ANALYSIS OF TOWED HYDROPHONE DATA COLLECTED AT COSTA HEAD, WESTRAY SOUTH AND CANTICK HEAD SITES BETWEEN JANUARY AND AUGUST 2012

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INTRODUCTION

Passive acoustic monitoring data have been collected between January – August 2012 at the Cantick Head and Westray South tidal energy sites, and the Costa Head wave power site. A preliminary analysis and assessment of these data is presented here with a focus on quantifying the effectiveness of both the visual and acoustic monitoring effort. These PAM data compliment visual survey data of cetaceans collected at the same time (see NRP 2013a, NRP 2013b and NRP 2013c).

The majority of cetaceans likely to be encountered in Orkney's inshore waters, including the three sites of interest here, are small odontocetes: dolphins and harbour porpoises. All small cetaceans are challenging to survey, in part because they are difficult to sight in real world conditions, and none are more problematic than the harbour porpoise (*Phocoena phocoena*). The harbour porpoise is a species of particular interest. It is by far the commonest cetacean species at these sites and is listed on both Annex II and Annex IV of the EC Habitats Directive. The harbour porpoise is a species that is known to make use of tidal rapid habitats in some areas (Gordon et al., 2011; Pierpoint, 2008) and to be very sensitive to acoustic disturbance (Brandt et al., 2011; Olesiuk et al., 2002). Harbour porpoises are small and undemonstrative animals, and this makes them difficult animals to sight at sea, especially when sighting conditions are not ideal. However, they vocalise frequently (Akamatsu et al., 2007) producing characteristic click vocalisation that can be detected at ranges of several hundred meters. Harbour porpoises clicks are in the high ultrasonic and narrow band (115-135kHz) far above the human auditory range. Thus, specialised equipment and acoustic analysis software are required to detect and localise them. Towed hydrophone systems have been in development for porpoise monitoring over the last few decades (Chappell et al., 1996; Gillespie and Chappell, 2002; Gillespie et al., In Press). The current generation of equipment uses high speed digital acquisition cards and computer programs (such as PAMGAURD) that can detect, classify and localise ultrasonic clicks in real time. The high level of automation that PAM systems can now provide means that acoustic surveys can be conducted by small field teams and potentially yield more consistent datasets than visual methods. In addition, acoustic detection is generally less affected by weather conditions than visual detection and can continue in poor sighting conditions and at night.

These are all important practical advantages especially on joint seabird and marine mammal surveys. Useful seabird data can be collected in higher sea states than for marine mammals. Thus, dual purpose surveys, such as this one, will continue in sea states that would normally preclude the collection of useful cetacean visual data. Further, high tidal current areas, such as the Westray South and Cantick Head sites are particularly challenging environments for survey. Gordon et al. (2011) made extensive use of passive acoustic systems during surveys for harbour porpoises in tidal rapid areas in Welsh waters. They reported that towed hydrophones were particularly useful for surveys in these habitats because strong tidal currents lead to disturbed waters and poor sighting conditions, even in good weather conditions. [The surveys reported below of the Cantick Head and Westray South sites encountered a range of sea-states (sea-states during surveys are reported in NRP 2013a, NRP 2013b and NRP 2013c). On most survey visits the majority of the survey areas had sea-state categories of between 1 and 3, though at times on these surveys localised areas, where strong tidal currents interacted with waves and swell, had higher sea-states than the rest of the Survey Area.]

Dolphin species can also be highly vocal. Thus, PAM methods can be helpful for monitoring dolphins, though the techniques for doing this are less well developed than those for porpoises and, because dolphins are usually easier to sight, the relative advantages of PAM might be considered less compelling for dolphins.

A further reason for using passive acoustic techniques in conjunction with visual monitoring on site surveys, such as this one, is that PAM provides a second independent method of detection allowing mark-recapture type analysis techniques to be used to determine g(0), the proportion of animals missed on the trackline. This allows absolute abundance to be calculated provided an adequate sample size is achieved. (As this is a relatively new methodology more details are provided as an Appendix.) Even when insufficient data are collected it allows useful abundance estimates to be made, however, mark-recapture comparison of visual and acoustic detections can still provide a measure of the effectiveness of each method on a particular survey.

METHODS

EQUIPMENT

The passive acoustic detection system used for this work is based on that developed for, and used successfully during, the SCANSII and CODA surveys (Gillespie et al., In Press). It consisted of a standard Marine Ecological Research Ltd high frequency stereo hydrophone comprising a streamlined oil-filled sensor unit towed on a long Kevlar strengthened cable. For the surveys described here a cable length of 100m was used. The sensor streamer contained two broad-band Magrec HP03 hydrophone units (each consisting of a spherical ceramic coupled with an HP02 preamplifier with 28dB gain and a 2kHz low cut filter). This hydrophone/preamplifier combination has a near flat response (equal sensitivity) between 2 and 150kHz. The sensor unit also contained a pressure sensor to provide hydrophone depth data. A recording station with topside electronics, a digitiser and a computer was established in the ship's saloon. Signals from the hydrophone were amplified using a Magrec HP27ST amplifier and filtered with a 20kHz high pass filter before being digitised at 500kHz per channel using a National Instruments USB-6251 DAQ. A computer running an appropriate PAMUARD configuration made continuous recordings to its hard drive as well as running a click detector and collecting GPS data. (PAMGAURD is an open source and free to use specialist passive acoustic monitoring program which can be configured to detect, classify and localise a range of different signals (Gillespie et al., 2008). Recent funding from a wind farm developer, Smartwind, has allowed much of the functionality required for small cetacean towed hydrophone survey to be programed within PAMGUARD. http://www.pamguard.org/)

DATA COLLECTION

During surveys, one of the MMOs set up the system before each day's work. MMO's monitored the system through the day, as far as was possible, bearing in mind that their primary task was to carry out the visual survey.

Full bandwidth recordings were made continuously as .wav files using PAMGUARD software whenever the hydrophone was deployed at sea. Data were posted to MER on hard drives for analysis as soon as possible after each survey to allow the first stages of analysis to be completed swiftly and any faults or problems to be identified and remedied.

Generally, the equipment has performed satisfactorily from this vessel. The hydrophone tow depth was usually about 5m sinking deeper during turns or when the speed dropped. The equipment collected useful data on all surveys on which it was deployed. Levels of underwater noise on the recordings have been quite high compared to those typical on other survey deployments from vessels of this size. It is probable that relatively shallow depths, hard bottom and high boat speed through the water on occasions, contributed to higher noise levels. The cable length of the hydrophone, 100m, was also less than the length (200m) typically utilised by MER on wind farm site surveys. This shorter length was specified in the light of the shallow water and sharp course changes required on the tidal surveys. During future surveys it is planned to trial the use of longer cable lengths (out to 200m).

There have been a number of issues related to high vessel noise. For example, on surveys in February and March high levels of noise and elevated trigger rates for the click detector caused frequent computer crashes. These occurred because a PAMGUARD configuration with a spectrogram (which is highly processor intensive) had been mistakenly loaded (e.g. Figure 1). Once MER was alerted to the problem it was easily remedied by increasing the trigger levels and removing the spectrogram. The intention is to avoid issues like this in the future by providing some more advanced training courses for survey personnel.

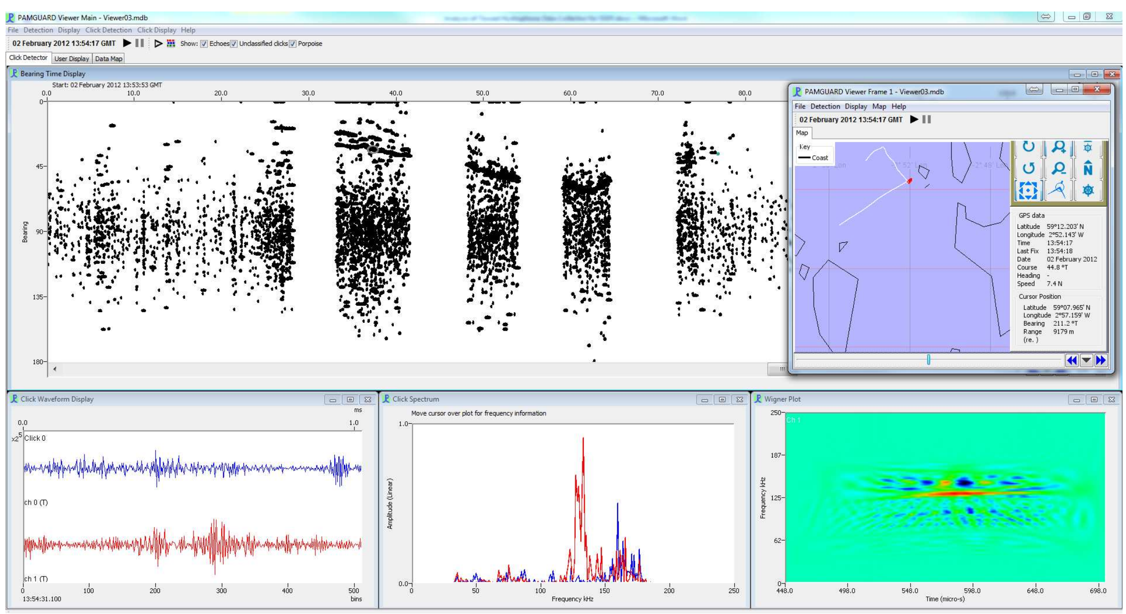


FIGURE 1. PAMGUARD ANALYSIS WINDOW SHOWING COMPUTER CRASHING DURING TURN BETWEEN LINES. THE TOP PANE IS A PLOT OF BEARING AGAINST TIME FOR CLICK DETECTIONS. BLANK SPACES INDICATE WHERE RECORDINGS WERE LOST DUE TO COMPUTER.

Another persistent acoustical problem has been interference from the vessel's echo-sounder. Although there is an agreement with the skipper that the echo-sounder should be used as little as possible, consistent with safe vessel operation, it was often inadvertently left running. Because the MMO could usually only check the equipment when off effort between surveys, it could take some time to identify and remedy such problems.

This was a particular issue in March when the sounder was on continuously throughout the survey. The frequency peaks of this particular echo-sounder are at 50kHz and at 150kHz (Figure 2) and the upper frequency could potentially mask porpoise detections. The extent to which this might also affect the behaviour of animals and thus also influence visual survey detections is unknown.

