Final Report for an Acoustic Survey of Beaked Whales Conducted from R/V *Song of the Whale* in the Rockall Trough, September to October 2010 and March 2011

Prepared by:

MCR Ltd.
1 High Street
Kelvedon
Essex CO5 9AG, UK
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Department of Communications, Marine and Natural Resources
Roinn Cumarsáide, Mara agus Acmhainní Nádúrtha

EXECUTIVE SUMMARY
Despite being one of the least known families of cetaceans, it is apparent the beaked whales are sensitive to anthropogenic noise. Understanding the distribution and ecology of these species is essential for effective mitigation. Previous sightings of beaked whales suggest the slope waters to the west of the UK and Ireland may provide important habitats for a number of species. Acoustic techniques to determine beaked whale presence are developing to the point where they may rival visual techniques in offshore environments such as those of the Atlantic margin. A visual/acoustic survey was conducted from *Song of the Whale* in September to October 2010 and March 2011 to explore potential beaked whale habitats of the Atlantic Frontier. Over 6000 km of survey effort was completed within 530 hours, of which 2800 km was 'on track'. Although cetaceans were encountered on 163 occasions during the survey, no confirmed sightings were made of beaked whales, in part due to inclement weather. However, six separate acoustic detections were made of beaked whale click trains using a towed array. The most stereotypic click trains were recorded in canyon systems to the west of Ireland and near the Hebrides Terrace seamount, west of Scotland. These detections reiterate that slope waters are important habitats for beaked whales, and canyon systems may provide favourable foraging conditions. In certain areas, the saturation of calls with ultrasonic energy from other species may confound acoustic detection effort for beaked whales. Sightings and acoustic detections of other cetacean species encountered are presented.

1. INTRODUCTION

The beaked whales, or ziphiids, are one of the least known families of cetaceans. They are particularly difficult to study as they dive deeply and are oceanic in distribution. They are also very difficult to detect visually at sea. Until relatively recently, some species were known only from the bones of stranded specimens. In recent years, there has been increasing evidence that they are vulnerable to anthropogenic sounds, particularly seismic airguns and military mid frequency sonar (2-10 kHz). In the past 40 years, over 40 mass strandings have been reported world wide (probably a small proportion of all beaked whale strandings). Some of these were concurrent with naval exercises and the use of active sonar, and the overall pattern of strandings provides a growing body of evidence that certain loud, mid frequency sonar can result in the death and injury of beaked whales.

In practical terms, mitigating the harmful effects of anthropogenic sounds on beaked whales is likely to be based on altering the nature or location of potentially harmful activities. This may be done by either monitoring for beaked whales and responding to positive detections, possibly in "real time" and in a precautionary way, or by demonstrating and/or predicting the whereabouts of important beaked whale habitats and proscribing harmful activity there e.g. by the designation of Marine Protected Areas (MPAs). Data collected during survey work conducted in the Rockall Trough and nearby waters may feed in to a descriptive model to account for beaked whale presence/absence in the area with the view to developing predictive models. Predictive models may allow the testing of hypotheses regarding ecological variables that influence beaked whale distribution. As such, the research described in this document feeds into both mitigation strategies mentioned above.

1.1 Cetaceans of the Atlantic Margin

The waters to the west of Ireland and the UK are utilised by a wide range of cetaceans. Of the 27 species documented in UK waters (Evans, 1995), 21 species have been confirmed in Irish waters alone (Berrow, 2001) and 15 species have been confirmed to the north and west of Scotland during SAST/JNCC surveys between 1979 and 1998 (Pollock *et al*., 2000; Weir *et al*., 2001). In recognition of their importance for marine mammals, the Irish government declared all Irish waters within the 200 nautical mile limits of the Exclusive Economic Zone (EEZ) to be a whale and dolphin sanctuary in 1991 (Rogan & Berrow, 1995). Ireland has recently submitted the first conservation assessment of cetaceans under the EU Habitats Directive (NPWS, 2008).

The availability and distribution of prey is one of the primary factors influencing the distribution of cetaceans along the Atlantic margin. Dynamic physical and oceanographic features maintain a heterogeneous marine environment that ensures a patchiness of preferred prey. The waters of the Atlantic margin are characterised by seasonally high productivity. Additionally, the shelf region incorporates areas of complex bathymetry which are of particular importance to deep diving species such as beaked whales (Figure 1). It is possible species such as the beaked whales are restricted to distinct areas of suitable habitat (Macleod, 2005). Several canyon systems around the Rockall Basin appear to be of particular importance as they have shown high levels of beaked whale activity in comparison to other areas surveyed (Wall, 2006; Wall, 2007). Species with specific habitat requirements may be more vulnerable to disturbance from anthropogenic sources and thus added measures for their protection are required. For example, ocean noise pollution has the potential to affect vast areas and may have a disproportionately large impact on beaked whales in critical habitats or ‘bottleneck’ areas such as the Faroes-Shetland Basin on the Atlantic Frontier.

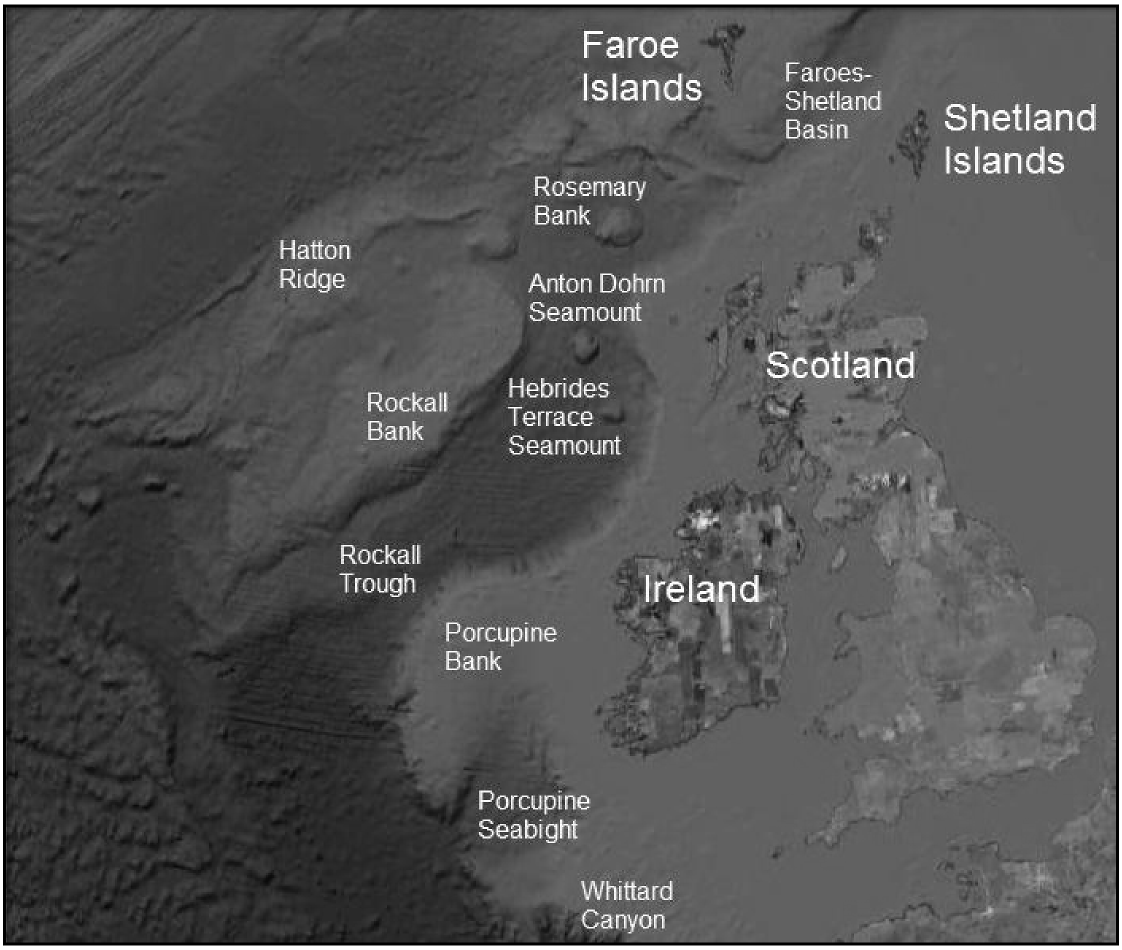


Figure 1. Bathymetry of the Atlantic margin of Ireland and the UK; pertinent features are displayed (source: Google Earth).

