An assessment of the effect of a tidal power generator on porpoise habitat use and an evaluation of the acoustic methods employed, August - October 2003

A report to the Highlands and
Islands Enterprise,
Shetland Islands Council, The Crown Estate &
The Engineering Business Ltd

by
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Summary

Porpoise detectors (PODs) were deployed at two sites in Yell Sound, Shetland to assess a porpoise alerting device (PAD) in a porpoise rich environment and to monitor harbour porpoise (Phocoena phocoena) activity during the trial of the ‘Stingray’ tidal generator. The POD is a hydrophone linked to a specialised signal processing system that recognises the very distinctive trains of clicks produced by porpoises and produces computer files with details of detections. The PAD generates brief sounds, resembling the click trains of porpoises that have been shown to attract the attention of porpoises. Visual observations were also made.

To monitor the impact of Stingray one POD and a PAD were substantially modified for this project and attached to the hull of the ‘Stingray’ barge with one POD deployed on the seabed 200 m due north. The hydrophones at the Stingray barge were exposed to a high velocity tidal stream of up to 7 knots, with suspended particles. Monitoring Stingray using acoustic methods presented a severe challenge because of high levels of flow and impact noise, and because of active sonars in use on the barge, service vessels and other vessels that were sometimes close to the POD sensors.

The detection of porpoises in this acoustically challenging location necessitated modifications to the equipment used during the project. These were successful and demonstrated that such monitoring is feasible. Further refinement of the hydrophone configuration and location would be valuable to increase detection rates in any further studies in such acoustically difficult environments in which porpoises are mainly only passing through.

A pair of PODs was also deployed in Hamna Voe, as the nearest site known to have high levels of porpoise activity. Tidal currents in Hamna Voe are at much lower speeds, and unmodified PODs could be used, one with a PAD attached to it.

Harbour porpoise click trains were detected at both sites every day. The number and duration of porpoise encounters were derived from click train detection times, with a ‘silent period’ of 10 minutes used to delineate consecutive encounters. Porpoise encounters were up to 310 minutes duration in Hamna Voe, compared with the maximum encounter of 8 minutes duration at the Stingray barge.

Visual observations from the barge and shore indicated that most click detections at the barge were produced by individual or small groups of 2-5 porpoises, ‘transiting’ through the sound. The acoustic data also showed none of the fast click trains associated with feeding at this site. This contrasts with Hamna Voe where multiple groups of porpoises (including mothers with calves), ranging in size from around 10 to 30 animals were seen, and fast click trains were commonly logged. Feeding, including ‘herding’ and ‘chasing’ prey on the surface, resting and social behaviour was observed during daylight watches at Hamna Voe. There was a sharp increase in the abundance of harbour porpoise in October, which was shown strongly in the acoustic data.

This study showed that porpoise movements through Yell Sound continued during the operation of Stingray. The shape of the ‘audiogram’ (frequency sensitivity) of the POD roughly matches that of a porpoise, and the logged data gives some indication that some boat sonars may represent more significant causes of actual disturbance to porpoises than the generator itself. The analysis required to verify this possibility has not been carried out.

For the Porpoise Alerting Device test in a porpoise rich environment, two PODs were moored to the seabed 250 m apart at Hamna Voe, at locations matched for substrate and water depth (22 m). One PAD was rotated between PODs on a monthly basis. Harbour porpoise detections increased two fold when the PAD was in operation demonstrating that porpoises interacted with the PAD. There was no noticeable trend in effect over the course of the study. The variation in click and encounter rates observed between deployments show that PAD does not obscure the underlying factors determining click rates such as diurnal and seasonal variability in food availability, porpoise behaviour and group composition.

The study does indicate that the PAD can enhance rates of detection, which makes it possible to gain significant volumes of data more quickly. The present knowledge of its effects is insufficient for routine use in acoustic studies, although it may have a role in studies of quiet environments with very low porpoise densities. The PAD results are sufficiently encouraging to justify further testing in varied contexts.

Porpoises are top marine predators and use an exceptionally wide range of sound frequencies. Their echolocation activity makes then uniquely suitable for long term, low cost, acoustic monitoring of ecosystem health with continuous objective data.

1. Introduction

The harbour porpoise (*Phocoena phocoena*) is the most abundant and widespread cetacean species in European waters, utilising inshore marine habitats for foraging, feeding and breeding year round. It is almost the smallest of all the cetaceans – whales, dolphins and porpoises. Porpoises are predators at the top of the marine food chain and can be considered key indicators of ecosystem health. They are heavily reliant on active echolocation (sonar) for hunting, and possibly for navigation also, and they also use the more commonplace mode of passive listening. This makes them potentially key indicators of acoustic pollution in their environment.

Shetland has one of the highest concentrations of harbour porpoise in European waters, and is therefore an ideal location to study their ecology, habitat requirements and the impacts of human activities. The effective implementation of conservation measures to protect harbour porpoise populations and their critical habitats has been limited by the lack of basic ecological information about the species. This is partly because the species is small and inconspicuous, generally avoids boats, and is difficult to approach.

