Final report for a cetacean research project in Iceland conducted from R/V *Song of the Whale* July to September 2012

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EXECUTIVE SUMMARY

Research was conducted from research vessel *Song of the Whale* (SOTW) in Iceland between 29th July and 28th September 2012. A total of 3,320 km (380 hours) of research effort was completed in Icelandic waters over the six week period. The majority of this time was spent investigating the behaviour of minke whales in Faxaflói including in the presence of whale watching vessels. Between 12th and 30th August the Song of the Whale team recorded the surface behaviour of minke whales using video range tracking techniques. During this period, 57 individual minke whales were tracked with over 70 hours of associated behavioural data. Individual whales were tracked from periods of 17 minutes to over 6 hours with at least eight of the tracks following individuals while whale watch vessels were present. A more comprehensive analysis of this dataset is still underway as of August 2013. During two offshore trips to deploy and retrieve an EAR (Ecological Acoustic Recorder) in collaboration with the University of Iceland, a total of 25 sightings were made of five species of cetacean, namely harbour porpoise, minke whales, pilot whales, white-beaked dolphins and fin whales. Harbour porpoises were additionally detected acoustically in the shallow shelf waters of Iceland out to the deeper waters to the south. There were only two acoustic detections of baleen whales in Icelandic waters. On 24th August, efforts were made to measure the acoustic output of the four main whale watching vessels operating in Faxaflói and a total of 24 separate passes were measured at a variety of speeds. Noise levels were lowest at speeds typical of vessels operating close to whales (127 dB re 1 µPa, 1/3-octave analysis from20 Hz to 20 kHz); however, levels during bursts of acceleration (136 dB) and typical searching speed (141 dB) were up to 20 dB higher.

1. INTRODUCTION

The International Fund for Animal Welfare (IFAW) has had a long-running interest in whale research in Iceland including support of responsible whale watching activities and conducting research from the R/V *Song of the Whale* (SOTW). IFAW first conducted a feasibility study for whale watching in Iceland in 1990. The SOTW and team has undertaken research projects in Iceland on three occasions in the last decade (2004, 2006 and 2012), which in addition to providing data on whales and their vocalisations around Iceland, have utilised non-invasive research techniques, provided internships for Icelandic students, and established collaborations with researchers at the University of Iceland, sharing data on cetacean presence, distribution and vocalisations.

The aims of the SOTW research activities in summer 2012 were twofold: firstly, to conduct a research passage in Icelandic offshore waters searching for baleen whales, primarily blue whales, and to deploy an Ecological Acoustic Recorder (EAR) for the University of Iceland. Secondly, the team carried out inshore visual behavioural tracking of minke whales (*Balaenoptera acutorostrata*) in Faxaflói, working closely with a PhD student from the University of Aberdeen and University of Iceland. Visual and acoustic data were also collected en route from Iceland to the UK in September.

1.1 Blue whales

Blue whales (*Balaenoptera musculus)* are thought to undertake extensive seasonal migrations within the Atlantic between low latitude wintering grounds, where mating and calving occurs, and high latitude summer feeding grounds such as the waters around Iceland (Clapham *et al*., 1999). Blue whales are most abundant in Icelandic waters in summer months (May to July) when they are often seen inshore in continental shelf waters to the west of Iceland (Pike *et al.,* 2009, Víkingsson *et al*., 2002) before moving further offshore to feed.

Baleen whales are known to produce numerous types of low frequency vocalisations, mostly below 50 Hz (*e.g.*, Boisseau *et al*., 2008; Cummings *et al*., 1986; Edds, 1988; McDonald *et al*., 2001; Thompson *et al*., 1996). There is limited knowledge on baleen whale vocalisations in the Atlantic but increasing evidence suggests that song patterns from blue whales can be used to distinguish between populations (McDonald *et al*., 2006). Efforts to describe the vocalisations of baleen whales therefore are particularly important from a conservation and management perspective.

A PhD student at the University of Iceland has been studying blue whale vocalisations during the last few years using EARs to record blue whale vocalisations from Húsavík Bay. Plans to record blue whales further offshore were realised this summer when the SOTW team offered to assist with the deployment of an EAR in Icelandic waters in the Denmark Strait (between Iceland and Greenland).

1.2 Minke whales

Fredrik Christensen (a PhD student from the Universities of Aberdeen and Iceland) has been studying minke whales in Faxaflói for the last three years, from both land based sites and from whale watch vessels. His recent findings, presented to the IWC Scientific Committee in 2011 (Christensen *et al*., 2011 SC/63/WW2), reported behavioural changes in minke whales in the presence of whale watch vessels – specifically changes in swimming speeds and foraging activities. The IWC SC discussed these findings and made some suggestions to improve the study. IFAW has supported the development of responsible whale watching in Iceland for many years, and so it was felt that additional research from an independent platform (such as SOTW) could help provide useful additional data to investigate whether whale watching activities are having an impact on minke whales in this area. The SOTW team hosted Fredrik on board to continue his research and to undertake data collection independently. During this study, IFAW's video range tracking technique was used to provide additional insights into minke whale behaviour.

1.3 Vessel noise

The aim of this study was to measure the acoustic signatures of the main whale watch vessels operating in Faxaflói over a range of cruising conditions including typical search speeds, bursts of acceleration and 'with animal' speeds. It is hoped the results from these measurements may identify steps that could be taken to reduce noise output.

1.5 Aims

The aims of the project with SOTW for summer 2012 in Iceland were to:

• Support the University of Iceland in their cetacean research by assisting with the deployment of an Ecological Acoustic Recorder (EAR) in offshore waters.
• Gather behavioural data on minke whales in Faxaflói, both in the presence of whale watch vessels and without vessels.
• Collect calibrated noise profile data for all whale-watching vessels operating out of Reykjavik.

2. METHODOLOGY

R/V *Song of the Whale* arrived in Reykjavik, Iceland on the 29th July 2012 after a research passage from Boston, USA. *Song of the Whale* is a 21 metre auxiliary-powered cutter-rigged sailing research vessel, owned by the International Fund for Animal Welfare and operated by Marine Conservation Research Ltd (MCR Ltd). The SOTW team spent six weeks in Iceland, leaving on the 20th September for the UK. A variety of research was undertaken while in Iceland ranging from offshore acoustic research to visual-based work within Faxaflói (Figure 1).

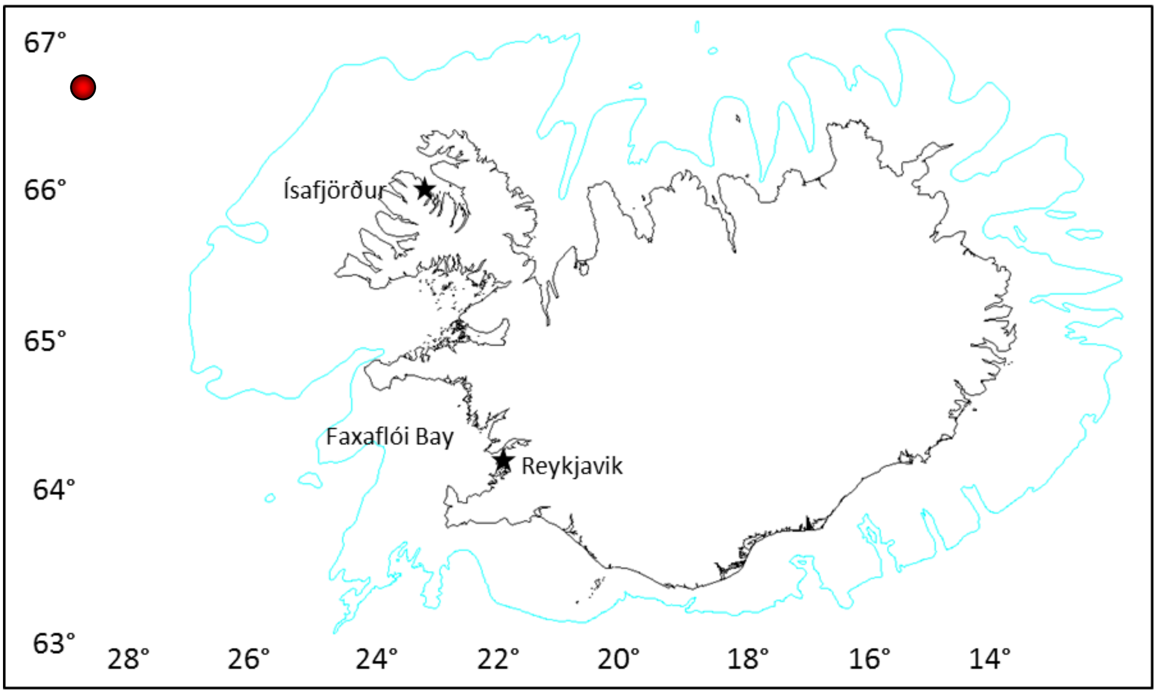

Figure 1. Map of Iceland showing Faxaflói and the offshore waters northwest of Ísafjörður where SOTW planned to deploy the EAR. The blue line illustrates the 200m depth contour; red circle represents site of EAR deployment.