1.2 Beaked whales of the continental shelf

Little is known about the ecology of the Ziphiidae, in part due to their occurrence in deep, oceanic waters that are often far from shore. Six species have been recorded in north-west Europe: Northern bottlenose whale, Sowerby's, True's, Cuvier's, Gervais' and Blainville's beaked whales (Reid *et al*., 2003; Ó Cadhla *et al*., 2004). These whales have been recorded during the summer and autumn months; however, strandings data indicate a year round presence. In general, beaked whales favour waters of intermediate depth over sloping seabeds and have often been reported to prefer areas of complex topography such as canyons, shelf-edges and seamounts (MacLeod, 2005; Kaschner, 2007). Modelling of habitat preferences has suggested the Atlantic Margin may be of value for beaked whales (MacLeod, 2005).

There appears to be two important areas for beaked whales along the Atlantic margin: The Faroes-Shetland Basin and an area to the south-west of the Faroes, including the northern end of the Rockall Trough. These areas are linked by a corridor of suitable beaked whale habitat approximately 80km long and 50km wide at its narrowest point. During movements between the two areas, this corridor may form a 'bottleneck' through which the beaked whales must pass (MacLeod and Reid, 2003). Weir (2000) describes the distribution of Mesoplodon species to be centred in an area to the north-west of the Western Isles and Pollock *et al*. (2000) found beaked whale distribution to the north and west of Scotland to be similar to sperm whales, but slightly more southerly, with a distinct peak of sightings in August and almost all sightings occurring in water deeper than 1000m. A number of other canyons systems in the Rockall area show a high level of beaked whale activity; for example, the area around the Rosemary Bank and Anton Dohrn seamount (Weir *et al*., 2001; Hammond *et al*., 2009). The IWDG has highlighted the fact that a number of canyons along the northern margin of the Porcupine Bank are the only locations thus far surveyed in Irish waters which consistently show the presence of beaked whales. A survey carried out in September 2008 also reported a significant number of sperm whale sightings in the easterly canyon, which also had the most beaked whale sightings.

1.3 Acoustic surveying for beaked whales

Visual surveys for cetaceans are limited to conditions of good visibility, during daylight hours and in a limited range of sea states. Visual surveys can prove difficult during the autumn and winter seasons due to poor weather conditions and reduced daylight hours. For some cetaceans, particularly those that dive deeply and spend extended periods of time at depth (e.g. beaked whales), passive acoustic monitoring is the most feasible method of survey. This method has greatly enhanced the information available on cetacean distribution along the Atlantic margin (e.g. Lewis *et al*., 1998; Swift *et al*., 2002; Hammond & Macleod, 2006; Hammond *et al*., 2009; Charif & Clark, 2009). For example, acoustic detections from the Atlantic margin in waters deeper than 1500m have indicated a higher number of cetaceans than expected, including regular detections of some rare species such as blue whales. It is likely that the Rockall Trough represents an important habitat for deep-diving species such as sperm and beaked whales (Aguilar de Soto *et al*., 2004).

The regular narrowband clicks reported for beaked whales appear to be quite distinctive from those of other cetaceans, with a relatively flat spectrum from 30 to 40 kHz (Johnson *et al*., 2004; Zimmer *et al*., 2005, Johnson *et al*., 2006). These characteristic clicks thus offer the potential to identify the presence of beaked whales using acoustic techniques alone. Since 2007 the IWDG has deployed deep-water passive acoustic detectors in the Whittard Canyon system, the Porcupine Seabight and the Hatton Bank. These 'Deep-PODs' are being used to monitor the presence of deep diving species in deep-water canyon systems and around cold-water coral mounds. Under the PReCAST project, the IWDG will conduct further deployments of Deep-PODs and will conduct acoustic surveys for cetaceans during offshore ship surveys. Static hydrophones such as these provide invaluable information on local habitat use. However, these systems do not necessarily provide information on relative abundance as a single individual may be recorded on several occasions. Certain bottom-mounted passive acoustic systems are also capable of recording vocalisations to hard disk for subsequent analysis and archiving. Recent developments in the miniaturisation of recording systems have allowed recordings to be made from tags attached to beaked whales (e.g. Johnson & Tyack, 2003; Johnson *et al*., 2004). However, the relative cost of each tag and the limitations of application on the high seas make this technique better suited to certain conditions (e.g. a known population of beaked whales in a relatively sheltered region).

Additional efforts to detect beaked whales have been made using towed arrays of hydrophones. This approach allows rapid surveying of large regions and may allow inferences to be made on local abundance and population demographics. However, despite the promise offered by towed arrays, relatively few recordings have been made of beaked whales in this way. Frantzis *et al*. (2002) recorded clicks in the presence of Cuvier's beaked whales off Crete (frequency response to 24 kHz). Hooker *et al*. (2002) presented recordings made near Northern bottlenose whales (frequency response to 40 kHz) off Canada. Pavan *et al*. (2006) recorded sounds associated with Cuvier's beaked whales in the Ligurian Sea (frequency response to 90 kHz). Rankin and Barlow (2007) recorded sounds in the presence of Blainville's beaked whales in Hawaii (frequency response to 24 kHz). Cato *et al*. (2009) recorded thousands of beaked whale clicks off Eastern Australia (frequency response to 150 kHz). Gillespie *et al*. (2009) recorded Gervais' beaked whales in the Bahamas (response to 96 kHz).

The *Song of the Whale* research team investigated the potential for using towed arrays of hydrophones for detecting beaked whale clicks in offshore regions (Boisseau *et al*., 2009). These surveys used broadband detection systems (frequency response to 90 kHz) to identify those clicks with centre frequencies of 30-50 kHz that were narrowband in nature and thus provide stronger evidence of beaked whale detection. Surveys conducted in 2008 in mid-Atlantic regions between the Canary Islands, Azores and Madeira identified several detections of beaked whale clicks near islands, ridges and seamounts. However, several detections were also made in open water over the abyssal plain, suggesting beaked whale foraging is not limited exclusively to areas exhibiting bathymetrical anomalies.

The application of towed-arrays in the acoustic detection of beaked whales is well suited for offshore environments such as those of the Atlantic margin. The research aims of the cruise described here were to:

1. Investigate the efficiency of detecting beaked whales using towed arrays.
2. Carry out exploration of habitats within the Atlantic Frontier for beaked whales.
3. Provide presence/absence data for models testing ecological hypotheses.

2. METHODOLOGY

The survey was conducted in the Rockall Trough between 15th September and 12th October 2010 and 4th and 7th March 2011 in British and Irish waters between 50°N and 60°N. The surveys were conducted from the 21m auxiliary-powered cutter-rigged sailing research vessel *Song of the Whale*[1]. Surveys were conducted under sail, motor or motor/sail 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). The main survey tracklines were selected in the field in a quasi-random fashion based largely upon winds favourable to sailing, regions of unusual and varied bathymetry and passage destination. Additional survey blocks of intensive survey track were selected

[1] RV *Song of the Whale* is owned by the International Fund for Animal Welfare and managed and operated by Marine Conservation Research Ltd.

based on IWDG visual survey data, which indicated habitats of importance for beaked whales within the Irish EEZ or based on habitats similar to those found to be of importance to beaked whales elsewhere (Figure 2). The survey thus encompassed a range of habitats including shallow shelf waters, upper and lower slope waters and deep abyssal regions. Random transects were designed in Matlab (The MathWorks Inc.) to optimise courses for sailing whilst providing an even probability of coverage throughout each survey block. Deviations from the planned trackline were made to confirm species identity and close on priority species for recordings and photos.

