Juan Islands and Monterey Bay, California (Dorsey, 1983; Dorsey *et al.*, 1990; Stern *et al.*, 1990), although they can be used to sustain a possible re-match (Anderwald, 2009; Baumgartner, 2008).

In fact, the percentage of individuals (just over 50%) identified by distinctive large or small DEMs seen in this study off Iceland is similar to values found in the San Juan Islands on the western coast of the USA (40.0%) by Dorsey *et al.* (1990) and around the Isle of Mull in Scotland (50%) by Gill *et al.* (2000). Some individuals photographed in Iceland had the potential to be identifiable due to their distinct dorsal fin shape, as in the Small Isles in Scotland (Anderwald, 2009). However, practical considerations render this feature difficult to use to support reliable re-matches except with excellent photographs from the correct angle;

Table 1

The survey effort for minke whale surveys conducted in (a) Faxaflói Bay between March and November 2007 to 2010 and in (b) Skjálfandi Bay between May and October 2003 to 2010 (no effort or sighting data were available for the years 2001 and 2002).

Study period	Survey effort (days)	Survey effort (trips)	Survey effort (hours)	Observation (days)	Observation (trips)	Observation (hours)
(a) Faxaflói Bay						
2007	77	167	310.56	73	145	284.58
2008	104	203	372.29	72	144	260.35
2009	86	178	350.46	82	157	305.37
2010	84	150	254.01	83	147	243.46
Total	351	699	1,288.20	310	594	1,094.56
(b) Skjálfandi Bay						
2003	48	51	156.03	45	48	142.57
2004	28	28	99.21	25	25	74.43
2005	71	75	192.17	47	49	128.31
2006	79	84	198.48	53	55	136.29
2007	105	105	257.31	59	59	149.27
2008	103	110	280.28	55	59	148.06
2009	103	132	286.11	61	80	191.03
2010	115	181	353.37	105	141	335.03
Total	652	766	1,803.23	450	516	1,306.19

photographs taken from the high platforms of whalewatching boats often resulted in distorted dorsal fin shapes. In the present study, dorsal fin shape without DEMs was used only for 14.7% ($n = 10$) resightings in Faxaflói. It is important to recognise that the value of a morphological characteristic depends on the platform used to approach and photograph the whale. To reduce the occurrence of false positives, only photographs of good quality, capturing the dorsal fin perfectly perpendicular to the body axis are considered and then only for particular types of analysis (e.g. Stevick *et al.*, 2001). Similarly, where individuals can be identified using only their body marks, re-identification will be possible only on photographs of the same side of the animal (animals photographed from only one side may be already in a catalogue photographed from the other side); if such features are to be used, analyses must be undertaken on datasets of only identifications from the same side (e.g. Hammond, 1986; IWC, 1990). The best traits for reliable re-identification of individuals therefore are DEMs. These nicks, notches or indentations can be identified even if only one side of the whale is photographed. Ultimately, however, what is the most appropriate dataset to use is dependent on the nature of the analyses proposed and the assumptions involved in those analyses.

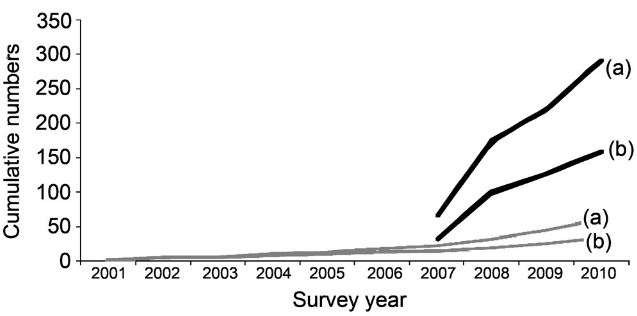

Fig. 2. Identification rate of minke whales along the southwest and northeast coasts of Iceland. The discovery curve is established by plotting the cumulative number of newly identified and catalogued minke whales each year, in (1) Faxaflói Bay from 2007 to 2010 (black line) and (2) in Skjálfandi Bay from 2001 to 2010 (grey line) inclusive. (a) Cumulative number of all classes individuals (b) Cumulative number of marked (DEM) individuals.