2.1 Offshore research cruise data collection

Two offshore research cruises were conducted under sail, motor or motor/sail at a speed between a minimum of 5 knots (to stream hydrophones) and a maximum of 8 knots (to reduce cable strum and keep the arrays at depth). During daylight hours and in sea states below four, two visual observers with binoculars were positioned on a sighting platform that provided an eye height of 5.5 m above sea level. Observers were prompted by acoustic cues and/or deck observers. In higher sea states, observers kept a lookout from deck. Sightings were logged to a database via the Logger software (IFAW). Environmental, GPS and heading sensor data were logged automatically to the same database, including date, time, vessel position (lat-long), sea surface temperature (°C) and wind speed (knots). Manual records of other environmental variables (such as sea state, wave and swell height) and survey effort (numbers and positions of observers) were made hourly.

Acoustic sampling was primarily conducted using 400 m towed two-element hydrophone arrays; one with broadband elements, the other with low frequency elements. Continuous stereo recordings were made at sampling rates of both 8 kHz and 500 kHz via bespoke buffer boxes passing signals to an NI-6251 and NI-6356 data acquisition cards respectively. The 8 kHz recording system also incorporated a Behringer Ultracurve DEQ2496 to introduce a 4 kHz low-pass filter prior to signal digitisation in order to prevent aliasing. The buffer boxes provided variable frequency responses; however, the entire system was capable of detecting signals from 10 Hz to 200 kHz. For the bandwidths of interest for baleen whale vocalisations (10 to 8000 Hz) and beaked whale and harbour porpoise clicks (25 to 50 kHz and 100 to 150 kHz respectively), the response of the system was approximately flat. Recordings were made using Pamguard (www.pamguard.org) and written to disk as two-channel 16-bit wav files. The click detection software RainbowClick (IFAW) was run continuously to log odontocete click trains in the audio range (2 to 24 kHz); whistle detection software (IFAW) was also run to detect frequency modulated calls produced by odontocetes in real-time as well as several modules in Pamguard.

When priority species such as blue, fin, beaked or North Atlantic right whale were sighted the aim was to obtain photo identification images of each animal. For each species markings at different areas of the body were used for identification purposes (Table 1).

Table 1. Key features for individual photo-identification.

Species	ID feature(s) for photographic identification
Blue whale	Skin mottling on sides including the dorsal fin as a reference point
Fin whale	White chevron marking on front right side of animal & dorsal fin
North Atlantic right whale	Callosities (white growths) on head as well as any scars
Beaked whales	Dorsal fin, beak and head (for species ID) and any scars or markings

2.2 Ecological Acoustic Recorder (EAR)

The EAR was deployed in offshore Icelandic waters between Greenland and Iceland, off Ísafjörður (Figure 1). SOTW departed from Reykjavik and searched for baleen whales en route to the deployment location. The EAR was deployed in an area known to have low fishing effort. Several transect lines were undertaken in search of baleen whales on the way back to Faxaflói .The EAR consisted of a hydrophone, float, battery and recording device which was anchored to the seabed with a biodegradable hessian sack filled with gravel. The EAR held two acoustic releases which when activated will detach the EAR and float from the anchor, allowing it to float to the surface for retrieval.

2.3 Behavioural tracking of Minke Whales in Faxaflói

Between 12th and 30th August, the SOTW team worked within Faxaflói to visually track and record the surface behaviour of individual minke whales using Video Range Tracking (VRT) techniques (Leaper & Gordon, 2001). Baseline behavioural data were collected in the presence and absence of whale-watch vessels. As such, exposure and control samples were obtained. VRT methods are proficient for measuring accurate distance and angles to a surfacing animal. This ensures that an accurate plot of the whale's movements in relation to the boat's track can be generated. Given that the absolute position of R/V *Song of the Whale* every second is known from GPS, the relative positions of other objects such as whales (by recording ranges and bearings) and ships (from AIS) can be compared.

An observer was situated at each side of the A-frame platform with a pair of 7 x 50 binoculars and a small Panasonic HDC-SD90 video camera (with three second pre-record buffer), both mounted on a monopod. On the first whale sighting of each surfacing event, the observer pressed record while aiming the binoculars at the animal, ensuring that both the target animal and the horizon were in frame. A running commentary by the observer was recorded to video in order to log the reticle reading from binoculars, the direction of travel of the whale, number of animals and type of surfacing (*e.g.*, flat surfacing, arched surfacing, lunge, fast swim). This information was collected for each surfacing event and the video was left on constant record while the whale was at or close to the surface.

In order to measure accurate distances for each surfacing, separate sequential images of each surfacing with the animal and the horizon in the image were extracted post-process. Using the observer's eye height above sea level, the radial distance can be calculated to the animal from measurements of the angle of dip from the horizon to the whale.

Four downward facing open dome CCTV cameras with 3.6 mm focal length lenses giving an approximately 45^{o} field of view were mounted above the A-frame to capture images of the observers as they directed their binoculars towards the focal animal. From a line running along the top of each binocular, angles to the animal, relative to the boat, were calculated (Figure 2).

Figure 2. CCTV image from the starboard camera showing the orientation of an observer's binoculars in relation to the vessel.

Each relative bearing from SOTW was converted to a true bearing using the vessel's true heading recorded by Logger from a Simrad HS70 GPS Compass.

2.4 Ship noise measurements

Ship noise measurements were taken for each of the whale watching vessels operating out of Reykjavik. Each of the vessels assisted with the data collection by passing by the anchored R/V *Song of the Whale* within 200 metres at different speeds as requested. Measurements of ship noise were made using a calibrated omni-directional RESON TC4032 hydrophone with a flat frequency response of within ±2.5 dB between 10 Hz and 80 kHz. The hydrophone was deployed using a running mooring to allow more weight to be attached to the system (Figure 3). Signals were digitised with a sound-acquisition device (National Instruments USB-6251) sampling at 96 kHz with 16 bit resolution (± 1 volt scaling).