Recent literature has highlighted concerns over threats to small cetaceans from by-catch in gill nets and from acoustic pollution of the marine environment, e.g. the impact of the uncontrolled development of aquaculture, in particular the use of acoustic deterrent devices that deter seals and potentially also non-target species such as otter (*Lutra lutra*) and harbour porpoise. By-catch in fishing gear has led to the development of 'pingers', acoustic devices used to signal the presence of fishing gear. However, recent research has suggested that porpoises may sometimes 'switch off' their echolocation when preying on certain species of fish (e.g. mackerel, *Scomber scombrus*) whilst hunting, and that their main entanglement risk could be during the small fraction of their activity when they are silent.

All pingers currently in use to reduce fishery captures of porpoises emit loud pulses that scare the animals away, denying them access to feeding areas or migration routes. This study trials an alternative to the pinger that encourages porpoises to 'switch on' their echolocation and investigate the pinger, potentially reducing the likelihood of entanglement. This 'porpoise alerting device' (PAD) is environmentally friendly because cetaceans are not excluded from any habitats and the signal is above the frequency range audible to seals and otters. The system has another role as an aid to monitor cetaceans more effectively by making monitoring of their echolocation more reliable as an indicator of their presence. At present the investigation of this alerting signal has shown that it can double or treble the frequency of detection of porpoises moving through a strongly tidal area south of the Lizard Point in west Cornwall.

1.1 Characteristics of porpoise echolocation clicks

Harbour porpoises produce short high frequency echolocation clicks of a narrow bandwidth centred near to 130 kHz, with little energy below 100 kHz. Echolocation clicks are used for orientation and locating potential prey and possibly also to some extent for communication.

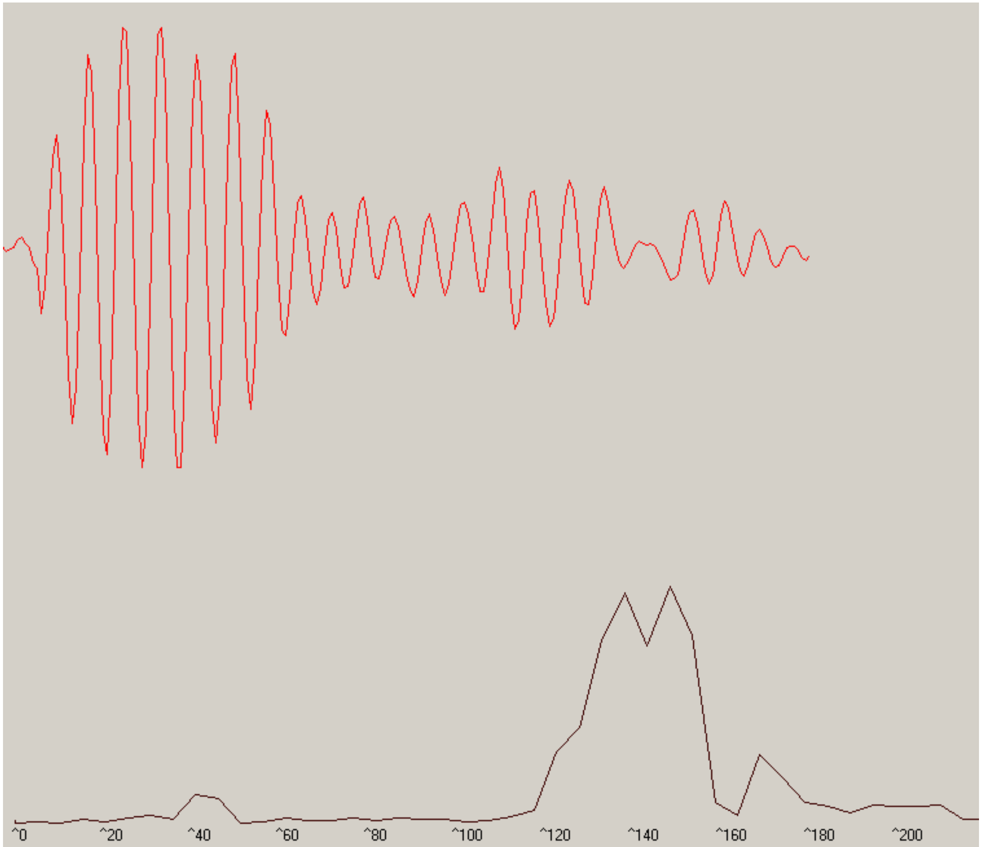


Figure1. Waveform and frequency spectrum of a porpoise echo-location click. The waveform is 200microseconds long; the x-axis of the spectrum is marked in kHz.

Clicks are produced in trains with Pulse (click) Repetition Frequencies commonly between 10 and 100 clicks per second. In general lower PRFs are thought to indicate echolocation that is not associated with feeding but may be used in navigation. Trains with higher PRF values ('fast trains') are known to be associated with capture of prey during feeding. These click trains show rapid rises in PRF and are commonly logged up to 600-800 clicks per second. The highest rates known are around 1200 clicks per second and were recorded from porpoises during feeding bouts in POD trials in Yell Sound in 2002.

1.2 Technical description of the POD data logger and PAD

The POD (Porpoise Detector) is a self-contained data logger that logs echo-location clicks from small toothed cetaceans. The model of POD used in this study is the T-POD and associated PC software. T-PODs log the time and duration of each click to 10microsecond resolution. Train detection within the stored set of times is then possible and is carried out by specialised software on a PC. Train detection allows the POD to achieve a very much higher specificity of cetacean detection than is possible using any method based purely on click characteristics.