Minimum abundance and photographic rate

The number of photo-identified individuals in the present study areas is rising steadily (Fig. 2) which suggests that new whales may be entering these areas although more photographic effort needs to be spent in order to achieve saturation level for the population as is shown by the nature of the non-asymptotic discovery curve (Karczmarski *et al.*, 1999). The rate of discovery of newly identified common minke whales and the shape of the curve could suggest an open population in both bays (Karczmarski *et al.*, 1999; Straley *et al.*, 2009), although more data and analysis on seasonal immigration and emigration as well as sighting frequencies are required to investigate this further.

Table 2

Distribution of annual re-sighting proportions between years for all minke whales identified in (a) Faxaflói and (b) Skjálfandi Bays.

Survey year	No. animals re-sighted	No. years animals were re-sighted
(a) Faxaflói Bay		
2007-2008	8	2
2008-2009	24	2
2009-2010	12	2
2007-2009	1	2
2008-2010	6	2
2007-2010	2	2
2008-2009-2010	3	3
2007-2008-2009	1	3
2007-2009-2010	2	3
2007-2008-2010	3	3
2007-2008-2009-2010	6	4
Total	68	
(b) Skjálfandi Bay		
2006-2008	1	2
2006-2010	1	2
2007-2008	1	2
2008-2009	1	2
2002-2009-2010	1	3
2004-2008-2010	1	3
2008-2009-2010	1	3
2006-2008-2009-2010	1	4
2002-2006-2007-2009-2010	1	5
2005-2007-2008-2009-2010	1	5
Total	10	

Fig. 3. Photograph of a minke whale (DEM24) sighted first in Skjálfandi Bay in July 2002, re-sighted in Faxaflói Bay (DEM162) in April 2010. Photographs by kind permission of Húsavík Whale Museum, Chiara G. Bertulli/Faxaflói Cetacean Research respectively.

At present, a crude minimum estimate of identifiable animals (i.e. those with distinctive characters) for the two study areas is just over 350 over the study period – this does not take into account births/deaths or immigration/emigration, the level of effort, the size of the study and the fact that not all whales are identifiable. With additional data it should be possible to undertake quantitative mark-recapture analyses to obtain abundance estimates of the number of identifiable animals that use the study areas. Information from aerial surveys reveals that the whales' distribution is much larger than the present study areas. For example, the study area within Faxaflói represents only a small part of Faxaflói, which according to previous sighting surveys exhibits a uniform distribution of minke whales and peak abundances of up to seven thousand animals (7,678, 95% Cl: 4,984 to 11,830) in the summer (stratum 1 of table 2 in Borchers *et al.*, 2009). Aerial survey results also confirm our general findings that more common minke whales use Faxaflói than Skjálfandi (Pike *et al.*, 2009b).

Several factors influence the number of individual photo-ID and re-sighting rates. These include the behaviour of individuals and levels of site fidelity, the general occurrence of identifiable animals within a population and changes in methods (Wedekin *et al.*, 2010). For example, the sampling area for both studies has generally been constant but the use of digital cameras since 2005 has made it easier to obtain good photographs which may contribute to the increased number of photo-IDs in Skjálfandi Bay.

Site fidelity

Low inter-annual resighting proportions were observed in both areas (Faxaflói: 23.3%, Skjálfandi: 16.4%) although a higher proportion of identified individuals was re-sighted in three years or more of study in Skjálfandi (9.8%) than in Faxaflói (5.1%). These results differ from observations made in other feeding grounds such as the Isle of Mull (Scotland) where 35% (n = 30) of all individuals (n = 66) were sighted in more than one year (Gill *et al.*, 2000) or Québec (66%, n = 115) if only annual re-sightings of DEMs are considered (Morris and Tscherter, 2005). In Scotland, certain whales were observed returning to the same areas at precisely the same time each year (Gill *et al.*, 2000). Dorsey *et al.* (1990) reported some seasonal residency and site fidelity in parts of the eastern North Pacific.