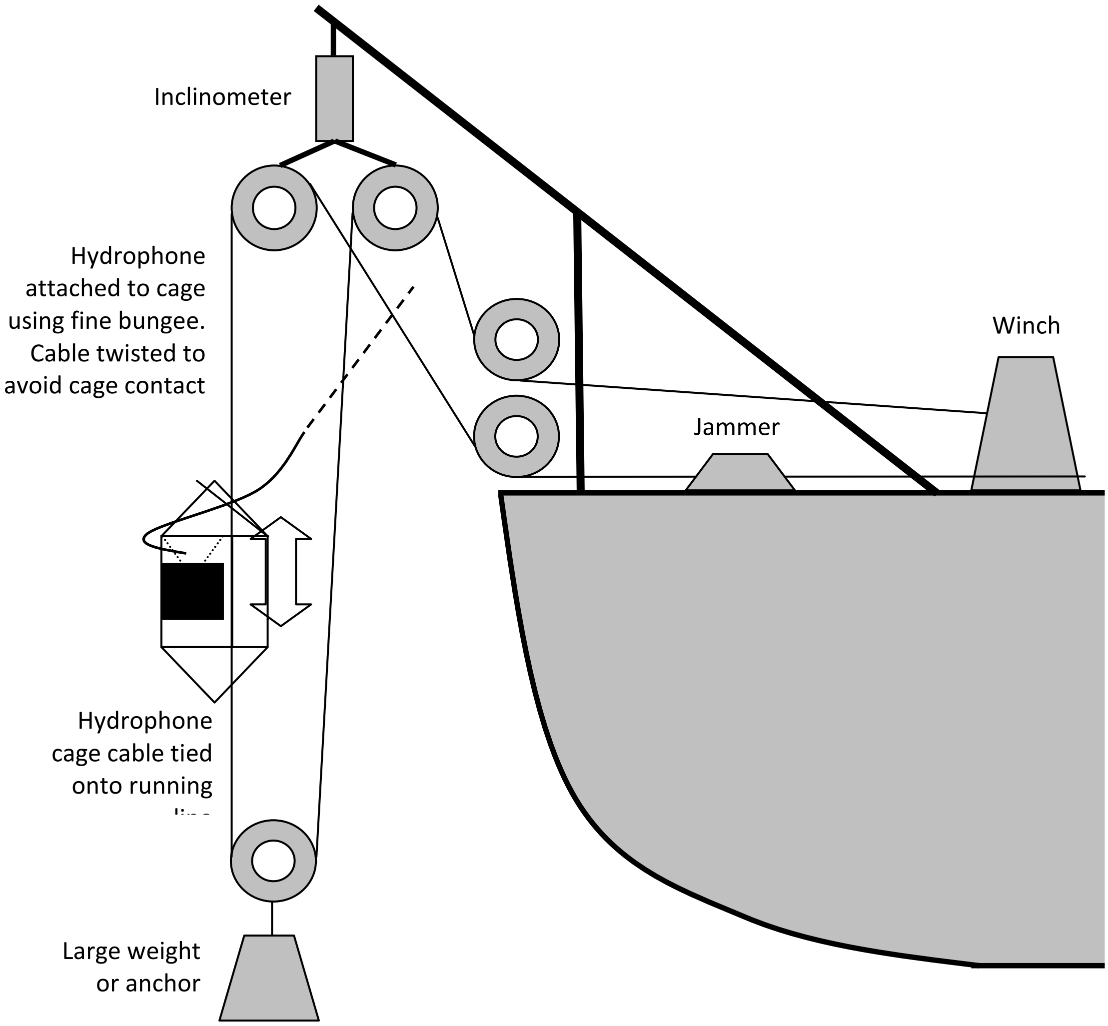

Figure 3. Deployment configuration of a calibrated hydrophone from Song of the Whale using a vertical running mooring. A continuous running line through a series of blocks allowed the depth of hydrophone deployment to be adjusted using the winch.

During recording, *Song of the Whale* was at anchor with the engine off; the depth sounder and all unused electrical equipment were powered down. Approximately 20 m of hydrophone cable was deployed vertically from aft davits using the weight system. The location of the hydrophone was taken from onboard GPS. Communications were maintained between the SOTW and each whale watch vessel throughout the recording period, primarily to ask them to pass as close to 200 m as safely possible but also to collect information regarding the target vessel's operational state.

Background noise measurements were recorded, for at least two minutes before and after each vessel measurement where possible, when the target vessel was >5 nm away from the recording elements. AIS details of all vessels in the area were continually logged. High pass filters were positioned at their lowest settings (*i.e.* 1 Hz). Supplementary AIS information was collected for each target vessel including: speed over ground, heading over ground, direction of longitudinal axis and length and breadth of the vessel. This information was supplemented by post survey information from the whale-watch companies including: year of construction, main engine type and power, number of shafts, number of propeller blades and tonnage.

Local environmental information was collected including: depth, wave and wind direction, wind speed and precipitation. Contact with the bridge of a target ship was established by the team on R/V *Song of the Whale* and thus attempts were made to maintain the Closest Point of Approach (CPA) between the hydrophone and the target ship at 200 m. The target ship was asked to maintain a straight course. When recording a target vessel, measurements were first made when the bow was within two boat lengths of the CPA; final measurements were taken when the stern was two boat lengths from the CPA. Recordings were continuous throughout the procedure but were truncated to just four lengths of the target vessel post-survey.

Repeat measurements of each whale watch vessel were made at cruising speed and speeds at which they manoeuvre around the animals. Additionally, opportunistic measurements were made of other vessels within Faxaflói. During post-survey analysis, a target vessel's noise signature was estimated allowing for background noise and propagation loss due to distance normalisation. Analysis was conducted using narrow band (0.73 Hz) resolution between 20 Hz and 2 kHz and third octave band analysis between 20 Hz and 20 kHz. Absolute noise levels were derived using the RESON hydrophone's calibration values (accurate at the point of manufacture in May 2011) and knowledge of the recording system's gain settings (namely 0 dB gain with ± 1 volt scaling). Background noise was measured for at least 120 s by the same recording system when the target ship was a considerable distance from the hydrophone. Underwater sound pressure levels from the target ship L_p were calculated using the following equation:

$$L_p = 10\ log\ (10^{(L_{pm}/10)} - 10^{(L_{pn}/10)})$$

Where,

$_{pm}$: Measured pressure in µPa using $10^{(L_{pm}/20)}$

$_{pn}$: Background pressure in µPa using $10^{(L_{pn}/20)}$

L_p: Underwater sound pressure level (dB ref 1 µPa) of the target ship after background noise adjustment

L_{pm}: Underwater sound pressure level (dB ref 1 µPa) including background noise obtained at measurement for the target ship

L_{pn}: Background noise pressure level (dB ref 1µPa)

Measurement of the noise output of a target vessel was started when the aft end of the target ship was within two boat lengths of the CPA and terminated when the aft end of the target ship was more than two boat lengths from the CPA. Noise levels were quantified as the RMS average within every frequency band during this period. Distance normalization of the underwater sound levels of a target ship L_{pdn} was calculated according to the following equation, assuming the propagation environment to be shallow-water giving cylindrical spreading:

$$L_{pdn} = L_p + 10 \log (D_i / D_0)$$

Where,

D_1 is the distance between the vessel and the hydrophone.

D_0 is the reference distance of 1 m.

The propagation loss assumptions were investigated by taking a number of measurements of vessels at greater ranges and comparing received levels with distance.

2.5 Whale-watching vessel speeds in relation to minke whales

Using VRT analysis of minke whales, coupled with AIS data for whale-watch vessels, analysis was undertaken to characterise the speed of whale-watch vessels at known distances from tracked minke whales. AIS data for three whale-watch vessels were selected for those time periods for which unbroken minke whale tracking data were obtained. AIS data were acquired during 30 minutes prior to and 30 minutes after whale watch vessels were deemed to have 'encountered' a minke whale that was being tracked. An encounter was defined as a vessel approaching to within 4 km of a minke whale that was being tracked by VRT. Vessel speeds before and after encounters were considered in order to determine cruising speeds of the respective vessels.

Vessel speeds were analysed for all vessels together, in 100 m bins. The vessel heading data were used to define when a vessel was heading back to port using vessel heading density plots. Importantly, all vessels were based at the same port and would therefore have similar headings when returning to port, assuming that they were viewing whales in the same area (*i.e.,* in the same area as SOTW). Kruskal-Wallis tests were used to check for differences in median vessel speed at different states (*i.e.,* 'returning to port', or 'other').

3. RESULTS

A total of 3,320 km (380 hours) of research effort was completed in Icelandic waters over the six week period (Table 2). The majority of this effort was within Faxaflói near Reykjavik, conducting behavioural tracking of minke whales; however two short offshore surveys were also conducted.

Table 2. Summary of research effort from 30th July to 20th September 2012.