The POD consists of a hydrophone, an amplifier, analogue electronic filters, a digital processor running at 20MHz and 32Mb FLASH memory to store click times. The digital and filter settings can be set to a range of different click durations, centre and reference frequencies, signal bandwidth and signal strength, to select the specific characteristics of echolocation clicks from cetaceans and discriminate clicks from boat sonars and other sources (e.g. crustaceans, propeller cavitations and shifting sediment in strong tidal areas) and to control memory usage.

The POD detects cetacean sonar clicks by the continuos comparison of the output of two bandpass filters. Each filter blocks all frequencies except those around its centre frequency. The start of a click is defined by the output level of the target frequency filter exceeding the reference frequency level by some selected factor. The POD can scan through six sets of settings each minute to enable the detection of species using different frequencies. In each scan the POD logs for 9.2 seconds using the set of chosen values. Click detection is followed by train detection and classification using an algorithm to discriminate cetacean trains from those that may be logged from boat sonars operating close to porpoise frequencies, or from fortuitously regular sequences of non-cetacean clicks. The results are put in the following train classifications:

CetHi - click trains with very high probability of coming from cetacean,
CetLo - less distinctively cetacean click trains, but still with a high probability of cetacean origin.

For the purpose of analysis this report only CetHi and CetLo trains will be examined, and termed ‘CetAll’.

Other trains classified include:
Doubtful trains (‘?’) In noisy environments a proportion of these are likely to have non-cetacean origins.
Very doubtful trains (‘??’), these category includes trains that may have come from boat sonars but cannot be reliably identified as having that origin. These trains have often been subject to multiple reflections and may contain multiple clicks in clusters
Fixed rate/Boat sonars - these are inevitably logged because boat sonars can be at the same pitch as porpoise sonar. True boat sonars are mostly reflected sounds as the source produces a narrow beam of downwardly directed sound that is often logged as large clusters of echoes from which a number of trains in step with each other may be detected by the software.

The software allows users to view all trains graphically to show the whole data set from which they have been selected to assess whether they are correctly classified etc., but this is not required in normal use. It is, however, very valuable in assessing the functioning of the system in new roles, such as the Stingray deployment.

Plate 1. Barge POD, with data cable and lead to remote acoustic sensor (in foreground)

A ‘remote’ POD was built specifically for this project because the 86mm diameter of the standard POD housing would create excessive drag in the fast currents. A receiving hydrophone element and a transmitting element for the porpoise alerting device were cast in an epoxy cylinder with an 8 m length of low-loss co-axial cable to allow the POD unit and TPAD to be installed on the deck of the Stingray barge. The hydrophone was positioned under the hull of the barge, passing through a 6 m galvanised iron pipe secured to the stern of the barge on the port beam. The POD and PAD unit were housed in a length of plastic pipe on the barge deck, secured in a static vertical position.

The PAD (Porpoise Alerting Device) is a self-contained pinger device designed to induce silent porpoises to start using their sonar and thereby become detectable. The device tested during this project was set to operate every alternate 30-minute interval to allow its effect to be assessed by comparison between active and inactive periods. The PAD signal used was a 4 pulse sequence with each pulse being a short burst of 130kHz sound of less than 50microseconds duration. In each signal the pulses were 0.1s apart. These sequences were produced every 4 seconds during operational periods. Both the POD and PAD use custom transducers resonant at porpoise frequencies.

Plate 2. A self-contained experimental porpoise alerting device (PAD)

1.3 Study area

Yell Sound is tidal, with a peak range of 1.6 m (Mean High Water Spring) and complex currents that pass several islands. Tides are semi-diurnal, approximately every six hours. The flood tide around Shetland flows from the north, running in to Yell Sound from the north while the ebb flows from the south, entering the Sound from a south-easterly direction. The strongest tidal flow of 4-6 kts is generally three hours after High Water (HW) and Low Water (LW), with slack water approximately one hour after the tabled HW and LW. The annual sea surface temperature ranges from 6 ºC (February) to 12 ºC (September), with sea temperatures often +1 to 2 ºC higher in shallow low-current areas of voes.

Commercial traffic in Yell sound is mainly associated with Sullom Voe Oil Terminal and fishing vessels transiting to open water or port. The west channel of Bigga and Samphrey (isles) is the designated shipping channel. Three salmon companies, managing four salmon and one mussel farm, operate from Colla Firth, Ness of Setter and Fish Holm at the southern end of Yell Sound. Creel pots and scallops are also fished in the area. Two inter-island ferries link Ulsta terminal (Yell) to Toft (mainland) with crossings every 30 minutes (Figure1).

Yell Sound and associated voes are important wintering and feeding grounds for seabirds and seaducks. Sections of the coastline form part of the Yell Sound Coast candidate Special Area of Conservation for important numbers of breeding otters (*Lutra lutra*) and common seals (*Phoca vitulina*).

1.4 Location of POD moorings

Four PODs were deployed at two sites with contrasting habitat features (Figure1). The locations were chosen to monitor porpoises passing through Yell Sound.