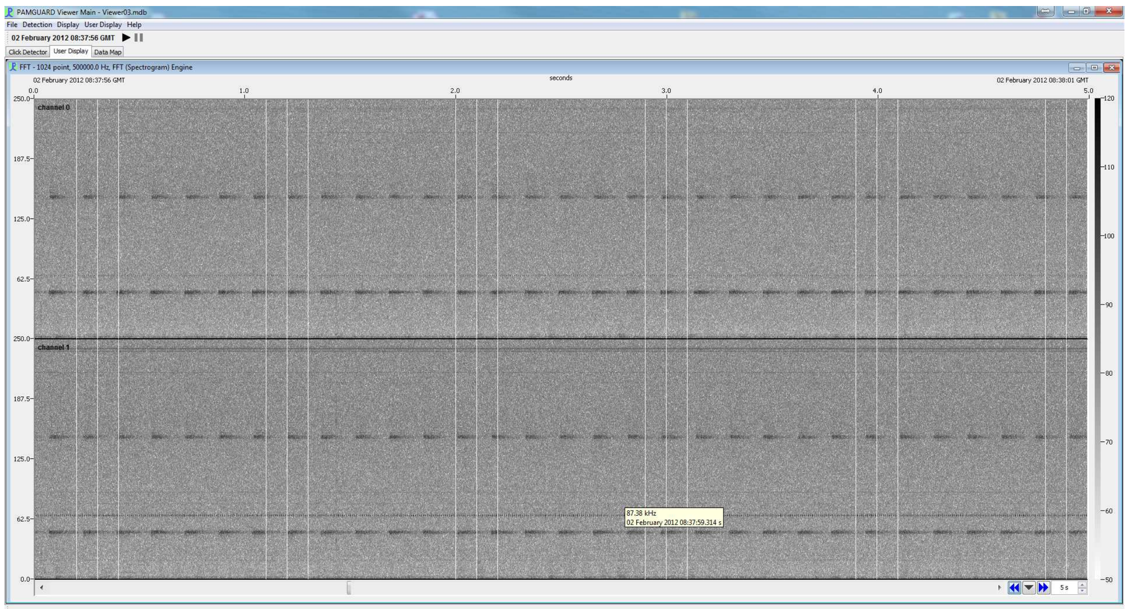


FIGURE 2: SPECTROGRAM SHOWING ECHOSOUNDER SIGNALS AT 50kHz AND 150kHz

Analysis Methodology

All recordings were analysed at MER once the hard drives were received. Broad-band .wav file recordings were batch-processed to produce PAMGAURD "Binary Files" containing summary data of all click detections along with GPS data.

A single experienced operator (AW) reviewed all of the batch-processed data in a PAMGUARD viewer. Clicks that the program had identified as being likely to be from porpoises (based on their acoustic characteristics) were distinctively coloured (shown as red triangles in the figures in this report). These putative porpoise clicks were further investigated by the operator; for example the waveform and spectra of individual clicks were examined, to confirm species identity. When the operator was confident of the event it was "marked up" by drawing a bounding line around the periphery of the group of clicks in the event. A summary of the event and the clicks that constituted it were stored along with range information in an access database.

Three types of porpoise acoustic encounters were distinguished.

A "porpoise track" was an acoustic encounter with a porpoise or pod where a series of clicks on a gradually changing bearing, from ahead to astern, could be detected. These occurred as the boat passed by a vocalising individual or pod and multiple detections were made. The operator discriminated and marked out independent tracks and for each track recorded their assessment of the species and number of animals present. The next analysis step for tracks was to apply target motion analysis in PAMGUARD. During this procedure, the pattern of changing click bearings in an event are analysed to determine the most likely location for the sound source. Figure 3 shows a typical "porpoise track" on a PAMGUARD display. This is a multiple animal event with two distinctive click trains. Figure 4 illustrates these two demarcated tracks, while

Figure 5 shows the application of target motion analysis to determine a likely location and range from the trackline for one of these tracks. It can be seen that two likely positions have been calculated, one on each side of the trackline. With a stereo array such an ambiguity will occur, unless the vessel track varied during the encounter. However, in line transect surveys, such as this one, these range data are principally used to determine a detection function for distance from the trackline, and whether an animal is to the left or right is not relevant for this.

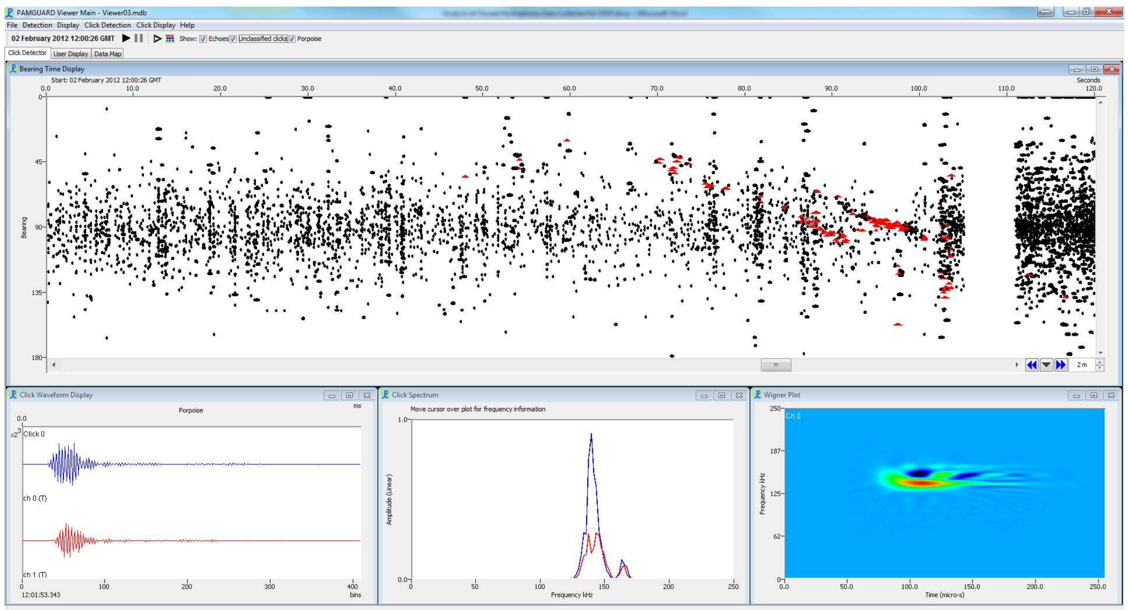


FIGURE 3. PAMGUARD DISPLAY OF A PORPOISE TRACK ENCOUNTER. TOP PANE SHOWS A BEARING TIME PLOT FOR CLICK DETECTIONS. THE CLICKS MARKED AS RED TRIANGLES HAVE BEEN CLASSIFIED AS PORPOISE CLICKS BASED ON THEIR ACOUSTICAL CHARACTERISTICS.

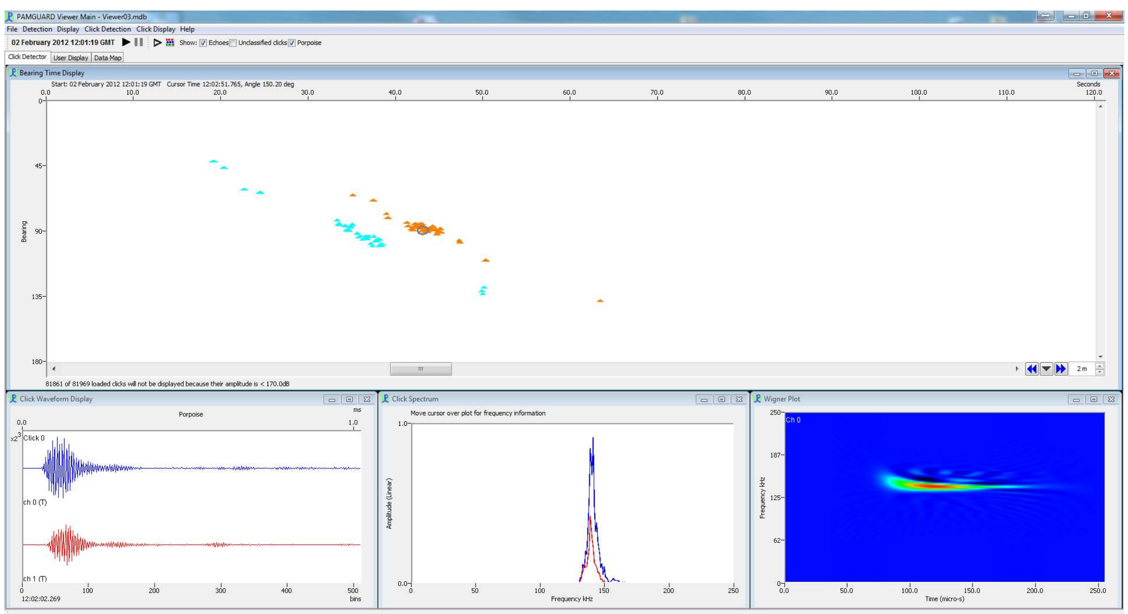


FIGURE 4. CLICKS ON A CONSISTENT TRACK ARE MARKED AS A TRACK EVENT, IN THIS CASE TWO TRACKS CAN BE DISTINGUISHED. IN THIS VIEW NON PORPOISE CLICKS HAVE BEEN EXCLUDED FOR CLARITY. THE BOTTOM PANELS SHOW VIEWS OF ONE HIGHLIGHTED CLICK. WAVEFORM ON THE LEFT, SPECTRAL PLOT IN THE MIDDLE (NOTE NARROW BAND 130KHZ PULSE) AND WIGNER PLOT ON RIGHT.