Effort status	Nautical miles	Kilometres	Time (hh:mm)
Passage	291	539	55:31
Passage + acoustic	291	539	98:38
Passage + visual	80	147	16:43
Passage + acoustic + visual	197	366	29:55

Survey	16	30	02:21
Survey + Acoustic	17	32	02:33
Survey + Visual	266	492	44:20
Survey+ Acoustic + Visual	104	192	17:23
With Animals	230	426	87:07
Other	24	44	25:24
Total track	1793	3320	379:58

3.1 Sightings

Logging of all sightings occurred during offshore research trips. During the EAR deployment SOTW undertook a four day research passage to offshore waters between Iceland and Greenland to deploy the EAR. A total of 25 sightings were made of five species of cetacean, namely harbour porpoise, minke whales, pilot whales, white-beaked dolphins and fin whales (Figure 4). All of the encounters with the harbour porpoise and minke whales were of solitary animals; in contrast, the encounters with pilot whales, white-beaked dolphins and fin whales, were of several animals. It is important to note there were two full days of fog which curtailed sighting effort.

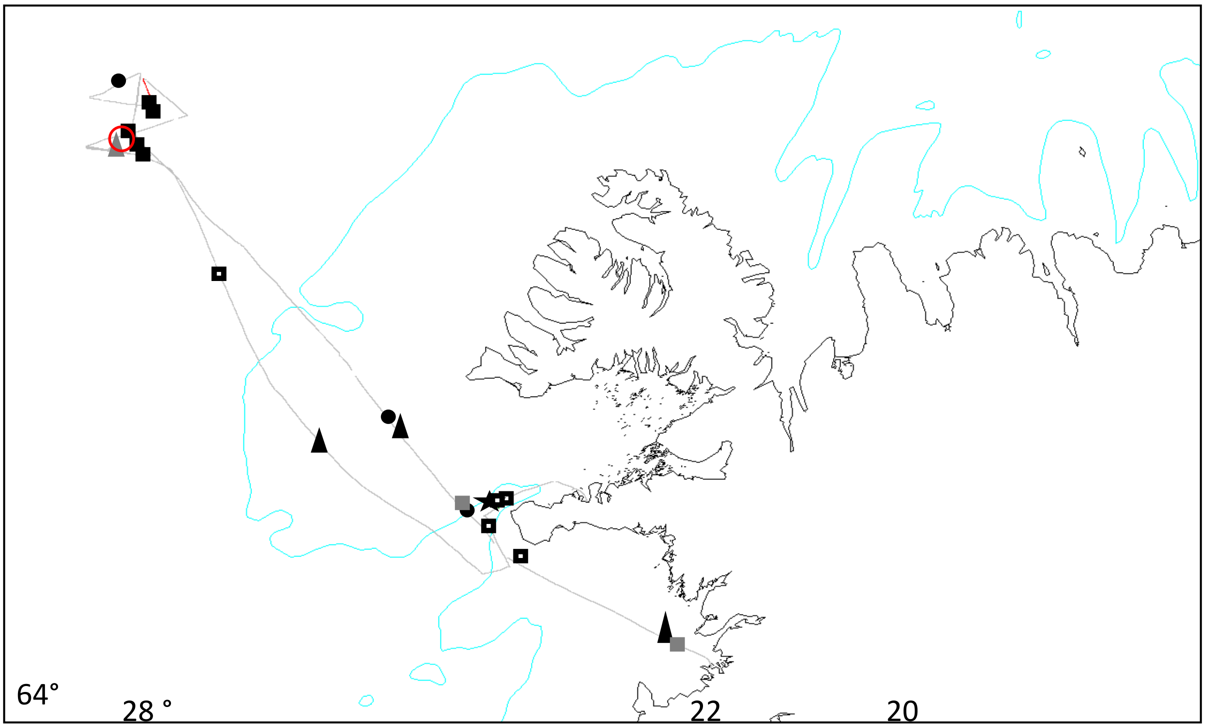

Figure 4. Sightings from offshore trip to deploy the EAR (red circle) off the north west coast of Iceland (turquoise line denotes the 200 metre contour). Five cetacean species were seen: harbour porpoise (*n*=3, black triangles), minke whale (*n*=3, black circles), pilot whale (*n*=5, hollow square), fin whale (*n*=10, black square), white-beaked dolphin (*n*=1, black star) as well as one unknown dolphins (grey triangle) and two unknown whale (grey square).

On the 31st August, *Song of the Whale* set out for the location where the EAR was deployed with the intention to retrieve the EAR, or at least survey the 200 metre contour off Northwest Iceland. Unfortunately the weather deteriorated and on the 2nd September the vessel was forced to return to shelter. During this period three species were sighted; a group of 5 to 8 white-beaked dolphins, a sunfish and an unknown shark species (Figure 5). Very little dedicated observation was possible during this period due to poor weather conditions.

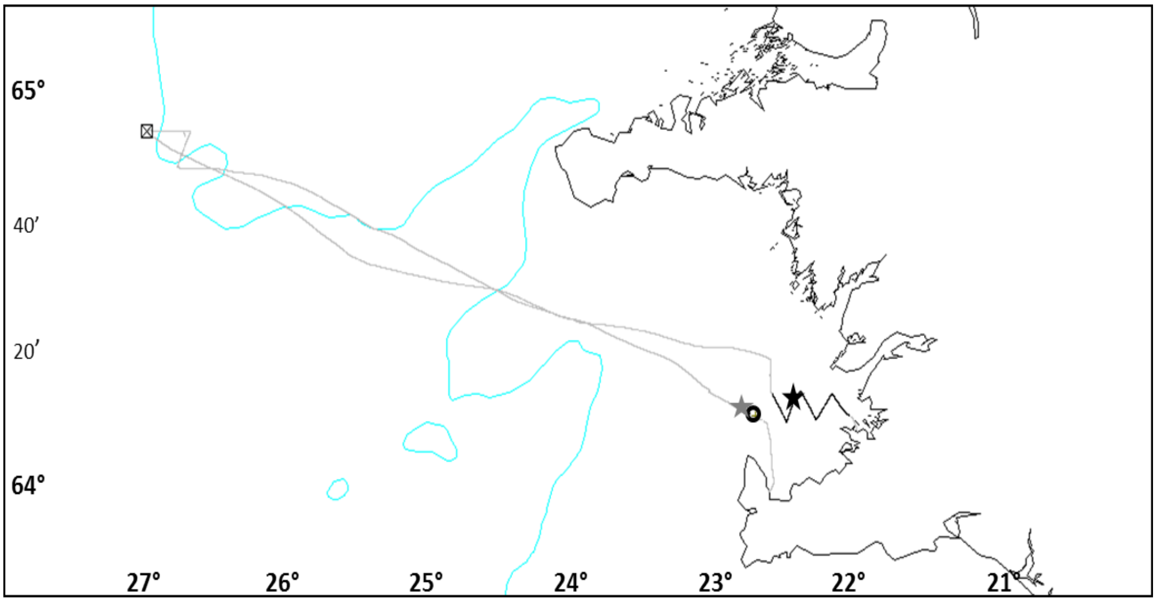

Figure 5. Sightings from an offshore survey off the North West coast of Iceland between 31st August and the 3rd September (turquoise line denotes the 200 metre contour). Three species were seen: white-beaked dolphin (*n*=1, black star), unknown shark species (*n*=1, grey star) and a sunfish (*n*=1, black circle).

3.2 Acoustic detections

Both high (up to 500 kHz sample rate) and low frequency (up to 8 kHz sample rate) recordings were made during both offshore passages around Iceland and the research passage to the UK. Using a click detector implemented in Pamguard, harbour porpoises were detected in the shallow shelf waters of Iceland out to the deeper waters to the south (Figure 6). As SOTW continued surveying offshore through waters deeper than 500 m, no more detections were made until water depth decreased on the approach to the Faroe Islands. There were only two possible detections of baleen whales (Figure 7).