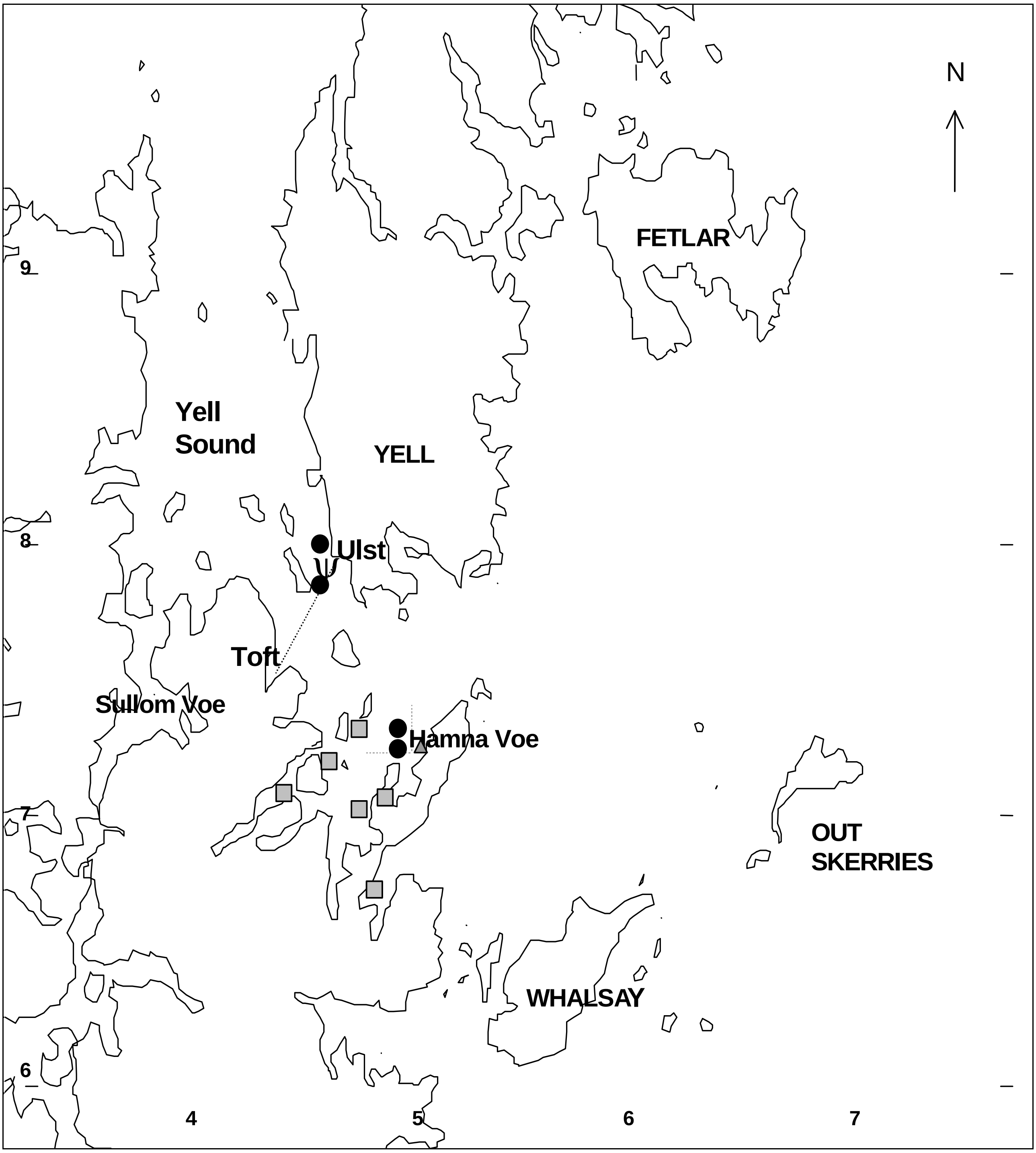
Stingray barge (HU4562079620) – a high tidal velocity site

Two PODs were deployed around the Stingray barge to monitor the occurrence of harbour porpoise and assess the effect of the Stingray tidal generator. The remote POD hydrophone with PAD was attached to the hull of the barge during the Stingray trials. The second POD unit was deployed on the seabed with an ADCP current profiler on two occasions off the bow of the barge. HW at Sites 1 (compared with Sullom Voe) is approximately 60 minutes before HW in Lerwick.

Hamna Voe (HU49457195, HU49457245), southeast entrance to Yell Sound – a high porpoise density site.

Two PODs were deployed 250 m apart on the coarse-sand seabed at a depth of 22 m, approximately 600 m due east of Ness of Setter. The PODs were deployed on a monthly basis by Setterness Salmon Ltd with due consideration to boat access to the Setterness shorebase, the adjacent mussel farm moored off Heog and creel and scallop fishing areas.

HW at the study site is 45 minutes before HW in Lerwick and 15 minutes after Sullom Voe (10 km north). At the southern mouth of Yell Sound, the current direction is predominantly from the E during flood and NW during ebb.