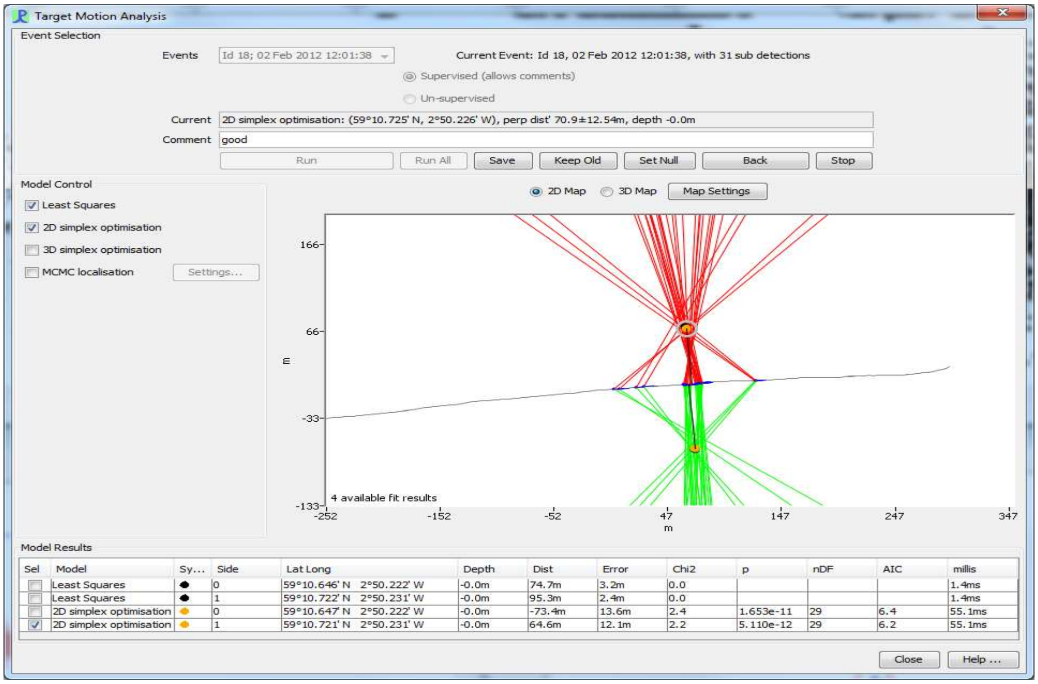


FIGURE 5. TARGET MOTION ANALYSIS IS USED TO DETERMINE THE LIKELY POSITION OF THE VOCALISING ANIMAL AND CALCULATE A RANGE FROM THE TRACKLINE. NOTE: BECAUSE THE HYDROPHONE HAS A LEFT RIGHT AMBIGUITY IT IS NOT ALWAYS POSSIBLE TO DETERMINE WHETHER THE ANIMAL IS ON THE LEFT OR RIGHT SIDE OF THE BOAT. FOR MOST SURVEY APPLICATIONS THIS IS NOT CRITICAL HOWEVER

Porpoise Events. The second acoustic encounter class, was termed an "Event". Events were groupings of porpoise-like clicks that didn't fall on a distinct bearing e.g. Figure 6. Ranges cannot be determined for "events" using target motion analysis because they provide insufficient directional information.

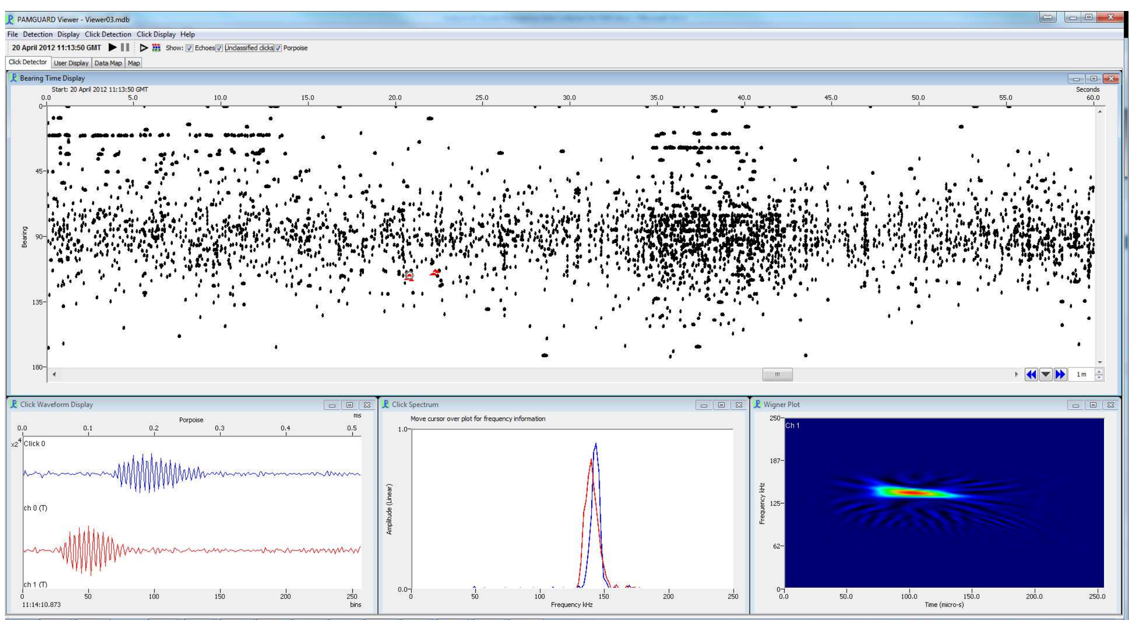


FIGURE 6. AN EXAMPLE OF A PORPOISE EVENT. A SIGNIFICANT CLUSTER OF PORPOISE CLICKS (RED TRIANGLES) ARE PRESENT BUT THEY DO NOT FALL ON A CLEAR TRACK.

Single Clicks The final encounter category identified was "single click". These encounters consisted of single clicks, which were often very clear and had the distinctive acoustic characteristics of porpoise clicks but occurred on their own e.g. Figure 7. Ranges and locations cannot be determined for single click encounters.

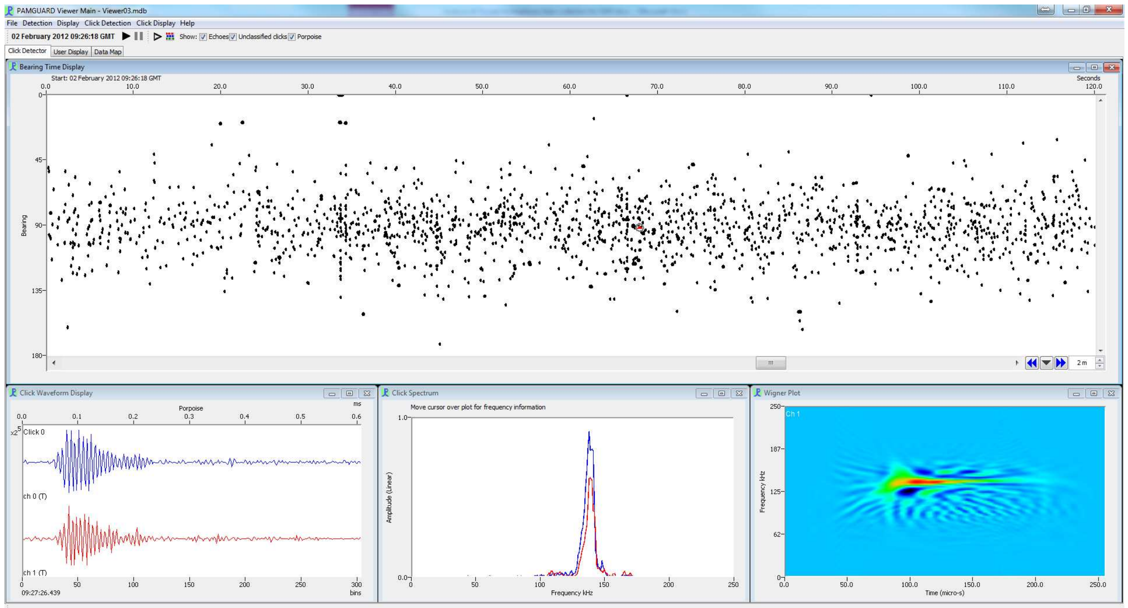


FIGURE 7 AN EXAMPLE OF A SINGLE CLICK ENCOUNTER. ALTHOUGH ONLY A SINGLE ISOLATED CLICK (RED TRAINGLE) CAN BE DISTINGUISHED IT SHOWS THE DISTINCTIVE ACOUSTIC CHARACTERISTICS OF PORPOISE CLICKS, LONG DURATION, NARROW BAND ~130KHZ SPECTRUM.

In addition, events were further classified into two confidence categories: certain and likely.

RESULTS

Table 1 summarises visual and acoustic effort and porpoise detections for the entire survey period broken down by month. Sighting data recorded by both the dedicated MMOs and the ESAS surveyors (see NRP 2013a, NRP 2013b and NRP 2013c for results of visual surveys) have been pooled with duplicate sightings being excluded. (A sighting was considered a duplicate if it was seen within 1 minute with a similar range and bearing). The dedicated visual MMOs made over twice as many sightings (35) as the ESAS surveyors (14). In part this reflects the fact that the ESAS observers only searched on one side of the vessel.

The overall acoustic detection rate (combining all event types) (Table 1) was slightly higher than the visual detection rate, while the detection rate of just the acoustic track events was slightly lower. As will be seen in a later section (Table 3), the proportion of sightings that were also detected acoustically (duplicates) is rather low (~12%). Thus, for porpoises at least, the addition of acoustic monitoring has served to approximately double the overall number of independent detections.

Both visual and acoustic detection rates varied between months and it is evident from Table 1 that the relative detection rate of visual and acoustic methods also varied considerably. Thus, many months had significant acoustic detection rates and no visual detections at all, while in other months visual detection rates were higher than acoustic. It is likely that much of the variation in relative detection efficiency reflects the effects of varying sighting conditions. Sea state is known to have a dramatic effect on sighting rates. For example, during vessel-based visual surveys in the Gulf of Maine sighting rates of porpoises in sea states 2-3 were one fifth of those in sea state 0 (Palka, 1996). Acoustic detection rates were less variable overall and they might be expected to better reflect actual changes in densities between months. It is known from other surveys that acoustic detection rates are less affected by sea state, remaining fairly constant until sea state 5 (pers. observation). Factors such as fog, visibility and daylight have no influence on acoustic efficiency.

Acoustic data suggest high detection rates in the spring (February and March) with a minimum in early summer with rates increasing through the later summer months. The relatively high visual detection rates in March may reflect good visual conditions for these surveys. This suggestion is supported by the elevated detection ranges seen in that month with some as high as 600m. Only four of the porpoises sighted in March were within 300 m of the vessel (the probable maximum acoustic detection range). Acoustic detection in March was likely also degraded by the ship's echo sounder which was left on continuously during that month's surveys.