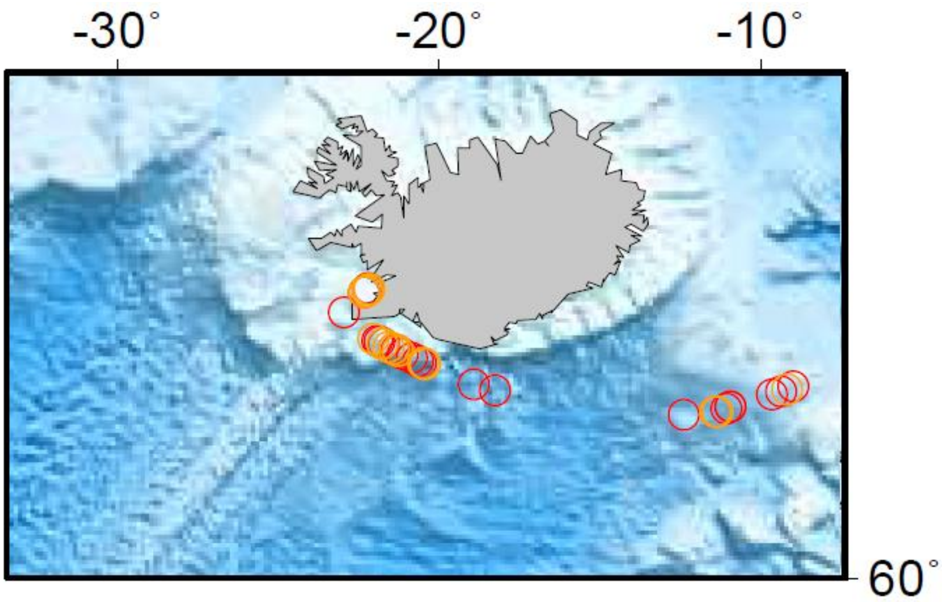

Figure 6. Summary of acoustic detections of harbour porpoises made in Icelandic waters. Red ellipses represent 'likely' detections; orange ellipses represent 'possible' detections. Detections were largely absent from deeper waters.

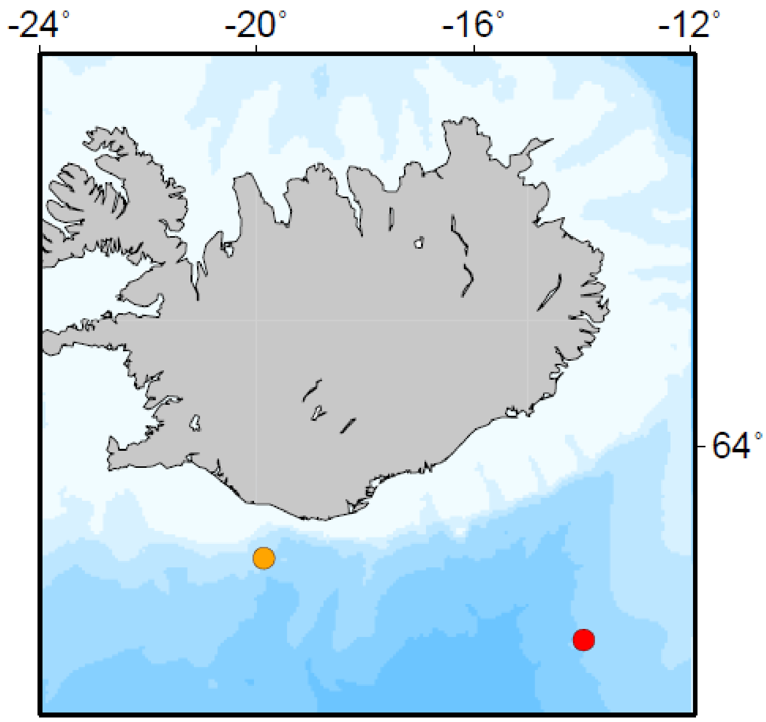

Figure 7. Summary of all acoustic detections of baleen whales made between Iceland and the UK. Red ellipses represent 'likely' detections; orange ellipses represent 'possible' detections.

3.3 Ecological Acoustic Recorder

The EAR was deployed at 66°38.3009'N 28°02.6015'W in offshore Icelandic waters on the 6th August 2012. The EAR was deployed in 310 metres of water. Subsequent poor weather prevented the SOTW team from retrieving the EAR, but the intention was for the University of Iceland to recover it at a later date.

3.4 Behavioural tracking of minke whales

During a three week period between 12th and 30th August the *Song of the Whale* team worked in Faxaflói, primarily studying the surface behaviour of minke whales. During this period, 11 days of video range tracking were carried out during which 57 individual minke whales were tracked with over 70 hours of associated behavioural data. Individual whales were tracked from periods of over 6 hours (Figure 8) to 17 minutes, with at least eight of the tracks following individuals while whale watch vessels were present (Figure 9). During this period, Fredrik Christensen and his research assistant, Michelle Braña worked alongside the SOTW team, collecting data on minke whale behaviour, utilising a similar methodology (see for example Christensen *et al.*, 2011). A comprehensive analysis of these data is on-going, and the results will be presented at a later date. Tracking of minke whales requires very calm conditions, ideally less than sea state three, with a clear horizon. Each morning when searching for whales to track, SOTW followed a set of predetermined transect lines. Additionally on poor weather days when it was not possible to track individuals, a visual survey was conducted of the transects in order to estimate overall density across the area. Data from these surveys were limited as rather few sightings of minke whales were made.

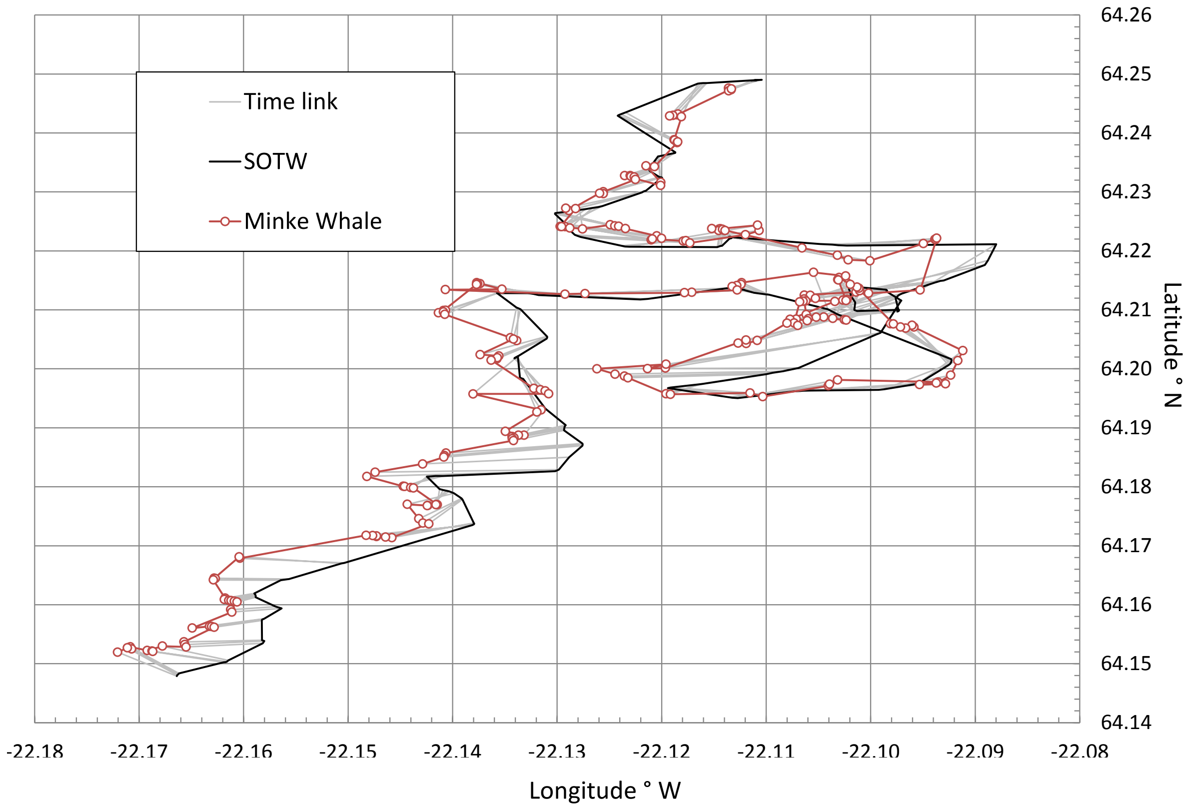

Figure 8. An example of continuous tracking of a single minke whale for 6 hrs from SOTW on 16th August 2012. The grey 'time link' lines represent the concurrent positions of SOTW and a surfacing whale.