Approximate location of hydrophones

ψ Approximate location of Stingray

Approximate locations of salmon farms (Yell Sound, southern approaches)

Approximate location of mussel farm

Inter island ferry route

Increments for scale are derived from the HU grid system (1 km squares)

Figure1. Location of acoustic monitoring sites and human activities in Yell Sound

2. Methods

2.1 POD deployments at Stingray barge

PODs were deployed from the barge, with the hydrophone and PAD transducers positioned just below the hull of the barge (2 m below the surface), and on the seabed attached to the frame holding the ADCP. Several 'rig' designs were considered to mount the self-contained POD unit securely to the barge using galvanised steel pipe to withstand the current flows of up to 7 knots. An alternative was selected to minimise drag. POD hydrophone and PAD transmitter elements were put in a separate slender housing remote from the main unit housing the electronic hardware and computer connections. This arrangement enabled the POD unit to be stationed on the deck of the barge for convenient setup and data retrieval and considerably reduced the size of the rig required to support the hydrophone below the hull of the barge.

Plate 3. Remote POD unit housing PAD electronics with laptop set up on the deck of Stingray barge. The 6 m length of vertical scaffold pipe houses the hydrophone and PAD cable with the hydrophone secured 30 cm below the hull of the barge.

The 'Stingray' barge was on site for seven weeks from early August and was recovered in September when the barge was relocated to Lerwick. Power generation was only possible during the flood tide from the north. The generator was lifted to the surface for routine maintenance and checks at intervals.

Tides in Yell Sound are complex, and may vary considerably at different locations within a few kilometres dependent on geographical and topographical features. For the purpose of the Stingray study, the Engineering Business Ltd used two ADCP devices moored to the seabed to measure the current velocity, direction and other physical characteristics, fore and aft of the Stingray barge. A sample of the current data collected from 9 to 18 September provided by EB in Excel format is incorporated in the results of this report.

Plate 4. Location of remote POD rig on barge. The scaffold pipe housing the hydrophone cable is indicated just to the left of centre picture. Stingray is deployed on the seabed 35 m below the stern of the barge in view.

The batteries of the POD were changed on the Stingray barge once per month, with data uploaded to a Sony PCG-GRZ515G laptop using the TPOD.exe version 6.0, train detection v2.3. software (www.chelonia.demon.co.uk). Duracell D batteries were used for all deployments. The number of TAD clicks and porpoise click trains detected per five-minute interval by the POD was exported to an Excel spreadsheet. The TPOD.exe software was used to visually examine the acoustic data and describe key parameters of the porpoise detections, including porpoise encounter rates and frequency distribution of click durations and PRFs.

2.2 POD deployments at Hamna Voe

Two PODs were moored to the seabed using a heavy wheel rim and 2 m length of chain to provide additional weight and anchorage. Three equal lengths of chain were used to link the rim to the mooring rope. The rim was deployed to sit flat on the seabed to enable sediment to cover the edge of the rim and provide a more secure holding. Lengths of 30 m mooring rope were used to ensure a few metres of slack (maximum depth of 25 m), in the event of heavy seas from stormy weather. One A5 buoy was secured to the end of the rope as a surface marker. The POD was attached to the mooring rope 2 m from the seabed, such that it floated in a vertical position toward the surface in slack water. Each POD site was matched for substrate type and water depth.

2.3 Experimental Design

The main aim of the experiment was to (i) assess the PAD effect on a harbour porpoise population in high and low tidal velocity habitats and (ii) assess the effect of the Stingray tidal generator on harbour porpoise habitat use.

The original plan was to deploy two PODs close together on the Stingray barge (high tidal velocity habitat) with the PAD on one and see if the detection rate increased at both when the PAD was 'on'. The PODs would then be moved as far apart as possible to assess the range of the PAD effect or even to detect a negative effect arising from re-orientation of animals. Subsequently the PODs could be moved closer together to get more detail. This method could be used to determine a detection threshold distance for the PAD and porpoise clicks in relation to the direction of current flow, and porpoise detection and encounter rate for both PODs for porpoises passing the Stingray tidal generator. If PADs actually only cause a re-orientation of acoustically active porpoises then as the separation between PODs increases, detections with the PAD 'on' should become lower than during the 30 minute control periods at some point. However, if they 'switch on' silent porpoises, no negative influence is necessary at any distance.

Following discussions with EB, the original plan was considered impractical with access to the barge required at several key locations for power supply, mooring cables and mooring of the standby tug. The design was modified by permanently fixing a remote POD hydrophone and PAD at the stern, positioned below the hull of the barge and above Stingray, to ensure a 360-degree detection range. The second POD was deployed on the seabed off the bow, c. 200 m north of the remote POD and PAD, providing an independent means to detect harbour porpoise approaching or travelling away from Stingray.

Hamna Voe, Yell Sound and Mousa Sound (SE Mainland) were originally considered as two low tidal velocity sites with known high porpoise densities to deploy a POD and PAD. Harbour porpoise ecology has been studied at Hamna Voe over the last five years and it has shown high levels of activity in each year, and it is close to the Stingray site. It was therefore considered as a 'control' site.

Some acoustic (POD) data for Hamna Voe is available from 2002, but experience at most marine sites is that there are large year-on-year variations in localised measurements related to fish movement etc. and the relative sensitivity of the PODs has not been established. In this study two PODs were deployed at Hamna Voe. One was adjacent to a PAD to investigate whether the PAD was a significant determinant of porpoise detection characteristics. Comparison could then be made between periods when the PAD was active and inactive in the data from one POD, with the other giving some independent data on porpoise activity nearby. A direct comparison of PODs with or without PADs is of limited usefulness because the PAD effect could not be disaggregated from location factors.