TABLE 1. A SUMMARY OF ACOUSTIC EFFORT, DETECTIONS AND DETECTION RATES. DETECTIONS WERE SEPARATED INTO CERTAIN (TOP) AND LIKLEY (BOTTOM) AND OFF VISUAL EFFORT (BRACKETS). FOR COMPARISON VISUAL SIGHTING RATES FOR BOTH ESASAND MARINE MAMMAL OBSERVERS COMBINED ARE PRESENTED.

Month	Tracks	Events	Single Clicks	Hours of Re-cording	Porpoise Tracks per Hour	All Porpoise Acoustic Detections per hour	Sight-ings (# of animals)	Hours of Sight-ing Effort	Sight-ings per hour
January	No Acoustic Effort						0	03:51:00	0
February	3	1	0	03:23:37	0.89	1.48	0	03:49:00	0
	0	0	2						
March	3	0	0	05:58:35	0.5	1.17	13 (25)	16:33:00	0.78
	0	3	1						
April	0	1	0	16:10:39	0.06	0.37	3 (4)	16:19:00	0.18
	1	3	1						
May	1	0	0	21:13:34	0.09	0.14	5 (6)	18:03:00	0.28
	1	0	1						
June	0	0	0	20:19:47	0.05	0.19	0	18:41:00	0
	1	2	1						
July	0	0	0	19:26:19	0.1	0.36	5 (6)	14:17:00	0.35
	2	2	3						
August	2	0	0	22:14:08	0.17	0.45	14 (31)	16:38:00	0.84
	2	2	4						
Overall	9	3	0	108:46:39	0.14	0.40	40 (72)	108:11:00	0.37
	7	12	13						

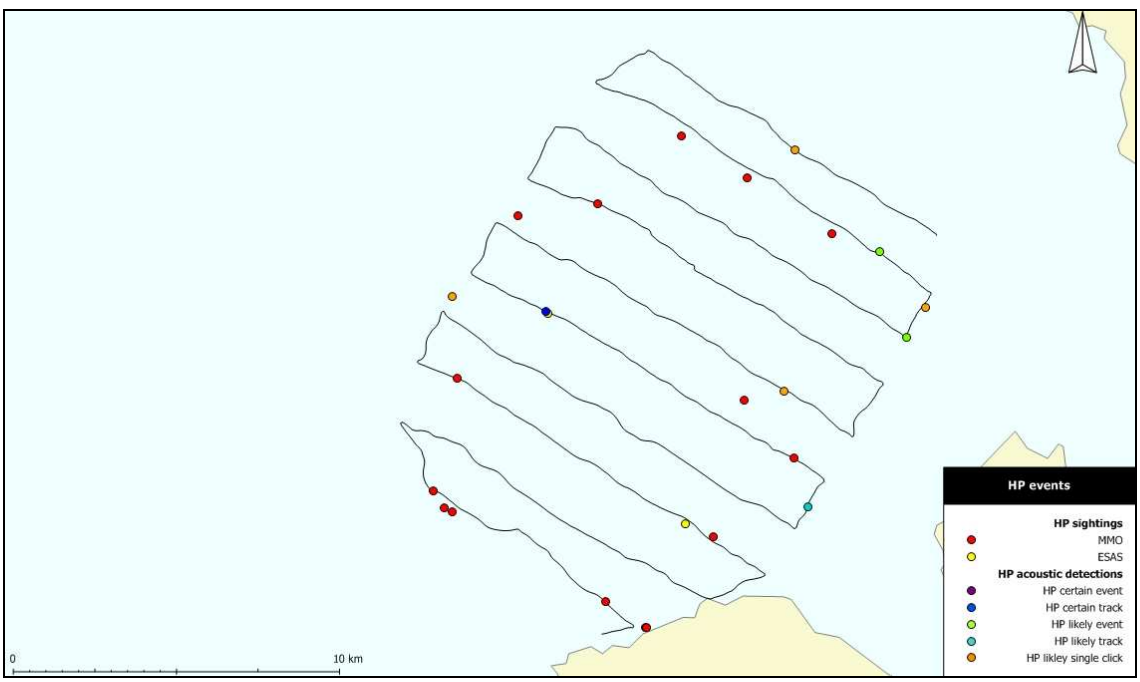
Table 2 shows the same data broken down by survey site and suggests some differences in the relative efficiency of visual and acoustic detection between sites. At the Costa Head site overall visual detection rates are higher than acoustic rates, at Cantick Head they are somewhat similar while at Westray South there are acoustic detections but no visual sightings.

TABLE 2. A SUMMARY OF ACOUSTIC EFFORT, DETECTIONS AND DETECTION RATES FOR ALL THREE SURVEY SITES. DETECTIONS WERE SEPARATED INTO CERTAIN (TOP) AND LIKLEY (BOTTOM). FOR COMPARISON VISUAL SIGHTING RATES FOR BOTH SEABIRD AND MARINE MAMMAL OBSERVERS COMBINED ARE PRESENTED.

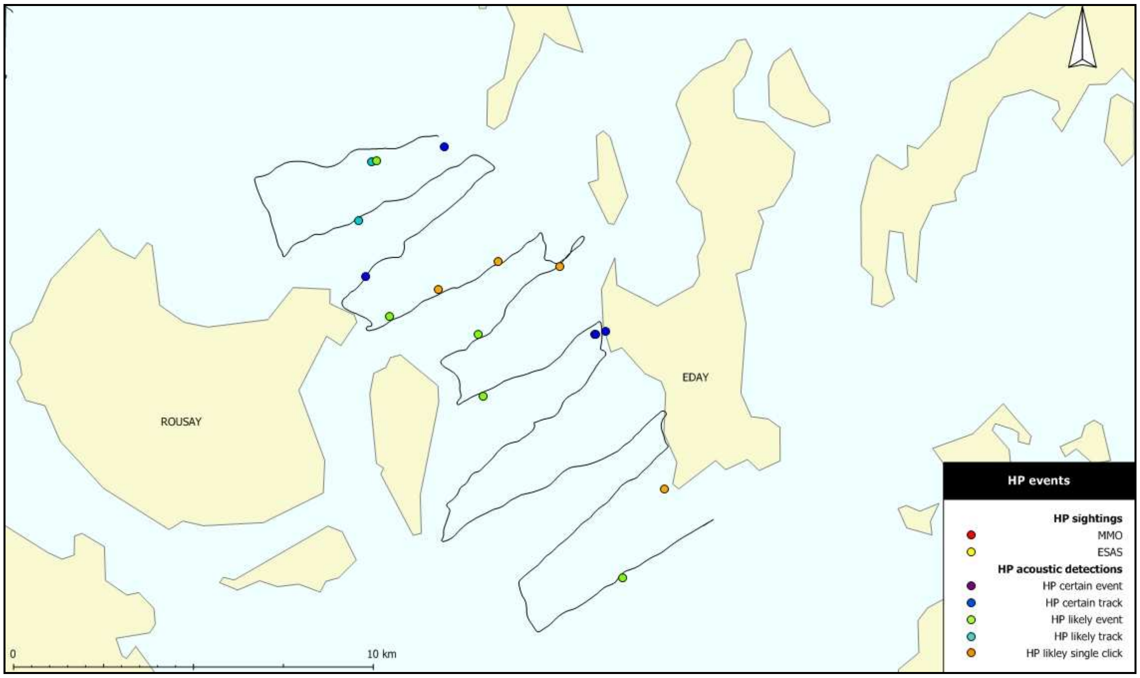
Month	Site	Trains	Events	Single Clicks	Hours of Recor-ding	Trains per Hour	Acoustic Detect-ions per hour	Sight-ings (# of an-imals)	Hours of Sighting Effort	Sight-ings per hour
January	Costa	NO SURVEY								
	Cantick	NO SURVEY								
	West-ray	NO ACOUSTIC DATA						0	03:51:00	0
February	Costa	NO SURVEY								
	Cantick	NO SURVEY								
	West-ray	3	1	0	03:23:37	0.89	1.78	0	03:49:00	0
		0	0	2						
March	Costa	1	0	0	03:09:12	0.31	0.63	4 (5)	07:24:00	0.54
		0	0	1						
	Cantick	2	0	0	02:49:23	0.71	1.78	9 (20)	05:34:00	1.62
		0	3	0						
	West-ray	NO ACOUSTIC DATA						0	03:35:00	0
April	Costa	0	0	0	07:07:39	0.14	0	1 (1)	07:09:00	0.14
		0	0	1						
	Cantick	0	1	0	05:34:21	0.18	0.54	2 (3)	05:35:00	0.36
		1	1	0						
	West-ray	0	0	0	03:28:39	0	0.58	0	03:35:00	0
		0	2	0						
May	Costa	0	0	0	07:43:01	0.12	0.3	4 (5)	07:21:00	0.54
		1	0	1						
	Cantick	0	0	0	06:28:58	0	0	1 (1)	05:17:00	0.19
		0	0	0						
	West-ray	1	0	0	07:01:35	0.14	0.14	0	05:25:00	0
		0	0	0						
June	Costa	0	0	0	07:27:01	0	0.13	0	07:37:00	0
		0	1	0						
	Cantick	0	0	0	06:31:59	0	0	0	05:18:00	0
		0	0	0						
	West-	0	0	0	06:20:47	0.16	0.47	0	05:46:00	0

	ray	1	1	1						
July	**Costa**	0	0	0	05:26:03	0	0.18	0	04:52:00	0
		0	0	1						
	Cantick	0	0	0	07:43:15	0.13	0.52	5 (6)	05:29:00	0.91
		1	1	2						
	Wes-ray	0	0	0	06:17:01	0.16	0.32	0	03:56:00	0
		1	1	0						
August	**Costa**	0	0	0	07:52:40	0	0	8 (18)	06:38:00	1.2
		0	0	0						
	Cantick	1	0	0	06:50:24	0.44	1.17	6 (13)	04:37:00	1.3
		2	2	3						
	West-ray	1	0	0	07:31:04	0.13	0.26	0	05:23:00	0
		0	0	1						
Overall	**Costa**	1	1	0	38:45:36	0.20	0.10	17 (29)	41:01:00	0.42
		1	1	4						
	Cantick	3	1	0	35:58:20	0.19	0.56	23 (43)	31:50:00	0.72
		4	7	5						
	West-ray	5	1	0	34:02:43	0.21	0.47	0	35:20:00	0
		2	4	4						