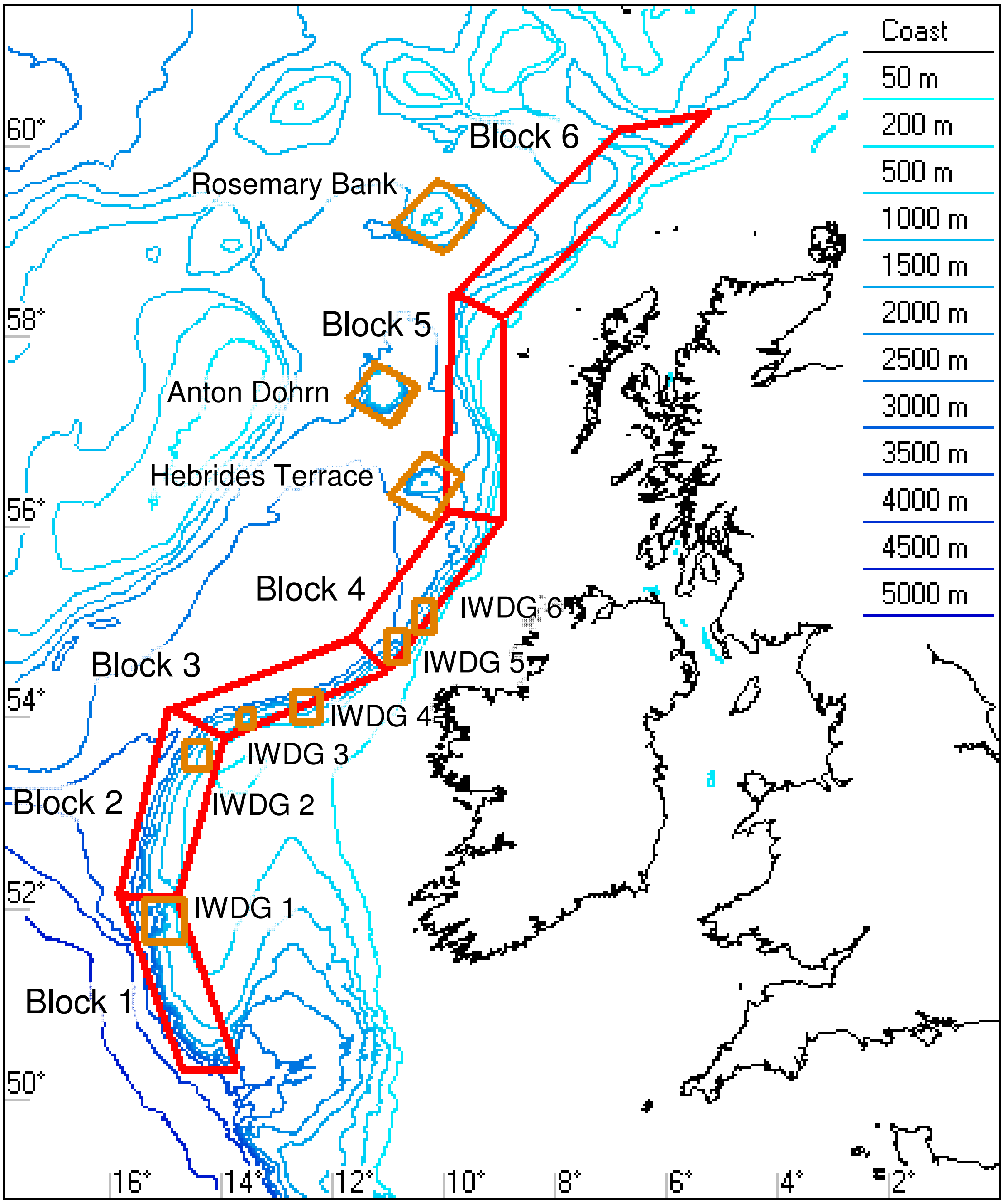


Figure 2. Proposed survey blocks along the slope of the Rockall Trough. Larger survey blocks of approximately equal size are displayed in red; smaller irregular blocks are displayed in orange.

2.1 Data collection
In daylight hours and in sea states below four, two visual observers with binoculars were positioned on a 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 and GPS 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 surveys were conducted using a 400 m towed four-element broadband hydrophone array (SEICHE Ltd.). Continuous stereo 192 kHz recordings were made via a bespoke buffer box passing signals to an RME Fireface 800 sound card. The buffers were configured to give a variable frequency response and the response of the system was 2 to 110 kHz (±10 dB). However, in the bandwidth of interest for beaked whale clicks (25 to 50 kHz), the response of the system was approximately flat. Recordings were made using Logger and written to disk as two-channel 16 bit wav files. As typical beaked whale clicks have the distinctive form of a relatively long duration (~200 µs) FM upsweep with dominant energy between 25 and 50 kHz (Johnson *et al*. 2004; Johnson *et al*. 2006; Gillespie *et al*. 2009), it is possible to detect and extract potential beaked whale clicks from background noise using click detection algorithms. Thus, acoustic signals were monitored in real-time using a click detector module in Pamguard (Passive Acoustic Monitoring Guardianship, www.pamguard.org) whereby sounds with significant energy (>6 dB above background noise) in the 25 to 50 kHz band were classified as potential beaked whale clicks (see Gillespie *et al*. 2009 for details).

The team on *Song of the Whale* also explored coastal and offshore habitats in the Rockall Trough for other marine mammals. Additional research effort was spent on priority species such as bottlenose dolphins and baleen whales and included photo-ID and high-frequency recording. 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 FM calls produced by odontocetes.

2.2 Data analysis
A more thorough investigation of potential clicks was conducted post-survey. Initially, the files created in the field using varying trigger thresholds were analysed using a basic click detection algorithm. Following this first pass, the click files were regenerated using the original recordings and those settings perceived to be most suited for the acoustic environment of this survey (trigger threshold of 6 dB, i.e. clicks were defined as those periods when signal level was 6 dB above the background noise level). During this second pass, an enhanced frequency sweep algorithm was used in Pamguard to identify those waveforms with more than five zero crossings, a useful diagnostic test to differentiate beaked whale clicks from those of other odontocetes. Candidate beaked whale clicks were selected if they had

significant energy in the 25 to 50 kHz energy band, had a waveform resembling that of published data for other beaked whale species, had an upswept narrowband structure revealed in a Wigner plot and formed part of a click train, i.e. with similar bearings and regular inter-click intervals. Potential beaked whale clicks were classified with a subjective measure of confidence (possible, probable or definite) according to how well they conformed to these parameters. The data was analysed in two separate passes. The occurrence of other non-ziphiid clicks was also logged.

3. RESULTS

A variety of habitats were surveyed for marine mammals in this study, including coastal regions, continental shelf, slope waters, the abyssal plain, canyon systems and seamounts. The total log for the research cruise was 6147 km of which 2779 km was ‘on track’ with at least acoustic effort (Figure 3). Inclement weather meant the proposed survey of the Rosemary Bank could not be completed.