2.4 POD settings and calibration

It was anticipated that noise would be a problem monitoring Stingray so trials of more selective operational settings of the POD were tested at Hamna Voe where porpoise detections were much more likely. A range of filter ratios and minimum intensity values were tested. Increasing the ratio of filters to 7 increased click detection specificity without creating undue insensitivity, as did increasing the minimum click intensity from 4 to 5. Similar settings were used initially for the PODs deployed from the barge. Logging only clicks longer than 20µs in duration was also used to reduce logging of short clicks in noise from the current flow.

The PAD output and POD hardware response was tested in an anechoic acoustic tank prior to deployment in the field. Differences in sensitivity between units of approximately 5dB were found, but cannot be accurately measured at present. This will change in a version currently under development. The two PODs were rotated between sites at Hamna Voe to control for differences in sensitivity between hardware.

2.5 Data Analysis Tools

The POD software includes tools for the analysis and examination of the data. The data can be viewed and exported at a time scale of minutes to weeks to identify patterns and trends in use. For research purposes high resolution displays also allow the user to view click structure at a resolution of 10microseconds. This is primarily of use in understanding acoustic pathway characteristics e.g. multipath propagation as this is only evident at very fine time resolutions.

The TPOD software effectively provides a graphical audit trail back to each click in the original logged data.

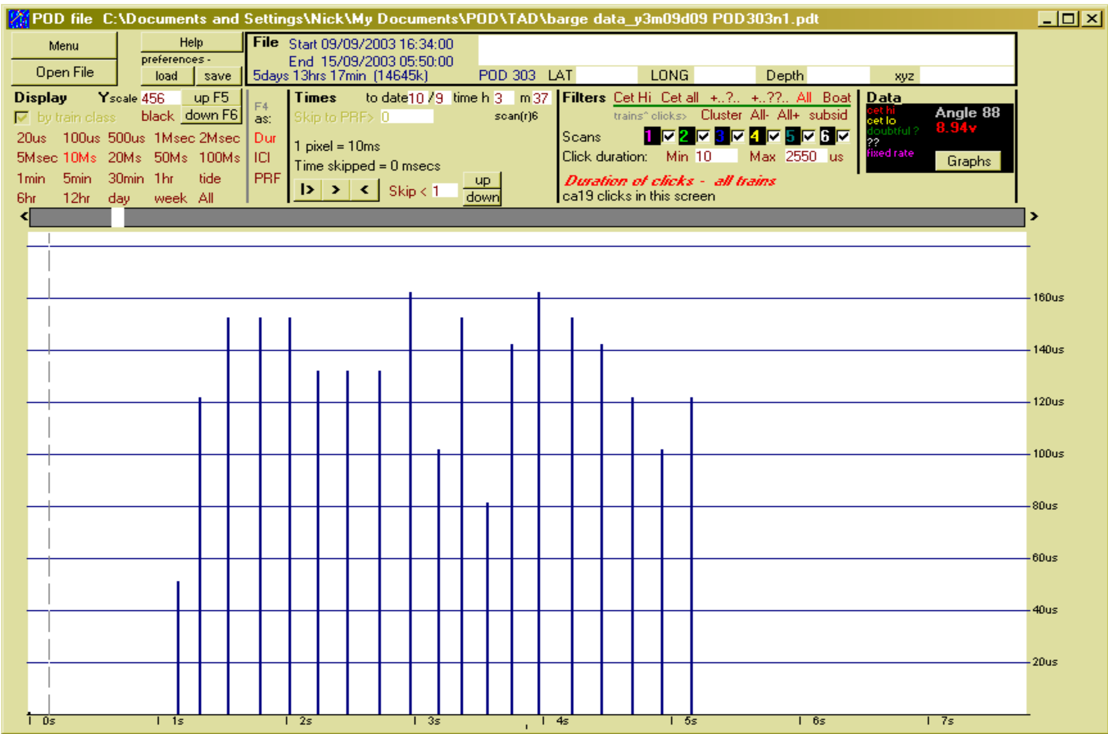


Figure 3. A train of porpoise clicks. Click durations are shown on the Y axis with time of occurrence on the X axis. This train has a low click rate (PRF) of around 4 clicks per second.