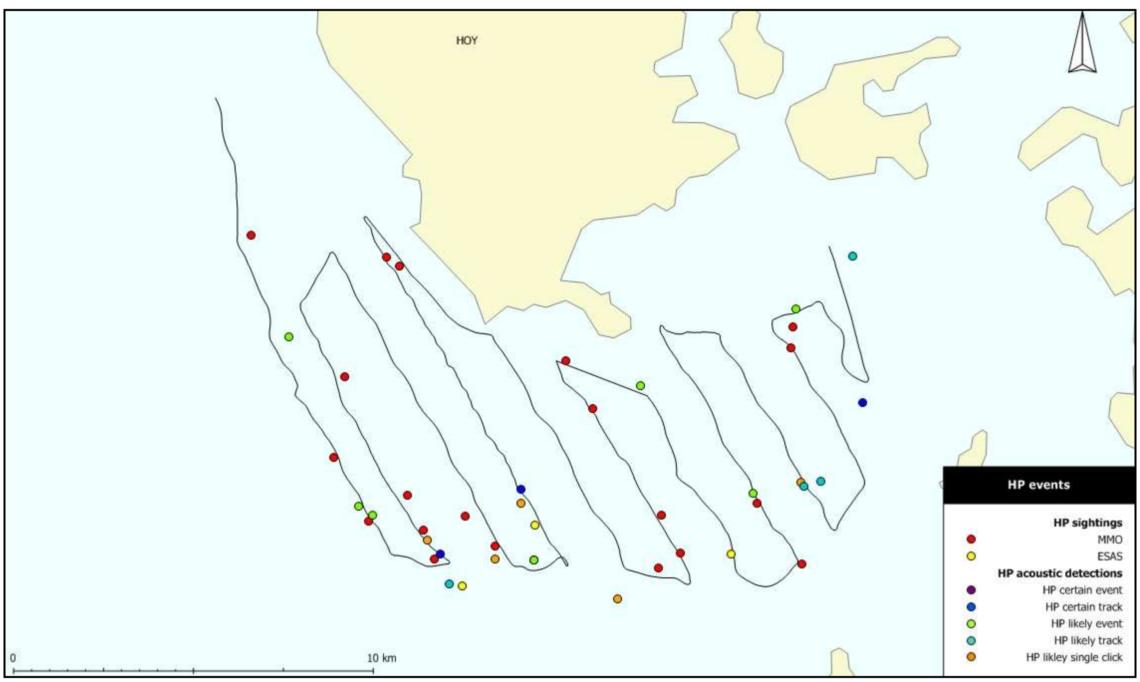
The locations of all acoustic detections are shown for each site in Figure8 A-C. (A vessel trackline in one month (My 2012) is also shown and an indication of the distribution of effort.)



A: COSTA HEAD



B: WESTRAY SOUTH



C: CANTICK HEAD

FIGURE 7A, B, C . TRACKLINE (DURING MAY) AND LOCATIONS OF PORPOISE ACOUSTIC DETECTION EVNETS AT COSTA HEAD, WESTRAY AND CANTICK HEAD SITES FOR JAN-AUGUST 2012 SURVEYS

DETECTION EFFICIENCY

Comparison of duplicate detections between independent detection “platforms”, carried out on a pod by pod basis, can provide a measure of the effectiveness of each platform, which allows observed detection rates to be put into context. Comparison of overall visual and acoustic detection rates, such as those in **Error! Reference source not found.**, are of limited value because the relative performance of the visual and acoustic is largely a function of sighting conditions and these data provide a measure of relative rather than absolute detection probability. Duplicate sighting methodology is used in line transect surveys as a way of determining absolute detection probability and, in conjunction with a detection function, for calculating g(0) for both visual and acoustic methods (see Appendix). We can examine acoustic and visual detections for duplicates to provide an indication of detection efficiency of both methods. A useful way to think about the process is to consider that detections made by one methodology set up trials for the second. If a detection is made close in time and space using the second methodology, then the detection is considered a duplicate and is scored as a success. Thus, for example, a visual observer might sight an animal which would set up a trial for the acoustic system. The time at which the sighted animal would be predicted to come abeam of the hydrophones could then be calculated, based on the estimated visual range and bearing to the animal, the speed of the vessel and the length of the hydrophone. If an acoustic detection is made showing an animal coming abeam of the hydrophones within an appropriate time period then the trial would be judged to have been a success. Clearly, we will expect there to be some degree of error between the predicted and actual times of duplicate detections. This will probably mainly result from errors in visual estimates of range and animal movements between the two detections. Based on analysis of a much larger dataset, (Leaper and Gordon, 2012) concluded that an appropriate error window would be 200s. In Tables 3 and 4 we have shown the actual time differences for all trials for which there were detections within 10mins of the predicted time and marked at successes those which were made within 200 seconds. There are, as yet, insufficient data from this survey to carry out a formal analysis; however, these trials do at least provide a qualitative handle for the proportion of animals being picked up by each method.

Table 3 summarises the trials for acoustic detection established by visual sightings. Sightings made in all sighting conditions were considered to initiate trials, though the majority were made during excellent and good conditions. The sightings distances ranged from 75m - 400m. Of 32 trials four were successful, giving a success rate of 12%.

TABLE 3 TRIALS OF ACOUSIT EFFECTIVENESS SET UP BY VISUAL DETECTIONS.

UTC	Dist-ance	exp acoustic detection abeam	Dist-ance a-beam	acoustic detection within 10 mins	Ac. Type	Ac. Range abeam (error) (m)	Time differ-ence (ex--actual)	Suc-cess or Fail	Site
25/03/2012 11:47:00	D	25/03/2012 11:48:15	130	25/03/2012 11:47:02	PcTr	175 (42)	00:01:13	S	Costa
25/03/2012 16:27:00	400	25/03/2012 16:28:19	257	NO	n/a	n/a	n/a	F	Costa
27/03/2012 08:03:00	100	27/03/2012 08:03:38	34	27/03/2012 07:54:22	PcTr	161 (27)	00:09:16	F	Cantick
27/03/2012 09:02:00	75	27/03/2012 09:02:30	53	NO	n/a	n/a	n/a	F	Cantick
27/03/2012 09:20:00	200	27/03/2012 09:20:44	153	27/03/2012 09:26:32	PcTr	276 (118)	-00:05:48	F	Cantick
27/03/2012 12:00:00	150	27/03/2012 12:00:47	51	27/03/2012 12:02:39	PlEv	n/a	-00:01:52	S	Cantick
27/03/2012 12:08:00	250	27/03/2012 12:08:54	177	NO	n/a	n/a	n/a	F	Cantick
27/03/2012 12:14:00	300	27/03/2012 12:15:10	150	NO	n/a	n/a	n/a	F	Cantick
27/03/2012 12:36:00	300	27/03/2012 12:36:57	230	NO	n/a	n/a	n/a	F	Cantick
27/03/2012 12:45:00	300	27/03/2012 12:45:39	282	NO	n/a	n/a	n/a	F	Cantick
27/03/2012 13:28:00	300	27/03/2012 13:29:12	127	NO	n/a	n/a	n/a	F	Cantick
18/04/2012 11:31:00	n/a	18/04/2012 11:31:19	130	NO	n/a	n/a	n/a	F	Cantick
18/04/2012 14:47:00	250	18/04/2012 14:48:05	86	NO	n/a	n/a	n/a	F	Cantick
19/04/2012 09:38:00	120	19/04/2012 09:38:27	114	NO	n/a	n/a	n/a	F	Costa
27/05/2012 16:12:00	400	27/05/2012 16:13:33	137	NO	n/a	n/a	n/a	F	Cantick
29/05/2012 10:29:00	300	29/05/2012 10:30:01	212	NO	n/a	n/a	n/a	F	Costa
29/05/2012 14:12:00	80	29/05/2012 14:12:33	40	NO	n/a	n/a	n/a	F	Costa
29/05/2012 15:51:00	75	29/05/2012 15:51:27	65	NO	n/a	n/a	n/a	F	Costa
20/08/2012 10:40:51	120	20/08/2012 10:41:33	21	NO	n/a	n/a	n/a	F	Cantick
20/08/2012 13:58:00	C	20/08/2012 13:59:15	130	20/08/2012 14:00:20	PlSi	n/a	-00:01:05	S	Cantick
20/08/2012 15:21:15	250	20/08/2012 15:22:12	161	NO	n/a	n/a	n/a	F	Cantick
20/08/2012 15:27:30	300	20/08/2012 15:28:44	103	NO	n/a	n/a	n/a	F	Cantick
21/08/2012 08:34:33	120	21/08/2012 08:34:56	118	NO	n/a	n/a	n/a	F	Costa

21/08/2012 08:50:10	270	21/08/2012 08:50:34	269	NO	n/a	n/a	n/a	F	Costa
21/08/2012 08:56:05	270	21/08/2012 08:57:05	174	NO	n/a	n/a	n/a	F	Costa
21/08/2012 09:15:45	75	21/08/2012 09:16:19	7	NO	n/a	n/a	n/a	F	Costa
21/08/2012 09:16:09	120	21/08/2012 09:16:50	41	NO	n/a	n/a	n/a	F	Costa
21/08/2012 11:59:31	275	21/08/2012 12:00:28	194	NO	n/a	n/a	n/a	F	Costa
21/08/2012 12:38:39	225	21/08/2012 12:39:32	145	NO	n/a	n/a	n/a	F	Costa
29/05/2012 12:54:00 (Off Effort)	300	29/05/2012 12:55:17	52	29/05/2012 13:02:13	PlTr	60 (15)	-00:06:56	F	Costa
20/07/2012 09:52:57 (Off Effort)	250	20/07/2012 09:54:05	22	NO	n/a	n/a	n/a	F	Cantick
20/08/2012 15:32:00 (Off Effort)	B	20/08/2012 15:33:15	130	20/08/2012 15:32:34	PlTr	29 (11)	00:00:41	S	Cantick
Summary 4 successes out of 32 trials = 12.5%									

Table 4 summarises the trials of the visual observation team set up by acoustic detections. Only harbour porpoise click tracks recorded during excellent to moderate sighting conditions were used to establish trials. Porpoise were successfully detected on one of 10 trials, a success rate of 10%. As tracks are thought to usually be detected from porpoises that are relatively close to the trackline and trials were only allowed in good sighting conditions this is likely to provide a somewhat optimistic value of visual effectiveness.