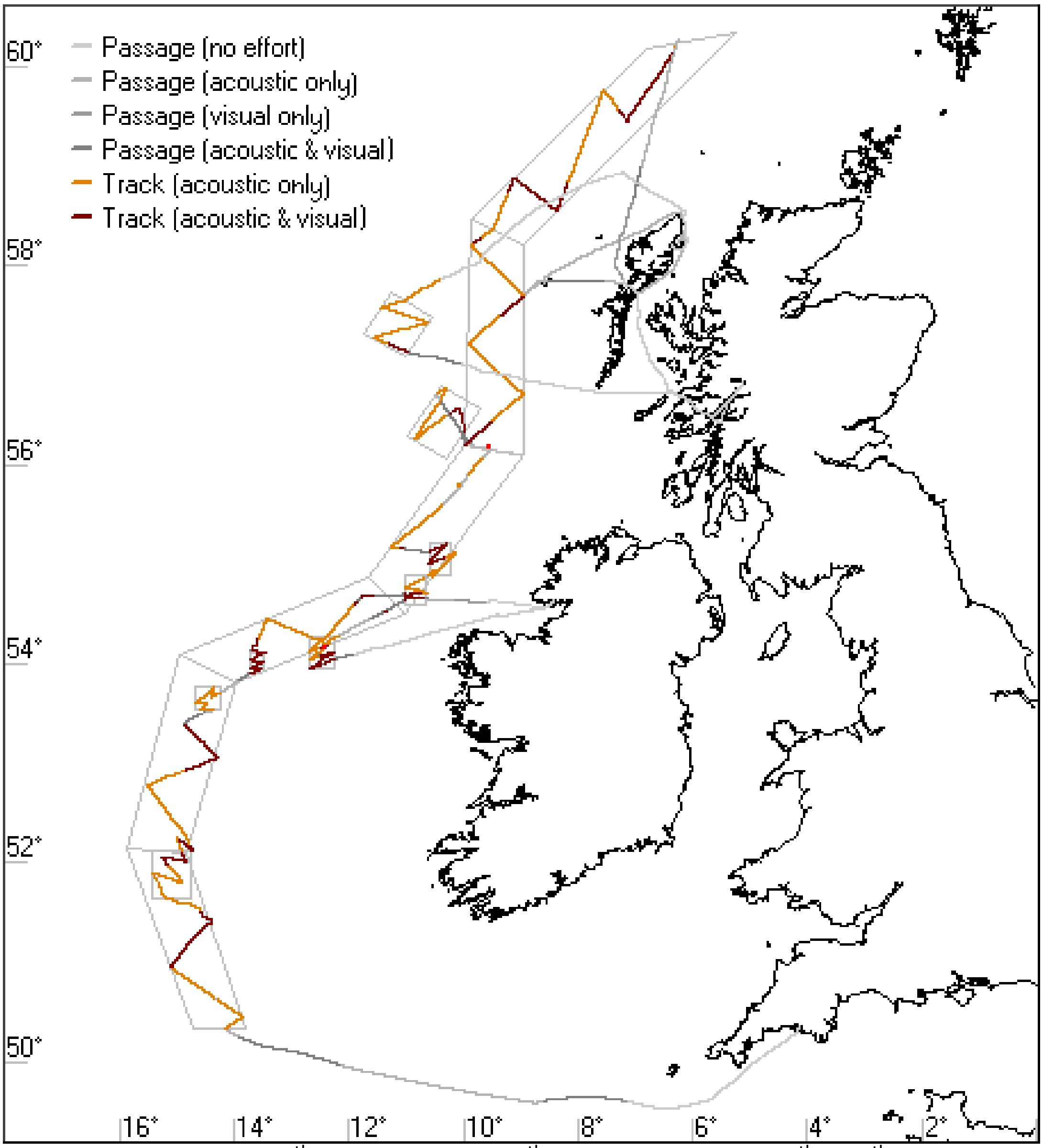


Figure 3. Effort from 15th September to 12th October 2010 and 4th to 7th March 2011.

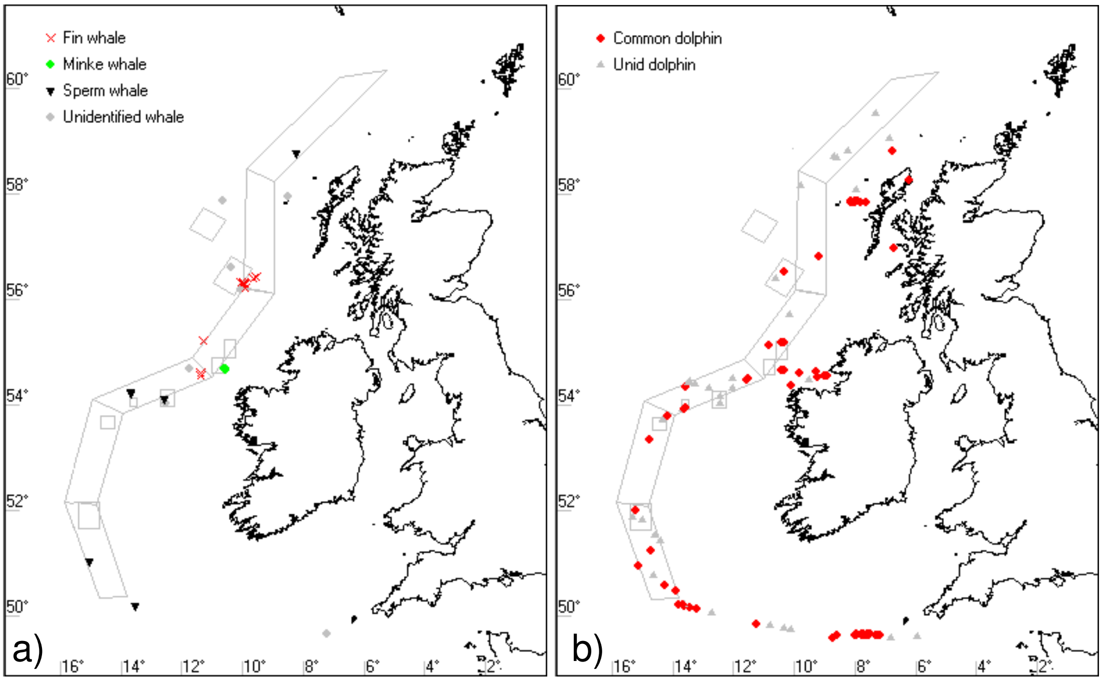
Of the 531 hours of total cruise time, almost 30% (160 hours) included visual effort; visual effort increased to 36% (94 hours) of the 260 hours spent on the survey track (Table 1).

Table 1. Summary of research effort during the survey. Acoustic effort involved hydrophones towed at survey speed and real-time signal detection. Visual effort involved at least one dedicated observer either on an observation platform or deck.

Effort status	Distance (km)	Time
Passage (no effort)	1531	117h 15m
Passage (acoustic only)	1019	88h 35m
Passage (visual only)	140	09h 49m
Passage (acoustic & visual)	678	56h 19m
Track (acoustic only)	1782	165h 24m
Track (acoustic & visual)	997	93h 53m
Total	6147	531h 15m

3.1 Sightings

A total of nine species of cetacean were identified visually in 163 separate encounters both on and off the survey trackline (Figure 4). The species identified were common dolphin (*n* = 69 sightings), long-finned pilot whale (*n* = 20), fin whale (*n* = 11), sperm whale (*n* = 6), bottlenose dolphin (*n* = 6), striped dolphin (*n* = 5), minke whale (*n* = 1), harbour porpoise (*n* = 2) and Risso's dolphin (*n* = 1).



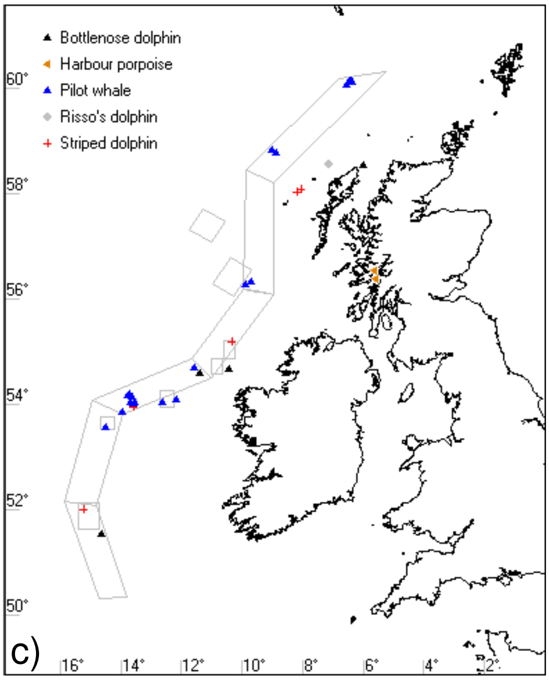


Figure 4. All 163 visual encounters with cetaceans during the survey; a) large whales, b) common and unidentified dolphins, and c) all other species.

The number of individuals in each encounter was variable, but typically the larger whales and harbour porpoises were in small groups of one to two individuals whilst the dolphins and pilot whales were typically in groups of 10 or more (Table 2).

Table 2. Mean group size for all species encountered (minima and maxima presented in parentheses). The numbers of on track encounters in each block are also presented; those blocks that had proportionally little visual effort are denoted with an asterisk.

Species	Group size	Block 1	IWDG 1 *	Block 2	IWDG 2 *	Block 3	IWDG 3	IWDG 4	Block 4	IWDG 5 *	IWDG 6	Block 5	Heb Terrace *	Block 6
Bottlenose dolphin	7 (2-20)	1	-	-	-	1	-	-	-	-	-	-	-	-
Common dolphin	7 (1-70)	4	1	2	-	5	-	-	1	-	2	1	1	-
Fin whale	1 (1-2)	-	-	-	-	2	-	-	1	-	-	5	-	-
Harbour porpoise	2 (1-2)	-	-	-	-	-	-	-	-	-	-	-	2	-
Long-finned pilot whale	6 (2-15)	-	-	1	-	5	3	1	-	-	-	2	-	7
Minke whale	1 (1-1)	-	-	-	-	-	-	-	-	-	-	-	-	-
Risso’s dolphin	12 (8-15)	-	-	-	-	-	-	-	-	-	-	-	-	-
Sperm whale	1 (1-2)	1	-	-	-	1	-	1	-	-	-	-	-	1
Striped dolphin	11 (1-40)	-	-	-	-	-	-	-	-	-	-	-	-	-
Unidentified dolphin	4 (1-12)	3	2	-	2	7	-	2	1	-	-	1	1	4
Unidentified whale	1 (1-2)	-	-	-	-	1	-	1	1	-	-	-	1	-

3.2 Acoustic detections

In addition to continuous recording, the signal from the hydrophone array was monitored aurally by an observer for two minutes every 15 minutes (approximately 1.4 nautical miles at the average survey speed of 5.7 knots). Acoustic detections of sperm whales were confined to waters deeper than 200m whilst the detection of other odontocete species appeared to be widespread throughout the survey blocks (Figure 5).