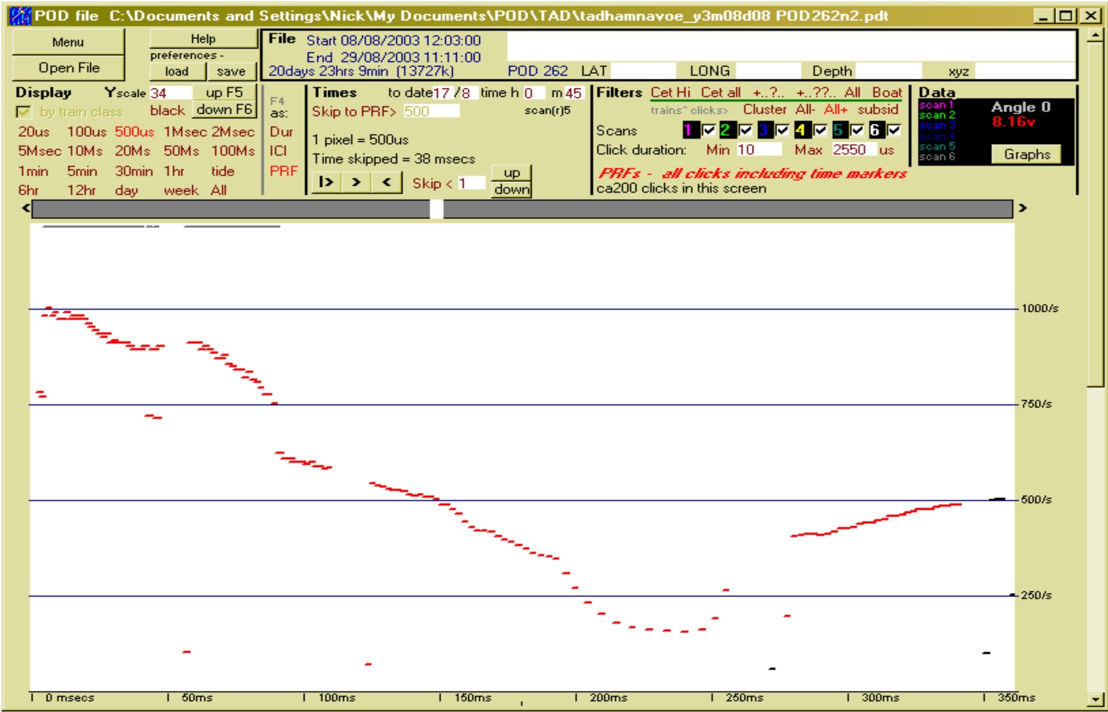
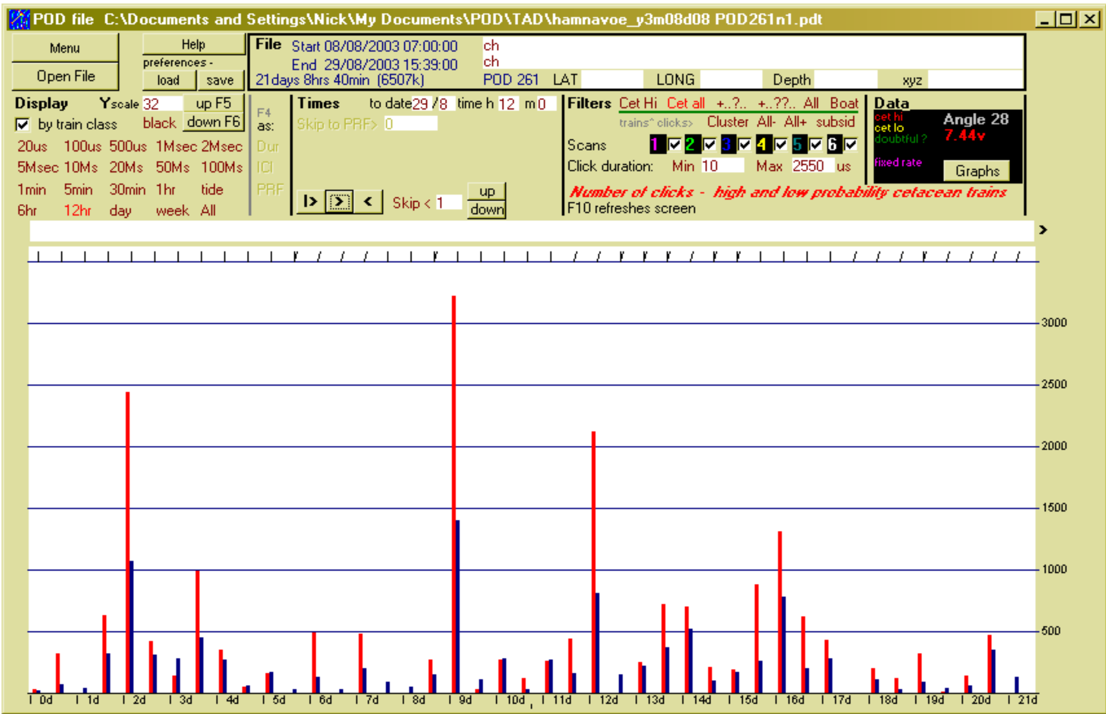


Figure 4. The click rate (PRF) of a fast train from Hamna Voe. Some clicks that have not been identified as belonging to the train are shown in grey.

Data can be viewed aggregated into a range of different time periods as here -



12hourly detection rates are shown, with CetHi and CetLo trains in red and blue.

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Small near-vertical lines at the top of the white area show the mean angle of the POD to vertical – this is a means of verifying correct deployment and of identifying current regimes from tides or storms that cause the POD to be deflected from vertical. The vertical coloured bars represent porpoise detection rates.