Determining whether site fidelity is present or not from the present dataset requires knowledge of the temporal and geographical scale of the site fidelity and the representativeness (and relative size) of the identified whales to the full population(s). The opportunistic nature of the study and the use of platforms of opportunity inevitably limits the ability of the study to draw firm conclusions on site fidelity. For example, the area of Faxaflói surveyed represents only a small part of the whole bay, which systematic aerial surveys have revealed to have a relatively uniform distribution of common minke whales with a peak season abundance of up to seven thousand animals (7,678, 95% Cl: 4,984 to 11,830) in the summer (stratum 1 of table 2 in Borchers *et al.*, 2009). The distribution of whales on their feeding grounds is related to the distribution and abundance of their prey.

Photo-ID is an important tool in addressing questions of site fidelity but further information is required before this question can be resolved for common minke whales off Iceland.

Overlap with the Skjálfandi minke whale population

Comparison of the Faxaflói Cetacean Research and the Húsavík photo-ID catalogues, resulted in one rematch: this is the first documented movement (of approximately 600km from southwest to northeast after eight years) of a common minke whale along the Icelandic coastline using photo-ID. No photo-identification studies occurred on the east and west coasts of Iceland during this period. Such surveys are necessary if information on travelling routes within Icelandic waters is to be obtained from photo-identification studies.

The lack of matches between Faxaflói and Skjálfandi between 2001 and 2010 suggests that most identified whales exhibit some degree of site fidelity to these areas but without more extensive and intense effort it is important not to over-interpret the data. In addition there are no photo-ID data prior to the year 2007 in the south or 2001 in the north which again limits the available comparisons. The one match between areas shows that whales can move from southwest to north. Movements between areas within (and outside) Iceland are evident from the distribution and density data from aerial surveys (Pike *et al.*, 2009b). It is also true that present levels of effort would not be able to detect subtle changes in density/abundance between the regions.

Food shortages in the southwest area, notably due to a severe decline in sandeels (*Ammodytes* sp.) since 2005 have been proposed to have affected whales and seabird colonies in the south area (Bogason and Lilliendahl, 2009; Víkingsson and Elvarsson, 2010) and there is evidence of increased water temperatures and salinity in the north and south of Iceland in recent years (Astthórsson *et al.*, 2007). Additional research investigating minke whale spatio-temporal habitat use will assist in the determination of potential underlying environmental drivers. Detailed sightings data within and amongst seasons such as those collected here may form a valuable component of spatial modelling exercises to examine the factors governing common minke whale distribution in Icelandic waters. Of course, this will require information from all around Iceland as well as better information on seasonal and inter-annual density changes such as that being obtained from aerial surveys (Pike *et al.*, 2009b).

This study has shown the importance of using whalewatching vessels to collect information of value to understanding the biology and distribution of common minke whales around Iceland as well as to conservation and management efforts. All companies should be encouraged to participate in such efforts.

The low level of re-sightings in both Faxaflói and Skjálfandi suggests that the present level of whalewatching in those areas is not be focussing excessively on the same individuals which may have possible short- and long-term negative effects on the animals. Occurrence marks of anthropogenic origin (e.g. propeller or net entanglement) have been reported on the skin of common minke whales in a recent photographic study (Bertulli *et al.*, 2012) of skin disorders, parasites and epizoa among common minke whales from Iceland. However, individuals that travel long distances (which may be more the case if there is little site fidelity) may have an increased risk of encountering and becoming entangled in fishing gear or being struck by boats.

This study has shown the value of photo-ID work on common minke whales in Iceland. However, it is clear that in order to better understand the distribution and movements of minke whales in Icelandic coastal waters an expanded geographical and temporal extent is required. Such studies, in conjunction with distribution and abundance surveys and efforts to undertake spatial modelling will contribute towards the knowledge base for the scientific community and for the whalewatching operators in the area and assist in evaluating the effectiveness of existing management actions.

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