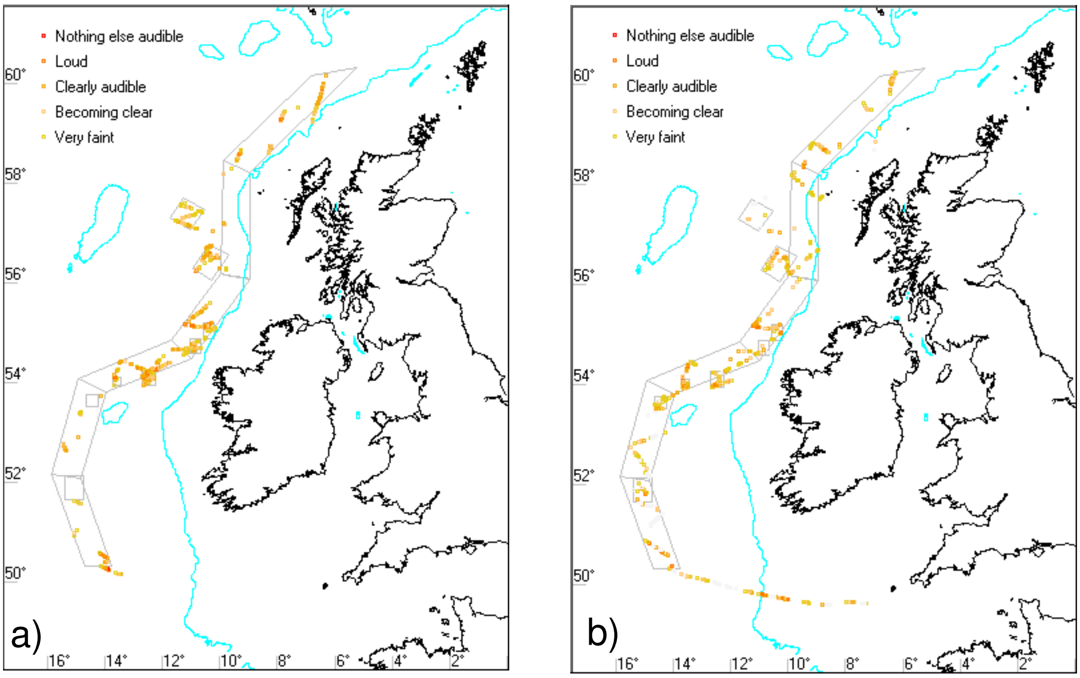


Figure 5. Presence of odontocetes as suggested by monitoring the hydrophone array every 15 minutes; a) sperm whale clicks were mostly heard in deeper waters (200 m contour shown), whereas b) clicks from other odontocetes were more widespread.

A more detailed analysis to identify potential beaked whale clicks was completed post-survey. Although no definite beaked whale clicks were identified, three probable and six possible click trains were identified (Figure 6).

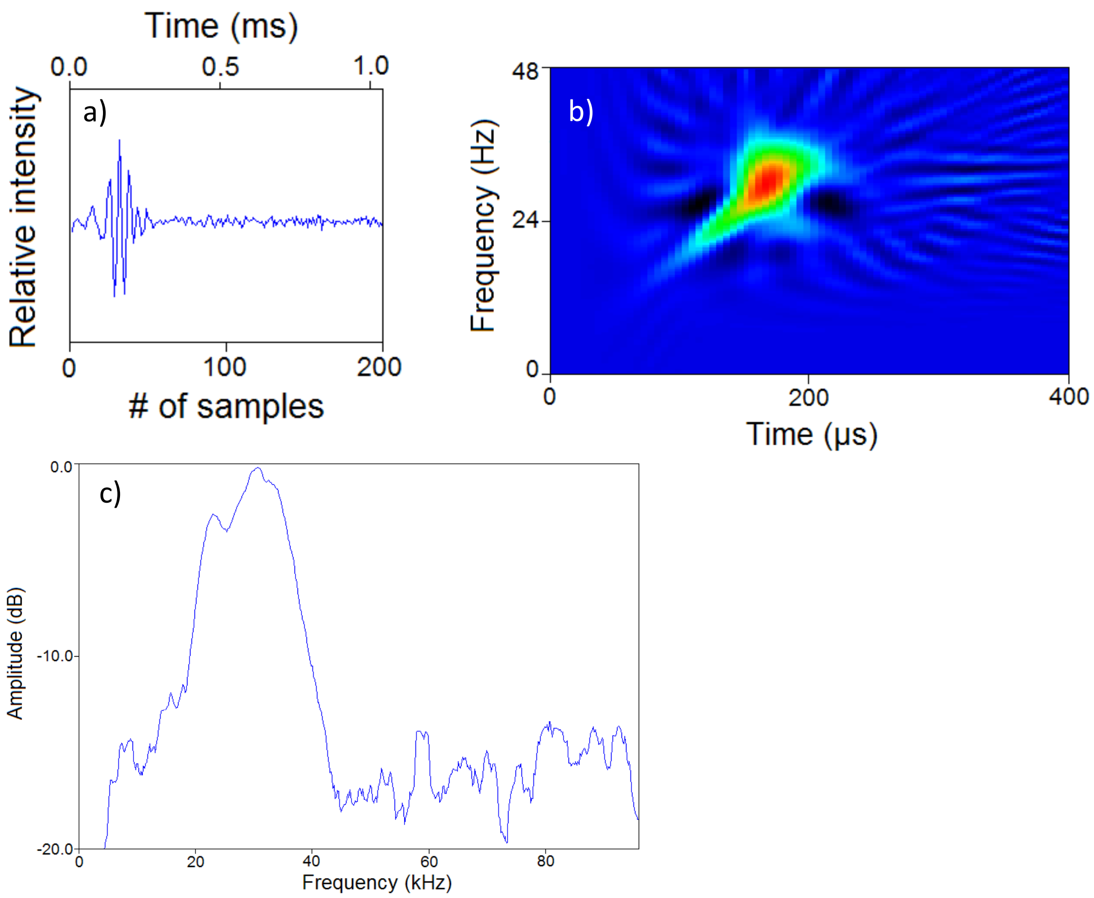


Figure 6. Features typical of a potential beaked whale click (recorded on 08:47:05 on 28/09/10) as shown in a waveform (a), time-frequency Wigner plot (b) and power spectrum (c).

Typically click trains appeared to be produced by single animals and were short (from several seconds to six minutes) with fewer than 100 clicks detected (Table 3). The potential click trains were all detected in waters between 700 and 2500 m deep in regions of moderate slope (0.2° to 10°).

Table 3. Potential beaked whale click trains identified during post-survey acoustic analysis.

Date	Track	Time of first click	Time of last click	Duration (s)	Confidence	# clicks	# trains	Depth (m)	Max. slope (°)
25/09/10	IWDG 4	12:58:06	13:04:31	385	Possible	82	1	-726	1.39
25/09/10	IWDG 4	20:54:12	20:54:19	7	Probable	36	1	-1986	3.19
25/09/10	IWDG 4	21:51:49	21:53:22	93	Possible	50	1	-1075	9.56
26/09/10	IWDG 4	02:13:51	02:13:58	7	Possible	18	1	-2434	2.60
26/09/10	IWDG 5	19:04:19	19:05:24	65	Possible	30	1	-1941	1.07
28/09/10	Block 4	02:24:29	02:25:14	45	Possible	85	1	-2192	0.73
28/09/10	Block 5	08:46:09	08:50:23	254	Probable	43	1	-1399	1.53
09/10/10	Block 6	09:23:57	09:24:58	61	Probable	30	1	-1683	0.21
10/10/10	Block 6	06:57:47	06:57:57	10	Possible	14	1	-952	0.47

All detections were made in a relatively short stretch of slope between 53°50’ and 59°40’ N, with only 810 km separating the most distant detections (Figure 7). Four of the potential detections occurred within the bounds of IWDG 4, an area thought to provide an important habitat for beaked whales (Dave Wall, *pers. commn*).