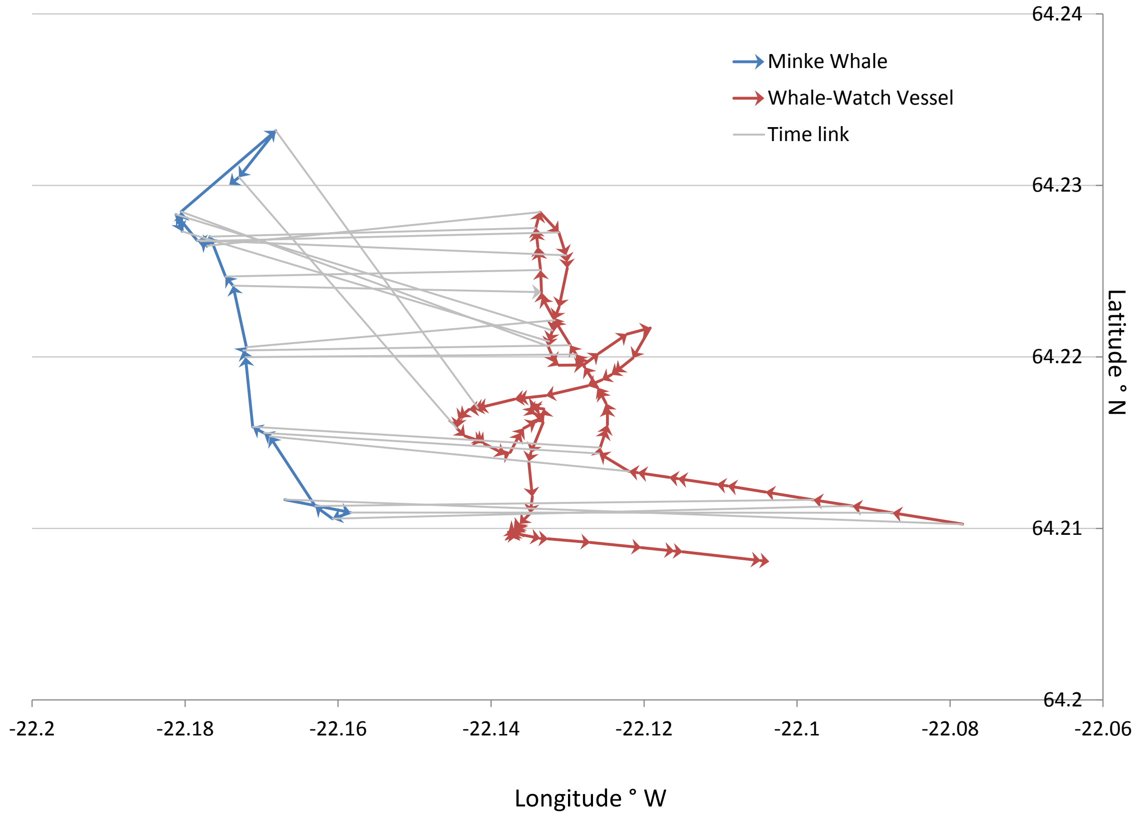

Figure 9. Example of a whale-watch vessel and an individual minke whale tracked using AIS and VRT respectively for 1 hr 09 min on 15th August 2012. The grey 'time link' lines represent the concurrent positions of the vessel and a surfacing whale.

3.5 Ship noise measurements

While in Faxaflói, ship noise measurements were collected. On 24th August, 25 separate vessel passes were measured; one of these was disregarded from further analysis as another vessel was close by. With the collaboration of the vessel crews, it was possible to take repeat measurements of each vessel and at a variety of speeds. On request, the headings of vessels were maintained throughout recording. Noise output was distance normalised and calculated as the RMS average for two boat lengths either side of CPA and characterised for three speed classes: 'with whale' (the typical operating speed of the vessel when close to whales), bursts of acceleration and typical searching speed (Table 3).

Table 3. Noise output (L_{pdn} normalised to 1 m and assuming shallow-water transmission) of all vessels presented as RMS averages for two boat lengths either side of the CPA (standard deviations in parentheses). Where possible, measurements are averaged for multiple passes.

Vessel ID	Speed class	CPA (km)	SOG (kn)	L_{pdn} dB re 1 µPa (20 Hz - 2 kHz narrowband)	L_{pdn} dB re 1 µPa (20 Hz - 20 kHz $^1/_3$-octave)
1	With whale $_{(n=1)}$	0.17	4.6	102.12	128.86
	Acceleration $_{(n=1)}$	0.22	4.6 to 7.8	110.76	136.45
	Searching $_{(n=3)}$	0.15	10.1	109.56 (±1.5)	137.46 (±2.2)
2	With whale $_{(n=1)}$	1.48	0.7	102.91	130.62
	Acceleration $_{(n=1)}$	1.29	6.3 to 9.2	108.62	134.27
	Searching $_{(n=4)}$	0.35	11.5	117.73 (±6.1)	142.56 (±5.1)
3	With whale $_{(n=1)}$	0.17	5.8	101.63	125.56
	Acceleration $_{(n=1)}$	0.30	5.80 to 10.2	108.64	136.70
	Searching $_{(n=3)}$	0.18	12.0	117.36 (±1.7)	144.52 (±2.8)
4	With whale $_{(n=2)}$	0.20	6.0	97.28 (±0.9)	122.67 (±0.1)
	Acceleration $_{(n=2)}$	0.23	6.0 to 23.3	110.88 (±4.3)	138.48 (±3.9)
	Searching $_{(n=4)}$	0.29	19.5	112.28 (±1.8)	139.82 (±0.9)

3.6 Whale-watching vessel speeds in relation to minke whales

Using a density (frequency of occurrence) plot for speeds of whale-watch vessels (from AIS), a bimodal distribution was clear from the data with maxima at speeds of 4.2 knots and ~11 knots (Figure 1 10). These speeds correspond to periods when the vessels were ‘with whales’ and searching for whales respectively.

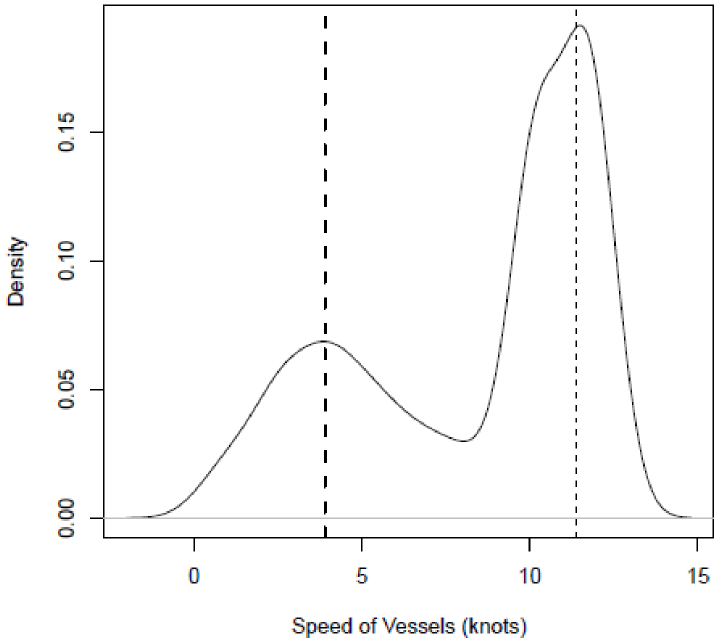

Figure 10. Vessels speeds from AIS showing 'with whale' (heavy dash) and searching (thin dash) speeds.