TABLE 4: TRIALS OF VISUAL EFFECTIVENESS SET UP BY ACOUSTIC DECTIONS

Acoustic Detection	Ac. Type	Ac. Range abeam (error) (m)	Sighting	Expected Sighting time	Vis. Ran-ge	Vis. Range abeam	Sight-ability	Time diff (expected-actual)	Success or Fail	Site
02/02/12 12:01:38	PcTr	71 (12)	NO	02/02/12 12:00:53	n/a	n/a	1	n/a	F	West-ray
02/02/12 12:01:54	PcTr	74 (17)	NO	02/02/12 12:01:09	n/a	n/a	1	n/a	F	West-ray
25/03/12 11:47:02	PcTr	175 (42)	25/03/12 11:47:00	25/03/12 11:46:17	D	130	1	-00:00:43	S	Costa
27/03/12 07:54:22	PcTr	161 (27)	27/03/12 08:03:00	27/03/12 07:53:37	100	34	1	-00:09:23	F	Cant-ick
27/03/12 09:26:32	PcTr	276 (118)	27/03/12 09:20:00	27/03/12 09:25:47	200	153	1	00:05:47	F	Cant-ick
28/05/12 13:59:22	PcTr	104 (22)	NO	28/05/12 13:58:37	n/a	n/a	2	n/a	F	West-ray
27/06/12 14:30:42	PlTr	105 (28)	NO	27/06/12 14:29:57	n/a	n/a	2	n/a	F	West-ray
18/07/12 15:44:57	PlTr	44 (4)	NO	18/07/12 15:44:12	n/a	n/a	2	n/a	F	West-ray
20/07/12 14:11:09	PlTr	100 (24)	NO	20/07/12 14:10:24	n/a	n/a	2	n/a	F	Cant-ick
20/08/12 11:02:17	PlTr	304 (92)	NO	20/08/12 11:01:32	n/a	n/a	2	n/a	F	Cant-ick
22/08/12 09:31:50	PcTr	53 (13)	NO	22/08/12 09:31:05	n/a	n/a	1	n/a	F	West-ray
Summary 1 successes out of 10 trials = 10%										

Leaper and Gordon (2012) carried out a similar analysis on a larger dataset from the Neart na Gaoithe offshore wind farm site off in the Firth of Forth. They reported a 45% success rate for trials of the acoustic system and a 14% success rate for trials of the visual observers (Note: the actual visual success rate was 7% but as these were ESAS observers that only searched on one side we have multiplied this by two). Comparing the Neart na Gaoithe results with those observed here, and bearing in mind the small sample size and the large levels of uncertainty, it seems that the visual observation team are achieving similar detection efficiency to that on a similar survey at different sites. The acoustic system appears to be performing less effectively than has been the case at other sites however.

Data such as these are extremely useful for putting the detection rates recorded on surveys like this one, which have not been designed to provide absolute abundance estimates, into context. By continuing to collect visual and acoustic data it should be possible to provide more robust estimates of efficiency and, provided sufficient high quality data can be collected, measures of effective strip width and g(0).

[Sightings from two independent visual platforms can also be compared to measure visual detection efficiency and determine g(0). This survey does employ two independent visual platforms: one provided by ESAS observers and one by the MMO observers (see NRP 2013a, NRP 2013b and NRP 2013c for interim results of the visual surveys). The ESAS observer data could be used to set up trials of the MMO observers, though, because the ESAS observers only make detections on one side of the survey vessel the number of trials is likely to be low and thus far there are insufficient data to attempt this.]

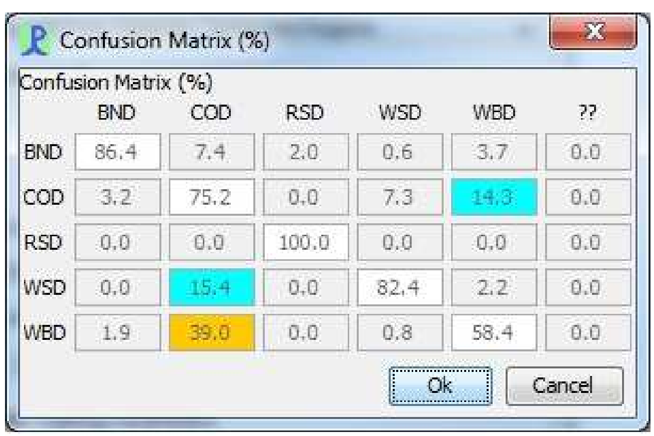
Both the combined data and duplicate identifications suggest that the acoustic system detects a greater proportion of available porpoises than the visual teams, and the low visual detection efficiency means that these are mainly additional detections; thus the total number of detections is approximately doubled by the addition of PAM. However, duplicate detection data also indicate that the acoustic system is performing less efficiently on these surveys than on others with identical equipment. We examine some of the likely causes of this, and strategies for improving performance on future surveys, in this report

DOLPHIN DETECTIONS

Harbour porpoise click vocalisations are highly characteristic, making it fairly straightforward to identify encounters with this species. However, the surveys are being conducted in an area where encounters with dolphins may also occur. In addition to echolocation clicks, whistles might be recorded during encounters with dolphins and for these species whistles are thought to provide more reliable data for species identification than do clicks. Appropriate whistle detectors and classifiers were therefore developed and configured in PAMGUARD and all the raw acoustic data have also been processed with a customised “whistle and moan detector” module.

Whistle classifiers can be developed within PAMGUARD to fit particular applications and species groups. To achieve this, contours of whistle vocalisations from known species are extracted from field recordings. These are then used to train a software classifier which can be used to classify whistles detected in new field recordings and acoustic encounters. Several dolphin species are likely to be encountered in this area. To be able to identify any whistles detected during these surveys we used a database of whistle contours for five dolphin species (the white-beaked dolphin (*Lagenorhynchus albirostris*), the bottlenose dolphin (*Tursiops truncatus*), the Risso’s dolphin (*Grampus griseus*), the Atlantic white-sided dolphin (*Lagenorhynchus acutus*) and the short-beaked common dolphin (*Delphinus delphis*)) which had been extracted by SMRU to train our classifier. As many dolphins have been found to have regional dialects (May-Collado and Wartzok, 2008) it is desirable to use whistle contours from the region in question. We do not yet have data from Orkney but the whistle contours used to build the classifier came both from the east and the west coasts of the UK.

The best five-species whistle classifier had substantial overlap between common dolphins and white-beaked dolphins, see confusion matrix in Figure 9.


Confusion Matrix (%)

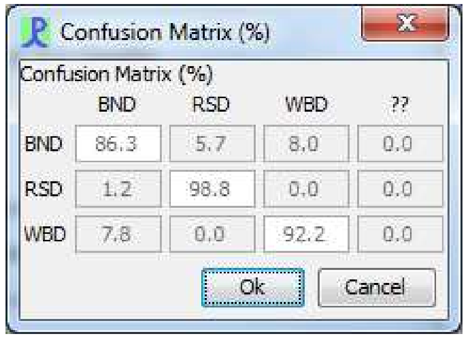
Confusion Matrix (%)

	BND	COD	RSD	WSD	WBD	??
BND	86.4	7.4	2.0	0.6	3.7	0.0
COD	3.2	75.2	0.0	7.3	14.3	0.0
RSD	0.0	0.0	100.0	0.0	0.0	0.0
WSD	0.0	15.4	0.0	82.4	2.2	0.0
WBD	1.9	39.0	0.0	0.8	58.4	0.0

Ok Cancel

FIGURE 9. FIVE-SPECIES CONFUSION MATRIX SHOWING CONSIDERABLE OVERLAP BETWEEN WHITE-BEAKED AND COMMON DOLPHINS (KEY BND, BOTTLENOSE DOLPHINS, COD COMMON DOLPHINS, RSD RISSO’S DOLHIN, WSD WHITE SIDED DOLPHIN, WBD WHITE BEAKED DOLPHIN).

Thus, we decided to reduce the species range to include only those most likely to be encountered at this site: bottlenose dolphin, Risso's dolphin and white-beaked dolphin. (These include the species that have been positively identified on these sites during visual surveys.) This resulted in a more robust confusion matrix (Figure 10).



	BND	RSD	WBD	??
BND	86.3	5.7	8.0	0.0
RSD	1.2	98.8	0.0	0.0
WBD	7.8	0.0	92.2	0.0

FIGURE 10. THREE-SPECIES CONFUSION MATRIX.

So far we have not detected any dolphin whistles. There was one sighting of Risso's dolphin on the 19/04/2012. Although probably within acoustic range, these dolphins were not detected on the recordings. Risso's dolphin are not very vocally active and visual observations suggested they were resting (slow swimming) when encountered, a behavioural state during which they are vocalise little (pers obs.). There were several sightings of white-beaked dolphin and although clicks were detected (see next section) the whistle & moan detector made no detections.

WHITE-BEAKED DOLPHIN CLICK CLASSIFICATION

There were 22 visual sighting encounters with white-beaked dolphins which mainly occurred during two survey months (July and August) with most sightings at the Cantick Head site. Often sightings occurred clustered together in time (within 30 mins) and it may be that these pods were all part of a larger dispersed aggregation. Our experience here and elsewhere has been that white-beaked dolphins have low whistle rates and they are rarely picked up with the whistle detector. For this reason we have been developing detection and classification methodologies for white-beaked dolphin based on their clicks.

White-beaked dolphin clicks are not as acoustically straight forward, or as characteristic as those of harbour porpoise, making acoustic identification more challenging. Individual clicks are highly variable, and to date, no automated click classifier capable of reliable species identification has been developed. White beaked dolphin clicks often have a multi-pulsed spectrum. A preliminary study using recordings from other areas around the UK (unpublished report to Smartwind) has shown that new techniques based on analysis of multiple peaks in the spectra can be used to reliably identify white beaked dolphins and possibly even reveal regional population structure.