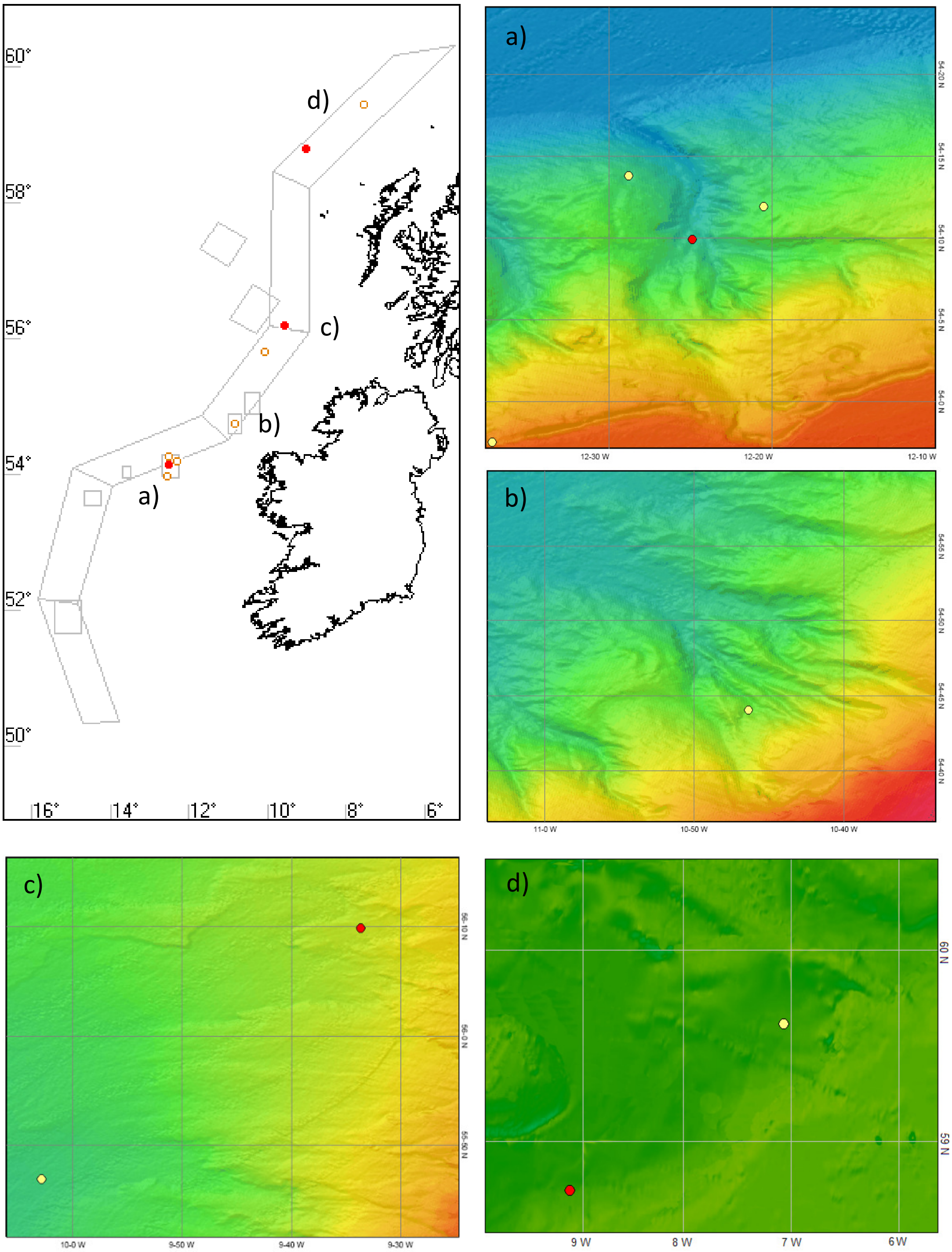


Figure 7. Positions of potential beaked whale clicks presented as a large scale view of the entire survey site with exploded views showing bathymetry (source: INFOMAR) and detailed views of the detections in a) IWDG block 4, b) IWDG block 5, c) block 5 and d) block 6. Red circles represent ‘probable’ detections; orange circles represent ‘possible’ detections.

3.3 Description of pilot whale clicks

During analysis, it became apparent that the beaked whale classifier in Pamguard often misclassified clicks from pilot whales as being from beaked whales. In order to investigate further this degree of similarity, the ten clicks with the most power from each pilot whale encounter were analysed. Although the range to the vocalising animals was not known, those clicks with the greatest energy were likely to be received on-axis and thus would be most representative of typical echolocation events. For each click, the centre frequency was measured using Raven 1.3 (Cornell Laboratory of Ornithology); this is defined as the frequency that divides a selection into two frequency intervals of equal energy. Similarly, the first and third quartile frequencies were measured as the frequencies that divide the selection into two frequency intervals containing 25% and 75% of the energy in the selection (Table 4).

Table 4. Summary of pilot whale encounters and the variables measured from the echolocation clicks with the highest signal to noise ratio (n = 10 for reach encounter; total n = 170).

ID	Date	Track	Time	Group size	Mean Q1 (Hz)	Mean centre freq (Hz)	Mean Q3 (Hz)
1	20/09	Block 2	18:27:43	10	40, 125	54, 675	69, 675
2	21/09	Block 3	07:24:36	8	20, 625	29, 400	35, 925
3	21/09	IWDG 3	11:51:26	15	28, 613	42, 263	59, 025
4	21/09	IWDG 3	12:58:16	5	23, 550	37, 425	51, 675
5	21/09	IWDG 3	16:06:08	10	26, 550	42, 975	52, 125
6	21/09	Block 3	16:35:03	8	36, 300	56, 250	67, 125
7	21/09	Block 3	16:42:55	3	26, 925	38, 550	53, 850
8	25/09	IWDG 4	07:51:29	7	11, 025	15, 675	32, 250
9	25/09	IWDG 4	13:27:27	8	21, 450	27, 750	35, 850
10	26/09	Block 3	10:02:38	6	30, 600	49, 350	63, 450
11	29/09	Block 5	13:52:42	8	45, 000	55, 650	63, 975
12	29/09	Block 5	15:03:15	4	23, 850	37, 050	58, 875
13	09/10	Block 6	09:22:53	7	26, 250	38, 625	57, 450
14	09/10	Block 6	10:42:46	6	38, 700	60, 450	75, 675
15	10/10	Block 6	15:39:49	5	39, 150	54, 525	69, 450
16	10/10	Block 6	16:37:50	7	63, 900	82, 275	89, 625
17	10/10	Block 6	17:10:34	6	36, 900	48, 300	67, 800
		OVERALL	MEAN:	7	31, 736	45, 364	59, 047

In all cases, the most intense clicks recorded from pilot whales all had significant ultrasonic energy. All but one of the mean centre frequencies were above 27 kHz, suggesting at least 50% of all the clicks' energy was above this frequency. A comparison between these mean values and measurements made from Cuvier's beaked whales (Zimmer *et al*., 2005) exhibit a great deal of overlap (Figure 8).

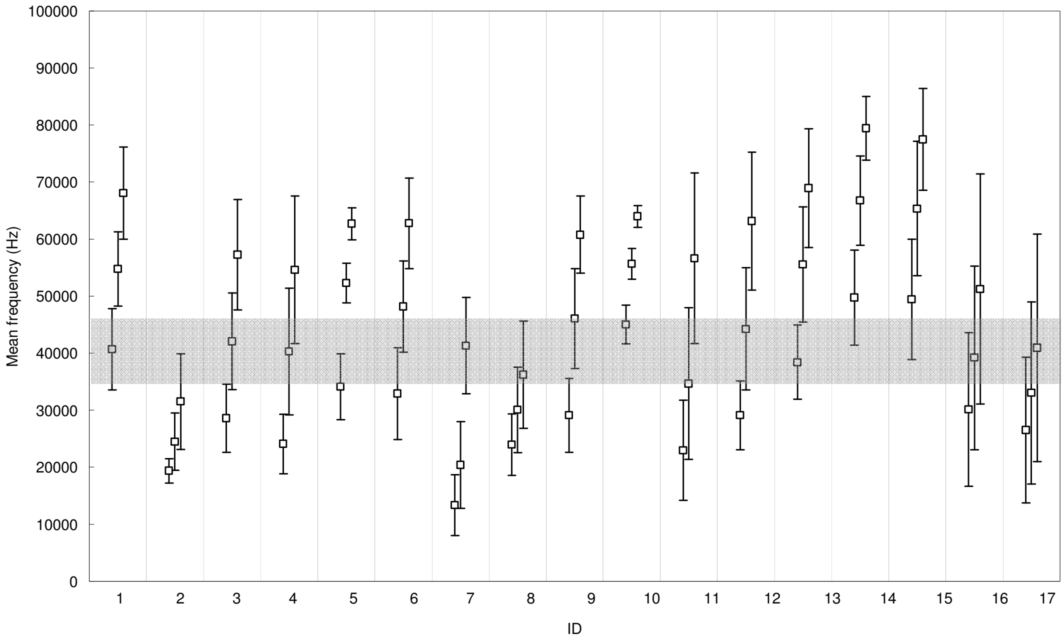


Figure 8. Mean values (plus confidence intervals) for Q1, centre and Q3 frequencies measured from pilot whale clicks. Grey region represents the half-power interval measured from Cuvier's beaked whale clicks by Zimmer *et al*., 2005.