Similarly, to determine vessel activity (*i.e.*, 'returning to port' or 'other') vessel headings were analysed. Two peaks in heading density are evident which correspond to vessels heading to port (70^{o} to 140^{o}) and vessels heading out to sea (Figure 11). Distances from tracked minke whales plotted for 'vessels heading to port' showed a higher speed than vessels 'at all headings'. This difference was statistically significant for distances between 650 m (Kruskal-Wallis chi-squared ranged = 3.79 to 6.34, df = 1, p = 0.01 to 0.05 respectively) and 1,200 m from whales. Vessel speeds were not found to be significantly different at distances of <650 m from a minke whale, however this may be due to a limited sample size at these distances. It is clear however, that vessels occasionally reach speeds of 10 – 11 knots at distances of 300 – 400 m from a minke whale (Figure 11). At a distance of 200 m from whales, vessels travelled at a mean speed of 4.6 knots (2.7) when heading for port, otherwise they moved at a speed of 3.3 knots (0.8). A similar differential was observed for distances of 300 and 400m (Figure 11) from tracked minke whales.

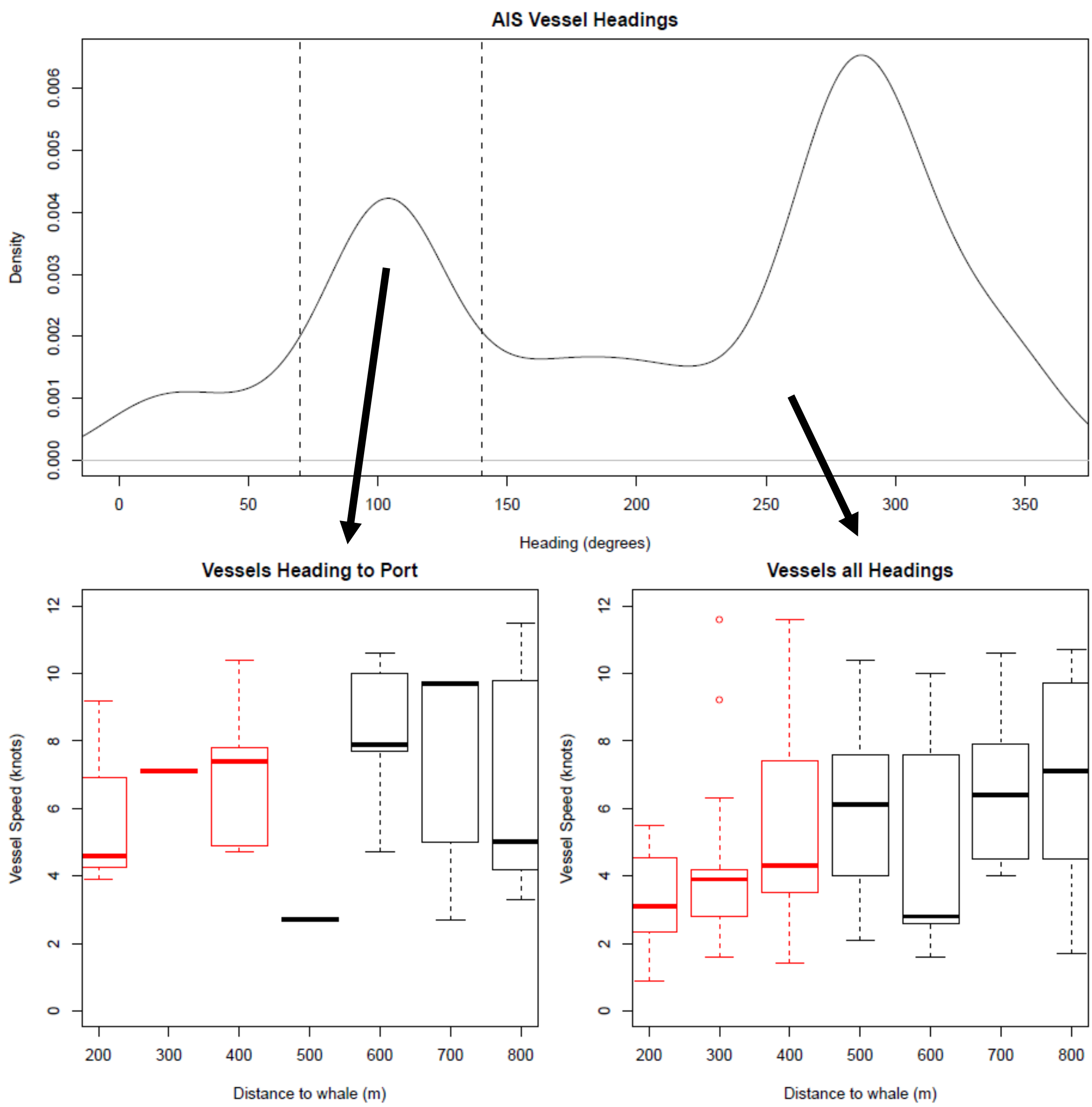

Figure 11. Above: vessel headings used to define when vessels were heading back to port (dashed line). Below: vessel speeds close to tracked whales, highlighted in red for distances of < 500m from a tracked minke whale. Whiskers represent minima and maxima.

In order to minimise the potential of startling whales with elevated sound levels resulting from sudden bursts of acceleration, an assessment is needed of the safe distance at which vessels can accelerate to typical searching speeds. The noise output of a vessel ‘searching’ for whales can be 15 dB higher than when manoeuvring near whales (Table 3); whale-watching regulations should thus require vessels to maintain ‘with whale’ speeds until such a distance that any increase in speed does not lead to an increase in received levels. These measures could be easily implemented to ensure Icelandic whale-watch vessels minimise noise disturbance to whales.

3.7 Pilot whale stranding recordings

On the 30th July 2012, immediately after arriving from Boston, SOTW joined a mission to prevent approximately 200 pilot whales from stranding off Akranes. SOTW left Reykjavik at 11:30 (UTC) and headed out to the location of the potential stranding event. Approximately 40 minutes later, as SOTW arrived, the pilot whales had been shepherded away from immediate danger and away from the coast by a number of fishing vessels. SOTW deployed a hydrophone array to monitor the pilot whales acoustically and record their vocalisations. Using these detections, SOTW tracked the pilot whales and they were located approximately one mile off the coast of Akranes. Over the next three hours the SOTW team stayed with the pilot whales, observing them from a distance of around 500 m, as they moved offshore. Video recordings, photographs and acoustic recordings were collected during this time. The initial acoustic recordings collected of the pilot whales while they were in distress, appeared to show the whales whistling at lower frequencies with fewer frequency modulation than typically described. After staying with the animals for a number of hours as they moved further offshore, the whistles gradually returned to “normal” mid-frequency frequency-modulated whistles. Further analysis is presently being carried out on these recordings to determine if the field observations were accurate.

Four other sightings and recordings of pilot whales were made just outside Faxaflói on the 7th, 8th and 9th August 2012. These data will be used to compare and contrast the acoustic recordings made during the near-stranding event.

4. DISCUSSION

Some analyses are still underway; however preliminary results are discussed below.

4.1 Harbour porpoise distribution

The characteristic clicks of harbour porpoises were routinely detected in Iceland’s shelf waters. Around Iceland, porpoises weren’t detected in waters deeper than 500 m.

4.2 Baleen whale acoustic detections

Although opportunities were limited, there were rather few acoustic detections of baleen whales noted in Icelandic waters. Although there is increasing evidence that some species of baleen whale produce a repertoire of calls away from their breeding grounds (Clark & Clapham, 2004; Vu *et al*., 2012), they tend to produce fewer vocalisations in higher latitudes (Stafford *et al*., 2002; Širovic *et al*., 2004). The vocal repertoire of some Atlantic species, most notably the minke whale, is poorly documented. Thus a lack of acoustic detections may not necessarily equate to an absence of baleen whales in Icelandic waters. Due to the limited sample size, it was not possible to infer the species identity for the calls detected in this study.

4.3 Behaviour of minke whales near whale-watch vessels

Although analysis of these data is on-going, it is clear that the methods presented herein are effective for tracking cetaceans given favourable sea states. By using video range tracking coupled with freely-available AIS data, we have been able to demonstrate that fine-scale tracking of minke whales can be carried out without the use of more invasive tagging techniques. While the focus of this study was to investigate minke whale behaviour and the movements of these whales in relation to whale-watch vessels, this approach can be extended to investigating, for example, foraging behaviour.