DATA PROCESSING – WHITE-BEAKED DOLPHIN

All the data were reprocessed using a new click detector configuration optimised for white-beaked dolphin detection. This was necessary because the PAMGUARD click detector incorporates two types of frequency filters to remove noise and maximise the detector's performance. The pre-filter removes sound at frequencies that are not useful for either detecting or classifying the clicks of interest. Sound in these bands is removed completely and is not available for later analysis. A second filter, the trigger filter, has a narrower pass band and is applied only to improve the efficiency of the triggering process. The broader band acoustic data output by the pre-filter is maintained and available for classification. Because porpoise clicks have most of their energy in a narrow frequency band at around 130kHz, relatively narrow pre-filters and very narrow trigger filters are applied. Dolphin clicks have energy over a greater frequency range than porpoise clicks however, and the standard porpoise filter settings would result in less effective detectors, and a much-reduced capacity for classification. Thus, new detectors were devised for white-beaked dolphin based on published information on click characteristics for these species (Rasmussen and Miller, 2002), and our own measurements. These detector parameters are summarised in Table 5.

TABLE 5: FILTER SETTINGS FOR PROCESSING RAW DATA .

Filter	Cut off Frequencies	White-beaked dolphin settings
Pre-Filter	High Pass	2,000 Hz
	Low Pass	180,000 Hz
Trigger Filter	High Pass	40,000 Hz
	Low Pass	150,000 Hz

Reprocessed data were further analysed in the PAMGUARD Viewer and every dolphin event was processed and stored to a database. Clicks with appropriate characteristics on clear time bearing "tracks" were marked (**Error! Reference source not found.**1).

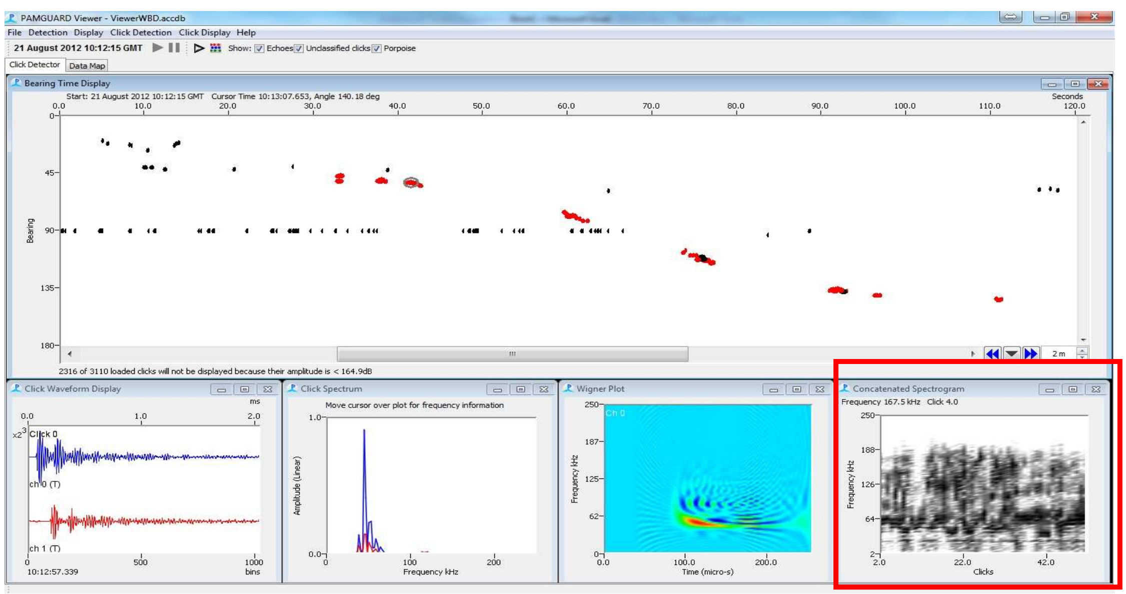


FIGURE 11: CERTAIN WHITE–BEAKED DOLPHIN CLICK TRAIN

Recording of some of the clicks were "clipped", that is to say the signal exceeded the dynamic range of the digitiser. Clipped signals are likely to be distorted and the PAMGUARD amplitude/time display was used to identify and remove clipped signals. The remaining clicks were displayed as concatenated spectrograms (e.g. Figure 11) which showed the spectra for each identified click stacked up sequentially. In these, spectral banding in the lower frequency range (<80kHz) was visible in most of the events, see Figure 11.

One certain click train and two likely click events were found coinciding with visual detections at distances at 110m, 250m and 275m. We believe that white-beaked dolphins can be detected acoustically to ranges of ~300m and only four of the sightings were within that range. With three of four "in range" events detected it is clear that white-beaked dolphin can be reliably detected using PAM.

An average spectrum was made from the single "certain" event and exported as a template for further analysis (Figure 12). A simple peak/notch algorithm was run using the software programme R (R Development Core Team, 2010)to identify all peaks and notches in the 0-80kHz frequency range.

An on-going and unpublished study indicates regional differences in white-beaked dolphin click characteristics between recordings made on the West Coast of Scotland, in the Hebrides, and recordings made on the East Coast and North Sea. These acoustic differences may indicate different sub-populations.

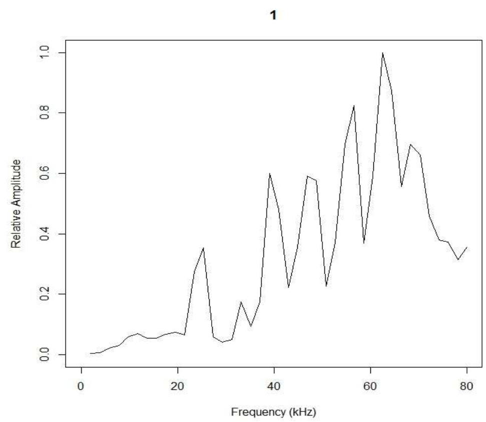


FIGURE 12: SPECTRAL TEMPLATE FOR WHITE-BEAKED DOLPHIN CLICKS RECORDED DURING SURVYES IN ORKNEY (<80 KHZ WITH RELATIVE AMPLITUDE).

Orkney lies between the East and West Coast and it will be interesting to know which "acoustic grouping" the white-beaked dolphins belong to. The clicks analysed from this study show two consistent peaks at **39 kHz** and at **45-47 kHz** and two stable notches at **41-43 kHz** and at **49-53 kHz** and these correspond with the patterns shown in Scottish East Coast / North Sea recordings (Figure 13) and differ from those from the West Coast. Work on white-beaked dolphin classification and regional differences is on-going and may reveal robust regional differences in white beaked dolphins vocalisations which may be indicative of population structure. This will enable existing and future recordings to be analysed in this context.

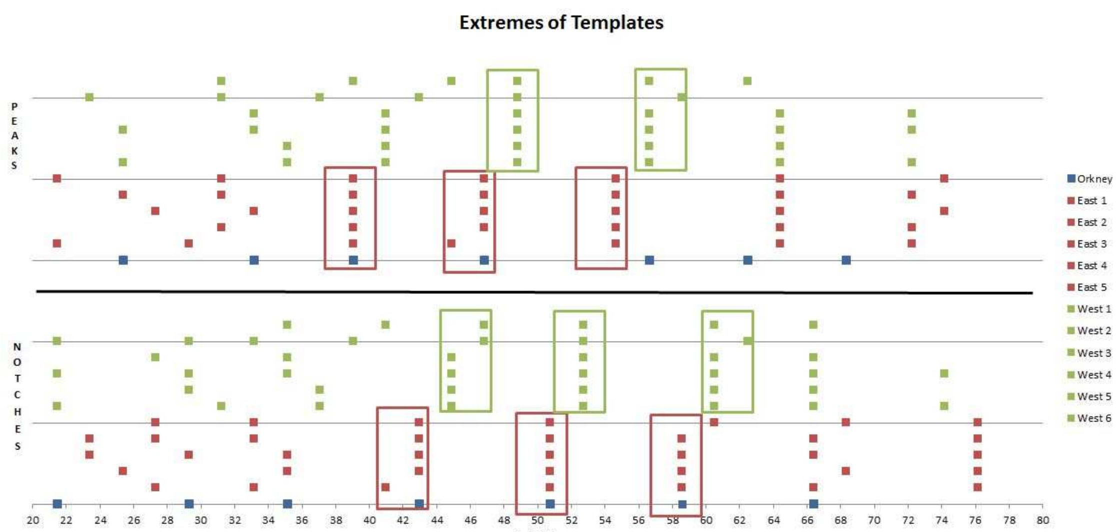


FIGURE 13: REPRESENTATION OF PEAKS (UPPER) AND NOTCHES (LOWER) FOUND IN WHITE-BEAKED DOLPHIN EVENTS. GROUPING WITHIN RED RECTANGLES INDICATE CONSISTENT FREQUENCIES WITHIN EAST COAST EVENTS (WITHIN A 4 KHZ RANGE) WHEREAS GREEN RECTANGLES INDICATE CONSTITENT FREQUENCIES WITHIN WEST COAST EVENTS (WITHIN A 4 KHZ RANGE).

OTHER ACOUSTIC FEATURES

Another type of acoustic feature noted during analysis was discrete areas of high background noise. An example is shown in Figure 14. The diagonal banding of these noise events indicates that the source has a discrete location and the boat is passing by it. Similar noisy patches were identified in tidal rapid areas in Wales by Gordon et al. (2011). These authors suggested, supported in part by earlier observations (Mason et al., 2007; Thorne, 1985; Thorne, 1986; Voulgaris et al., 1995), that these were likely due to patches of sediment moving in the current.