4. DISCUSSION

Although cetaceans were encountered on 163 occasions during the survey, no confirmed sightings were made of beaked whales. Indeed only one of the unidentified whale sightings expressed any likeness to a beaked whale, such as an inconspicuous blow and suitable body shape. However, sighting conditions were rarely ideal during the study. The mean wind speed was 15 knots (equating to Beaufort state 4) and the average sea state estimated in the field was over 3 with 1.7m swell and 1m waves. As it is extremely unlikely to see a beaked whale in these conditions, acoustic techniques offer the possibility to establish the presence of ziphiids using their vocalisations alone.

Although few beaked whale clicks were noted in real-time, post-survey analysis identified nine separate potential click trains. The two most stereotypic beaked whale click trains logged in the study were recorded in the canyon system of IWDG 4 and near the Hebrides Terrace seamount. The former region has been identified as a potentially important habitat for beaked whales (Wall & Murray, 2009). In addition to the 'probable' click train identified in the main body of the central canyon system, a further two 'possible' detections were made on the canyon margins. The remaining two 'probable' detections were made in the waters surrounding the Hebrides Terrace and Rosemary Bank seamounts respectively. These seamounts formed part of a zone with relatively high sighting rates of beaked whales in the CODA survey of 2007 (Hammond *et al*., 2009). These last two detections were not made over the seamounts themselves but rather in regions of relatively low-slope (<1.6°) and shallow water (<1700 m).

The detections reported here suggest slope waters are important habitats for beaked whales, and canyon systems may provide favourable foraging conditions. The importance of canyons for beaked whales has been echoed in other studies (D'Amico *et al*., 2003; Macleod, 2005; Wimmer & Whitehead, 2004). However the detections near the Hebrides Terrace and Rosemary Bank imply that seamounts may also provide conditions conducive for the preferred prey of ziphiids as has been suggested previously (Ferguson *et al*., 2006; Kaschner, 2007). Although sufficiently rigorous algorithms do not yet exist to determine species identity from acoustic recordings alone, the detected clicks were not typical of northern bottlenose whales (peak frequencies of 10 to 25 kHz; Hooker & Whitehead, 2002). Rather, the detected clicks were likely to be produced by a *Mesoplodon* (Sowerby's or True's beaked whale) or a *Ziphius* (Cuvier's beaked whale).

A confounding factor in the detection of beaked whale clicks is the saturation of calls with ultrasonic energy from other species, such as sperm and pilot whales. As the algorithms in *Pamguard* and *Rainbow Click* are reliant on beaked whale clicks being several decibels above background noise levels, the sheer volume of vocalisations from other odontocetes has the potential to mask the less intense clicks of ziphiids. The routine presence of sperm whales in this study may present an obstacle to the effective acoustic detection of beaked whales as the energy of *Physeter* clicks may reach up in to the typical ziphiid range (above 25 kHz; Mohl *et al*., 2003). Sperm whale detections were confined to waters deeper than 200m. A high degree of clumping appeared to be evident over the Hebrides Terrace seamount and in survey blocks 3 and 4. This apparent concentration of individuals may reflect favourable feeding conditions over seamounts and the canyon systems of the shelf margin.

Similarly, pilot whales clicks have the ability to confound a detection algorithm designed to detect beaked whale clicks, with peak frequencies reported from 25 to 40 kHz (Fish & Turl, 1976). In this study, those clicks thought to be most representative of echolocating pilot whales had 75% of their energy between 32 and 59 kHz. Although this does not provide an insurmountable overlap with beaked whale clicks (35 to 45 kHz bandwidth), the high degree of variation exhibited in pilot whale clicks means that occasional clicks fit the typical profile of a beaked whale click. As pilot whales were spread widely along the slope waters of the study area, their presence often confounded the detection algorithms used in this study. Inspection of the Wigner plots of candidate clicks, in conjunction with an upsweep classifier in Pamguard to measure the number of zero crossings in the waveform, appeared to be the most useful diagnostic approaches to differentiating pilot whale clicks from those of beaked whales; beaked whale clicks were invariably found to be upswept with at least five zero crossings. However, in those areas where overlap with beaked whales is likely, such as over canyon systems, care should be taken in analysing acoustic data alone. Typically, consecutive clicks produced by pilot whales (and sperm whales) vary in their tonal characteristics, a key diagnostic tool when differentiating from uniformly narrowband ziphiid clicks. Most problems seem to arise when only a few clicks are available for analysis, such as when animals are at depth and orientated away from the hydrophone elements, and this tonal variability may not be fully captured.

During the surveys conducted along the Rockall Trough, the most regularly sighted species was common dolphin, often in large groups of up to 70 individuals. On three occasions, mixed groups of common and striped dolphins were observed; on a single occasion, a mixed group included both common and bottlenose dolphins, an unusual assemblage. There has been some suggestion in recent years that the distribution of common dolphins in Europe may be dispersing northwards (Macleod *et al*., 2005). Indeed, common dolphins were encountered as far north as 58°N. In the North Atlantic, the common dolphin is typically found in warmer waters, while the white-beaked dolphin is restricted to the colder waters. Perhaps surprisingly, no white-beaked dolphins were encountered in this study, even though the survey tracklines reached as far as 60°N. The water temperature averaged 14.5°C throughout the study (with a range from 10.9 to 17.6°C) which are values more in line with the peak temperature summer months off Britain and Ireland (Macleod *et al*., 2008). The presence of a warm-water trend was also indicated by the presence of striped dolphins, as this is a species typically found from warm temperate to tropical waters.

As might be expected, some species were only encountered in certain habitats. Harbour porpoises were only encountered in the shallower shelf waters close to land. Risso's dolphins were only seen off Lewis, a known hotspot for this species in UK waters. Although only one minke whale was encountered, it was seen in shallower shelf waters on the approach to the Irish mainland, as is in keeping with the known habits of this species in the area. Sperm whales were only seen or heard in waters deeper than 200m, the preferred habitat of foraging *Physeter*. Conversely, odontocete clicks and whistles were uniformly distributed throughout the study area. As these vocalisations are produced by several species that may favour different habitats (for example resident bottlenose dolphins close to land), it is perhaps not surprising that they were found to be ubiquitous. Further refinement of detection algorithms may allow species identification from acoustic recordings, thus allowing future (and retrospective) surveys to ascertain odontocete habitat partitioning. Fin whale sightings were highly clustered, with all sightings occurring within 200 km of each other. Many of these were to the east of the Hebrides Terrace seamount and it is not clear if this aggregation represented a transient group of animals or a more significant region of productivity. Further research over the seamounts of the Rockall Trough would be extremely beneficial to our understanding of cetacean distribution in the area.

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6. REFERENCES

Aguilar Soto, N., Rogan, E., Ó Cadhla, O., Gordon, J. C. D., Mackey, M. and Connolly, N. 2004. Cetaceans and seabirds of Ireland's Atlantic Margin. Volume III – Acoustic surveys for cetaceans, Report on research carried out under the Irish Infrastructure Programme (PIP): Rockall Studies Group (RSG) projects 98/6 and 00/13, Porcupine Studies Group project P00/15 and Offshore Support Group (OSG) project 99/38.

Berrow, S. 2001. Is Ireland a sanctuary: protection of cetaceans (whales, dolphins and porpoise) in Irish waters. In: Convery F, Feehan J (eds) *Achievement and Challenge: Rio+ and Ireland*. The Environmental Institute, University College, Dublin, Dublin, p 358-363.

Boisseau, O., Lacey, C., Lewis, T., Thorne, T., Moscrop, A., Gillespie, A. and Aguilar de Soto, N. 2009. *Mid-Atlantic surveys for beaked whales: The potential for acoustic prediction of critical habitats*. Poster presented to the 23rd Conference of the European Cetacean Society, Istanbul.

Cato, D. H., Blewitt, M., Cleary, J., Savage, M., Parnum, I., McCauley, R. D., Dunlop, R. A., Gibbse, S. and Donnelly, D. 2009. *Preliminary results of acoustic surveying for beaked whales in Coral Sea near Australia*. 3rd International Conference & Exhibition on "Underwater Acoustic Measurements: Technologies & Results".