4.4 Ship Noise

The four vessels measured produced lowest noise levels when travelling at slower ‘with whale’ speeds (i.e. 6 knots or less). Highest noise levels were produced at typical survey speeds and were typically 15 dB higher than ‘with whale’ levels. Periods of acceleration could be as noisy as the measurements made of vessels at typical survey speeds; this may be due to increased cavitation as the vessel accelerates. Indeed, noise levels recorded for all vessels when accelerating were with 3 dB of each other at lower frequencies, at approximately 110 dB. Generally noise levels were highest just after a vessel passed the CPA which follows the typical pattern of greater noise levels aft of the beam seen in many vessels. Although the sample size is small, it appears some of the vessels generated more underwater noise than others. The general length of the vessel did not seem to have a bearing on noise output, as both the smallest vessel and longest vessel had similar noise levels. These two vessels had very similar noise outputs when searching for whales and accelerating (111 dB), although the smaller vessel was marginally quieter when travelling at ‘with whale’ speeds (97 vs. 102 dB). The two other vessels showed almost matching noise signatures, with low-frequency noise levels of 102 dB when ‘with whales’, increasing to 109 dB when accelerating and reaching 117 dB when in a searching pattern. There are marked differences in design between these two vessels, most notably one being single-hulled and the other twin-hulled so the similarity of noise levels is likely just a coincidence. For further discussion of these findings, see the separate MCR report on Faxaflói ship noise (MCR, 2013).

4.5 Vessel speeds around minke whales

There are some minor caveats in our analysis of vessels speeds: namely that we only considered vessel speeds for departures from whales when the vessel was heading towards port. There are times when a vessel departs a whale and heads in another direction; however our analysis omitted these in order to insure a rigid data stratification process. Whale-watch boats generally navigated near whales in a responsible manner, with speeds below 6 knots. The departure speeds however were occasionally found to be high at close ranges to the whales, and as mentioned in the previous section, bursts of acceleration can be as noisy as a vessel running at its typical operating speed of 10 to 20 knots. It is recommended that greater cognisance is paid to the arrival and departure speeds of vessels once the skipper decides to begin or end an encounter with whales. While the speed and angle of approach to whales tends to be carefully considered, departure from an encounter with whales might not be thought of as being so important. However, this study indicates that the departure manoeuvre may disturb whales equally if not more-so than arrival.

Considerations regarding departure speeds from whales do not appear to be listed in most whale-watching guidelines or regulations internationally (Carlson, 2012). Much emphasis has been placed on regulating vessel activity on approach to cetaceans, however it is likely that the departure may be as potentially disturbing to cetaceans as the arrival of a vessel. Departure speeds should therefore be considered and incorporated into whale watching codes of conduct and regulations to minimise the disturbance and potential impacts from whale watching. While currently no mandatory code of conduct for whale-watching exists in Iceland, efforts are underway to develop a voluntary code set out by Ice Whale and the Húsavík Museum (Martin, 2012) and Elding has developed its own set of guidelines (Whittaker, 2012).

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6. REFERENCES

Boisseau, O., D. Gillespie, R. Leaper, and A. Moscrop. 2008. Blue (*Balaenoptera musculus*) and fin (*B. physalus*) whale vocalizations measured from northern latitudes of the Atlantic Ocean. *Journal of Cetacean Research and Management* **10**(1):23-30.

Carlson, C. (2012). A review of whale watch guidelines and regulations around the world version 2012. Online Report to ACCOBAMS, sourced 7 May 2013:
http://iwc.int/cache/downloads/4mc4x7y9nlicc8g0wwg00cg0c/WWREGS%202012.pdf

Christiansen, F., Rasmussen, M. H. & Lusseau, D. (2011) Whale watching boats disrupt the foraging activities of Minke whales in Faxaflói bay, Iceland. 13 pp. Presented to the IWC Scientific Committee. SC/63/WW2.

Clapham, P., Young, S., Brownell Jr., R. 1999. Baleen Whales: Conservation Issues and The Status of the Most Endangered Populations. *Mammal Review* **29**(1): 35-60.

Clark, C. W. & P. J. Clapham. 2004. Acoustic monitoring on a humpback whale (Megaptera novaeangliae) feeding ground shows continual singing into late spring. *Proc. Roy. Soc. Lond. B*. 271(1543): 1051-1057.

Cummings, W.C.P., Thompson and S.J. H.A. 1986. Sounds from Bryde's, *Balenoptera edeni*, and finback, *B. physalus*, whales in the Gulf of California. *Fishery Bulletin, U.S*., **84**: 359-380.

Edds, P.L. 1988. Characteristics of finback *Balaenoptera physalus* vocalizations in the St. Lawrence Estuary. *Bioacoustics* **1**: 131-49

Hammond, P. S., K. Macleod, D. Gillespie, R. Swift, A. Winship, M. L. Burt, A. Cañadas, J. A. Vázquez, V. Ridoux, G. Certain, O. Van Canneyt, S. Lens, B. Santos, E. Rogan, A. Uriarte, C. Hernandez & R. Castro. 2009. *Cetacean Offshore Distribution and Abundance in the European Atlantic (CODA).* Report prepared by SMRU, University of St. Andrews: 43 pp.

Leaper, R. & Gordon, J. 2001. Application of photogrammetric methods for locating and tracking cetacean movements at sea. *J. Cetacean Res. Manage*. **3**(2): 131-141.

Martin, S.M. 2012. *Whale watching in Iceland: an assessment of the whale watching activities on Skjálfandi Bay*. Unpublished MSc. Thesis, University of Akureyri, pp. 86.

McDonald, M.A., Calambokidis, J., Teranishi, A.M. and Hildebrand, J.A. 2001. The acoustic calls of blue whales off California with gender data. *Journal of the Acoustic Society of America* **109**(4): 1728-35.

McDonald, M. A., Mesnick, S. I. & Hildebrand, J. A. 2006. Biogeographic characterisation of blue whale song worldwide: using song to identify populations. *J. Cetacean Res. Manage*. **8**(1): 55-65.

MCR. 2013 Final Report describing measurements of ship noise taken from R/V Song of the Whale in Faxaflói in August 2012. Report prepared by MCR International, February 2013. 15 pages.

Pike, D.G., Víkingsson, G.A., Gunnlaugsson, Th. and Øien, N., 2009. A note on the distribution and abundance of blue whales (*Balaenoptera musculus*) in the Central and Northeast North Atlantic. NAMMCO Scientific Publication **7**: 19-29.

Širovic, A., J. A. Hildebrand, S. M. Wiggins, M. A. McDonald, S. E. Moore & D. Thiele. 2004. Seasonality of blue and fin whale calls and the influence of sea ice in the Western Antarctic Peninsula. *Deep-Sea Res. II* 51: 2327-2344.

Stafford, K. M., S. L. Nieukirk & C. G. Fox. 2001. Geographic and seasonal variation of blue whale calls in the North Pacific. *J. Cetacean Res. Manage*. 3(1): 65-76.

Thompson, P.O., Findley, L.T., Vidal, O. and Cummings, W.C. 1996. Underwater sounds of blue whales, *Balaenoptera musculus*, in the Gulf of California, Mexico. *Marine Mammal Science* **12**(2): 288-92.

Víkingsson, G.A., Ólafsdóttir, D. and Hauksson, E., 2004. Iceland – Progress report on marine mammal research in 2002. In: NAMMCO Annual Report 2003, NAMMCO, Tromsø, 323-327.

Vu, E. T., D. Risch, C. W. Clark, S. Gaylord, L. Hatch, M. A. Thompson, D. N. Wiley & S. M. van Parijs. 2012. Humpback whale song occurs extensively on feeding grounds in the western North Atlantic Ocean. *Aquatic Biology* **14**: 175-183.

Whittaker, M. 2012. Guidelines for responsible whale watching, Unpublished guidelines prepared for Elding: 12 pp.