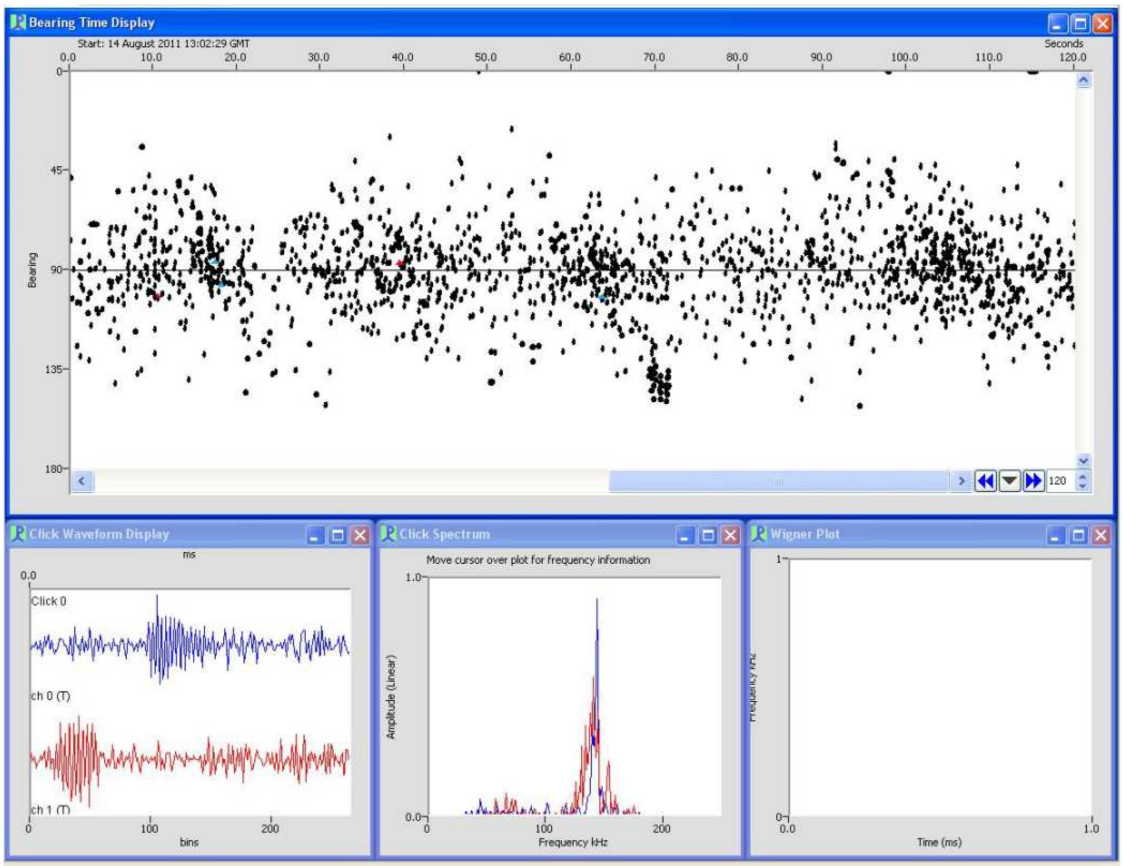


FIGURE 14. DISCRETE NOISY AREA THOUGHT TO BE DUE TO PATCHES OF MOVING SEDIMENTS. DIAGONAL TRACKS TO NOISE SOURCE INDICATES THAT THESE ARE RELATIVELY SMALL AND DISCRETE SOURCES THAT THE BOAT IS MOVING PAST THEM.

Discussion

Both the acoustic and visual data indicate that detection rates for dolphins and porpoises are low at these sites. Consequently it is probable that, by the end of the study, it will only be possible to attempt to calculate absolute density estimates for harbour porpoises, and even these may well have wide confidence intervals.

The overall acoustic detection rate for porpoises was slightly higher than that of the visual team and (because the duplicate detection rate is low) PAM provided many additional detections roughly doubling the number of independent detections. Acoustic monitoring has also provided all of the detections at the Westray South site. By providing an additional independent dataset the acoustic monitoring system provides the opportunity (if sufficient data are collected) to use dual platform methods to calculate g(0) and allow absolute density estimation. Thus, acoustic monitoring is substantially enhancing the quality and quantity of porpoise data collected.

The second most commonly detected cetacean species on these surveys was the white-beaked dolphin. White-beaked dolphins can be detected and identified acoustically. There are indications of regional differences in the spectral characteristics of white beaked dolphin clicks and preliminary results indicate that the white-beaked dolphins recorded on this survey produce clicks like those recorded on the East Coast of Scotland and North Sea.

Analysis of duplicate (visual acoustic) identifications provides an indication of the detection efficiency of both the visual and acoustic monitoring efforts. This analysis suggests that the visual team are achieving a detection efficiency that is similar to that observed on similar surveys at other locations. However, the efficiency of the acoustic system on this survey is lower than has been achieved using the same equipment on other surveys. It is believed the main issues are likely to be from noise from various sources. Some of these may be inevitable consequences of the environment and working practices. However, some procedural issues have been identified that could be addressed by changing survey protocols. It is intended to use greater hydrophone cable lengths to reduce boat noise at those sites where this is possible.

These are challenging environments in which to conduct marine mammal surveys. Indeed, methodologies for surveying marine mammals in strong tidal current areas are still to be fully developed. To achieve the best results surveys should use an appropriate combination of the most effective detection methodologies and the survey design should be well coordinated, combining the outputs from different survey efforts (ESAS, MMO and PAM in this case) appropriately to draw power from the strengths of each.

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APPENDIX

OBTAINING ABSOLUTE ABUNDANCE ESTIMATES OF HARBOUR PORPOISE FROM SMALL SURVEY VESSELS BY COMBINING VISUAL AND ACOUSTIC DATA

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Ecologic UK, 7th February 2012

Surveys for harbour porpoise[1] to assess potential environmental impacts of off-shore renewable energy developments often use small vessels with a single observation platform to make visual observations combined with Passive Acoustic Monitoring (PAM). The aim is usually to conduct line-transect type surveys to determine spatial and seasonal patterns of abundance. Observations may be made by a small team of observers, some or all of whom may also be collecting data on seabirds, generally using ESAS methodology (Often sea bird survey is seen as the primary goal and has driven the design and methodology of the survey.) Single observation platform methods can be used to estimate relative abundance but can rarely be used to estimate absolute abundance. Distances and angles to sightings can be used in Distance sampling methods to estimate the relative sighting probability as a function of perpendicular distance from the trackline, but estimating the absolute probability requires some form of independent observations. On sighting surveys from large vessels, independent observations are usually provided by a second observation platform. Two platform data can be used to estimate the absolute detection probability for an animal directly on the trackline, which is often referred to as g(0).

There are several advantages to providing estimates of absolute abundance compared to relative indices. As well as being able to provide an estimate of the actual numbers of animals that may be affected by an activity or development, absolute estimates are much easier to compare between surveys and areas, and have greater potential for data validation. For example, if absolute numbers are available from more than one survey method or for subsets of the survey data, these can be directly compared in a way that relative indices cannot.

PAM can be a more effective means of detecting harbour porpoises than visual observations. PAM detections are less affected by weather and sea state conditions. Detection rates are typically higher than visual in all but flat calm conditions, and data sets are also more consistent. PAM data collection can be highly automated with continuous full bandwidth recordings being made in the field for later analysis ashore. This greatly reduced field costs and further contributes to consistency in analysis. By using two hydrophones to measure bearings combined with target motion analysis perpendicular distances to vocalising animals can be measured. The methods described here have been used to obtain estimates of g(0) for both visual and acoustic observations by using visual and acoustic data sets as independent observations. PAM methods have not yet been used to estimate harbour porpoise group size and so all detections were considered as potential groups to generate an estimate of the density of groups which could then be multiplied by the estimate of group size from visual data to obtain an overall abundance.

The analysis was based on Mark Recapture Distance Sampling (MRDS) techniques with each method used to generate a set of trials which could then be used to estimate what proportion of these were detected by the other method. The outcome of each trial was a binary result (detected/not detected) and relied on identifying

[1] This method should work for other odontocetes that can be reliably detected acoustically. However, at this stage we have only applied it to harbour porpoise detections.

duplicates between visual and acoustic data. Duplicates cannot be identified with certainty because there are a number of factors that could lead to either selecting false duplicates or missing real ones. For visual data there may be errors in the recorded time of the cue and associated location. In particular angles and distances are notoriously difficult to estimate to sightings at sea and so an allowance for location has to be made based on the likely magnitude of errors (Leaper et al., 2011). Animals may also move considerably between the visual sighting and the acoustic detection. Animal movement will affect the accuracy of perpendicular distances from acoustic data derived from target motion analysis.

In higher density areas there is a possibility that detections of different animals by the two methods would be classified as duplicates. To avoid this, the criteria for a detection to be considered a suitable trial included that no other detections had been made by the method setting up the trial for a given time either side of the trial detection time. This time can be selected for each data set based on the detection rates and aggregation patterns observed.

Once a set of suitable trials had been selected these can be investigated for possible duplicate detections by the other method. The speed of the vessel, the estimated distance ahead of the vessel and the length of the hydrophone towing astern of the vessel are used to estimate the expected time delay between the sighting and the acoustic detection coming abeam of the hydrophone. If there is a detection with the pod coming abeam within a time window of a certain time period either side of this time then that is classified as a duplicate. To determine the most appropriate time period, the number of duplicates can be plotted by time relative to the predicted delay. The expected shape of this plot is for a peak at zero dropping away to either side followed by 'noise' from false duplicates at longer time intervals. In the data examined so far, this peak was sufficiently pronounced to be able to select an appropriate time window for duplicates which allowed for the various sources of uncertainty but was not so long as to be likely to include many false duplicates.

The analyses to date have used the estimate for g(0) suggested by Buckland et al (1993) where g(0) for method *A* is given by

$$g_A(0) = \frac{n_{AB} w_B}{n_B w_{AB}}$$

Where n_{AB} is the number of duplicates detected by both methods, n_B is the number of trials based on detections by method *B*, w_{AB} is the strip width of the duplicated data and w_B is the strip width of the trial data. This method is simple and easy to apply but does rely on a sufficient number of duplicates to estimate a strip width for the duplicate detections. The estimates for g(0) for data sets examined so far have all been close to what would be expected from other studies and have given consistent density estimates between acoustic and visual methods. Density estimates have also been consistent when just using subsets of the data restricted by sea state (e.g. sea state 0and 1 compared to sea states 2-4). Further analytical development is required to generate reliable estimates of variance taking into account uncertainty in duplicate identification.

There has been considerable recent development in MRDS techniques in recent years including incorporating these into the Distance software analysis package. The aim is to develop ways in which the visual and acoustic duplicate data can be used within Distance to make use of the standard analysis methods that are now available.

Two final points on field data collection are worth noting. The first is that the reliability of duplicate matching can be enhanced by improving the accuracy with which visual and acoustic data can be collected and tracking animals as close to the detection field of the hydrophones as possible. Some technical and methodological solutions for this are covered in another document. The second point is that in the case where acoustic detections will provide the main data set, some of the usual survey requirements for a visual marine mammal survey can be relaxed, they need only set up accurate trials and measure group size. This may be an important consideration in cases where the main visual observation team has a different primary task, for example, carrying out bird surveys.

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