Charif, R. A. and Clark, C. W. 2009. *Acoustic monitoring of large whales in deep waters north and west of the British Isles: 1996 - 2005*, Technical Report 08-07, 40 pp.

D'Amico, A., Bergamasco, A., Zanasca, P., Carniel, S., Nacini, E., Portunato, N., Teloni, V., Mori, C. and Barbanti, R. 2003. Qualitative correlation of marine mammals with physical and biological parameters in the Ligurian Sea. *IEEE Journal of Oceanic Engineering* 28: 29-43

Evans, P. G. H. 1995. *Guide to the identification of whales, dolphins and porpoises in European seas*. Sea Watch, Oxford.

Ferguson, M. C., Barlow, J., Reilly, S. B., Gerrodette, T. 2006. Predicting Cuvier's (*Ziphius cavirostris*) and *Mesoplodon* beaked whale population density from habitat characteristics in the eastern tropical Pacific Ocean. *J. Cetacean Res. Manage*. 7: 287-299.

Fish, J. F. and Turl, C. W. 1976. *Acoustic source levels of four species of small whales*. Report No. ADA037620, Naval Undesea Center San Diego, California. 21 pp.

Frantzis, A., Goold, J. C., Skarsoulis, E. K., Taroudakis, M. I. and Kandia, V. 2002. Clicks from Cuvier's beaked whales, *Ziphius cavirostris*. *J. Acoust. Soc. Am*. 112(1): 34-37.

Gillespie, D., Dunn, C., Gordon, J., Claridge, D. E., Embling, C. and Boyd, I. L. 2009. Field recordings of Gervais' beaked whales *Mesoplodon europaeus* from the Bahamas. *J. Acoust. Soc. Am.* 125(5): 3428-3433.

Hammond, P. S. and Macleod, K. 2006. *Progress report on the SCANS-II project*. ASCOBANS Advisory Committee, Finland, 6 pp.

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

Hooker, S. K. and Whitehead, H. 2002. Click characteristics of northern bottlenose whales (*Hyperoodon ampullatus*). *Marine Mammal Science* 18: 69-80.

Johnson, M., Madsen, P. T., Zimmer, W. M. X., de Soto, N. A. and Tyack, P. L. 2004. Beaked whales echolocate on prey. *Proceedings of the Royal Society of London Series B-Biological Sciences* 271: S383-S386.

Johnson, M., Madsen, P. T., Zimmer, W. M. X., Aguilar de Soto, N. and Tyack, P. L. 2006. Foraging Blainville's beaked whales (*Mesoplodon densirostris*) produce distinct click types matched to different phases of echolocation. *Journal of Experimental Biology* 209: 5038-5050.

Johnson, M. P. and Tyack, P. L. 2003. A digital acoustic recording tag for measuring the response of wild marine mammals to sound. *IEEE J. Oceanic Eng*. 28(1): 3-12.

Kaschner, K. 2007. *Air-breathing visitors to seamounts: Marine Mammals*. In: Pitcher, T. J., Morato, T., Hart, P. J. B., Clark, M. R., Haggan, N., Santos, R. S. (eds) Seamounts: Ecology, Conservation and Management. Blackwell, Oxford, p 230-238.

Lewis, T. P., Swift, R., Gonzalbes, P., Butler, J. and Gordon, J. G. 1998. *Passive Acoustic Monitoring of Cetacean Distribution North-west of the Hebrides, 1997-1998*. Hebridean Whale and Dolphin Trust, Mull, 75 pp.

MacLeod, C. M. 2005. *Niche Partitioning, Distribution and competition in North Atlantic Beaked Whales*. PhD thesis submitted to the School of Biological Sciences, University of Aberdeen.

MacLeod, C. M., Bannon, S. B., Pierce, G. J., Schweder, C., Learmonth, J. A., Herman, J. S. & Reid, R. J. 2005. Climate change and the cetacean community of north-west Scotland. *Biological Conservation* 124: 477–483.

MacLeod, C. M. and Reid, J. B. 2003. *Distributions, migrations and bottlenecks: Implications for anthropogenic impacts on beaked whales on the Atlantic Frontier*. Presented at the 17th European Cetacean Society Annual Conference, Las Palmas de Gran Canaria, 9 - 13th Match 2003.

MacLeod, C. D., Weir, C., Santos, M. B., Dunn, T. E. 2008. Temperature-based summer habitat partitioning between white-beaked and common dolphins around the United Kingdom and Republic of Ireland. *J. Mar. Biol. Ass*. 88:1193-1198.

Møhl, B., Wahlberg, M., Madsen, P. T., Heerfordt, A. and Lund, A. 2003 The monopulsed nature of sperm whale clicks. *J. Acoust. Soc. Am*. 114: 1143-1154.

NPWS. 2008. *The status of EU protected habitats and species in Ireland. Conservation status in Ireland of habitats and species listed in the European Council Directive on the Conservation of Habitats, Flora and Fauna 92/43/EEC*. National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government.

Ó Cadhla, O., Mackey, M., Aguilar de Soto, N., Rogan, E. & Connolly, N. 2004. *Cetaceans and seabirds of Irelands Atlantic Margin. Volume II – Cetacean distribution and abundance. Report on research carried out under the Irish Infrastructure Programme (PIP): Rockall Studies Group (RSG) projects 98/6 and 00/13, Porcupine Studies Group project P00/15 and Offshore Support Group (OSG) project 99/38*. 82 pages.

Pavan, G., Fossati, C., Priano, M. and Manghi, M. 2006. *Recording Cuvier's beaked whales (Ziphius cavirostris) with a wideband towed array*. SC/58/E18. Report to the 58th IWC Scientific Committee, 3 pp.

Pollock, C. M., Mavor, R., Weir, C. R., Reid, A., White, R. W., Tasker, M. L., Webb, A. and Reid, J. B. 2000. *The distribution of seabirds and marine mammals in the Atlantic frontier, North and West of Scotland*. Joint Nature Conservation Committee: Aberdeen, UK. ISBN 1-86107-505-7., 92 pp.

Rankin, S. and Barlow, J. 2007. Sounds recorded in the presence of Blainville's beaked whales, *Mesoplodon densirostris*, near Hawai'i. *J. Acoust. Soc. Am*. 122(1): 42-45.

Reid, J. B., Evans, P. G. H. and Northridge, S. P. 2003. *Atlas of cetacean distribution in north-west European waters*. JNCC, Peterborough, 82 pp.

Rogan, E. and Berrow, S. D. 1995. The management of Irish waters as a whale and dolphin sanctuary. In: *Whales, seals, fish and man*. Edited by A. S. Blix, L. Walløe and Ø. Ulltang. Elsevier Science (Amsterdam): 671-681.

Swift, R. J., Hastie, G. D., Barton, T. R., Clark, C. W., Tasker, M. L. and Thompson, P. M. 2002. *Studying the distribution and behaviour of cetaceans in the northeast Atlantic using passive acoustic techniques*. Report for the Atlantic Frontier Environmental Network, 87 pp.

Wall, D. 2006. *Cetacean distribution and relative abundance survey during FSS deep water survey 2006*. Unpublished Report to the Marine Institute, Oranmore, Galway, Ireland.

Wall, D. 2007. *Cetacean Distribution and Relative Abundance Survey during FSS Deep Water Survey 2007*. Unpublished Report to the Marine Institute, Oranmore, Galway, Ireland.

Wall, D. and Murray, C. 2009. *ISCOPE II work package 3: Ship surveys and ferry surveys*. Final report to the ISCOPE II Steering Committee, Irish Whale and Dolphin Group. 58 pages.

Weir, C. R. 2000. Sightings of beaked whale species (Cetacea: Ziphiidae) in the waters to the north and west of Scotland and the Faroe Islands. In: *European Research on Cetaceans – 14. Proceedings of the fourteenth Annual Conference of the European Cetacean Society, Cork, Ireland, 2-5 April 2000*.

Weir, C. R., Pollock, C., Cronin, C. and Taylor, S. 2001. Cetaceans of the Atlantic Frontier, north and west of Scotland. *Continental Shelf Research* 21(8-10): 1047-1071.

Wimmer, T. and Whitehead, H. 2004 Movements and distribution of northern bottlenose whales, Hyperoodon ampullatus, on the Scotian Slope and in adjacent waters. *Canadian Journal of Zoology* 82: 1782-1794

Zimmer, W. M. X., Johnson, M. P., Madsen, P. T. and Tyack, P. L. 2005. Echolocation clicks of free-ranging Cuvier's beaked whales (Ziphius cavirostris). *Journal of the Acoustical Society of America* 117(6): 3919-3927.