Data at all time resolutions can be exported to spreadsheets and work-processors. Summary statistics can also be viewed –

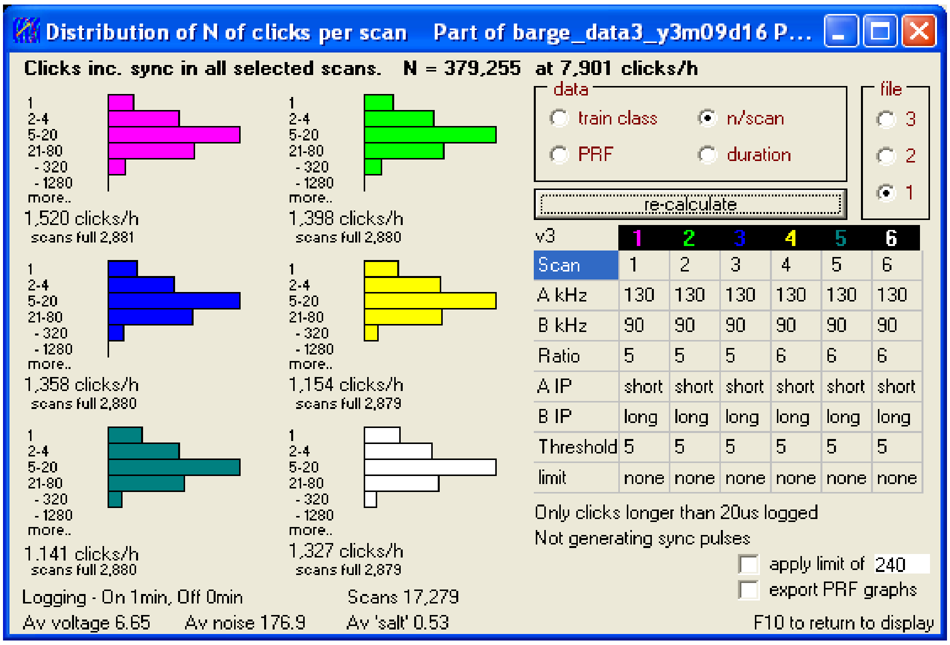

Figure 5. Click counts per 12hours over 21days in Hamna Voe during August

This shows that most clicks are logged at 5 to 20 clicks in each 10second scan, sufficiently low for the detection of porpoise clicks during periods of peak current flow. The number of spurious clicks logged by the trailing hydrophone was three times lower than for the fixed hydrophone configuration, even when using a more sensitive lower intensity setting.

A similar display is available for click duration, repetition rate and numbers in each class of train.

2.6 Porpoise detection statistic

Three summary statistics are principally used to describe porpoise detections; the percentage of clock minutes with porpoise clicks (TPM - train positive minutes) each day, the average number of clicks per minute (MTCR - Mean Train Click Rate), and the Encounter Rate. Discrete porpoise encounters are delineated by 'silent periods' of at least 10 minutes without any click trains detected. All these statistics ignore all clicks that are not classified as being in cetacean trains ('CetHi' or 'CetLo' classes, called 'CetAll').

3. Results

Descriptive statistics are summarised in Table 3.1 including two deployments from the POD on the Stingray barge in September and three monthly deployments of two PODs at Hamna Voe.

Porpoises were detected at the Stingray barge site and in Hamna Voe site to the south but POD data was only available from the barge for part of September and therefore comparison of trends between the two study sites are not possible. When comparing data for September the percentage of train positive minutes (TPM) indicate that porpoises were considerably less common at the barge with 0.4% TPM compared to Hamna Voe with 1.4% and 3.6%.

3.1 Stingray Barge Site

The remote POD was installed on the barge in August and checked bi-weekly to determine if the securing system was adequate. ‘Strumming’ of the pipe encasing the microphone cable and hydrophone from the strong current turbulence was not found to be a problem, however, modifications were necessary to reduce the ambient current noise at the hydrophone as non-cetacean clicks were logged at such high rates that train detection would inevitably be very insensitive.

It was not initially clear whether these high rates were actually arising from acoustic sources or from radio frequency (RF) interference, which is not normally a problem because PODs deployed beneath the sea surface are shielded from RF interference by the seawater. RF interference arises from narrowband sources, mainly the use of radio communication at frequencies close to porpoise acoustic frequencies, and also from broadband sources such as the various petrol engines in use on and around the barge.

Assessments were undertaken with a third POD that was trailed over the bow of the barge on a length of rope, five metres below the surface. These trials provided comparative data, which indicated that most of the noise was acoustic and generated from turbulence and from particles and perhaps bubbles colliding with the hydrophone housing, mainly during periods of high velocity tidal flow. To reduce this noise the hydrophone enclosure was converted to trail in line with the current instead of being held rigidly in a position transverse to the current.

Plate 5. Trailing hydrophone on the barge deck.

A flexible rubber sheath was wrapped around the hydrophone and PAD cable at the end of the pipe to prevent damage to the cables and allow the hydrophone to trail with the current. A rope tail was attached to the end of the hydrophone casing to minimise oscillations created by water flow over the hydrophone housing.

The second POD on the seabed was damaged in August when the seabed rig for the ADCP rolled in the current destroying both the POD and the current meter for which the rig was primarily deployed. The replacement POD was damaged during retrieval from the barge in September, with no data recovered.

These events represent the size of the task of establishing a monitoring system in a novel and difficult context. By contrast the two PODs at Hamna Voe, operating in familiar environmental conditions, were successfully deployed and retrieved by the aquaculture staff and logged continuously during deployment with all data recovered.

One Stingray POD proved to have a faulty memory chip which could not be replaced until 9th September.

The effect of the tides was evident in the overall click rates logged. Figure 6 shows data gathered with the hydrophone fixed vertically at 90 degrees to current flow. The peaks in the distribution correspond to the increase in current velocity with the flood and ebb tide; the troughs correspond to slack water.

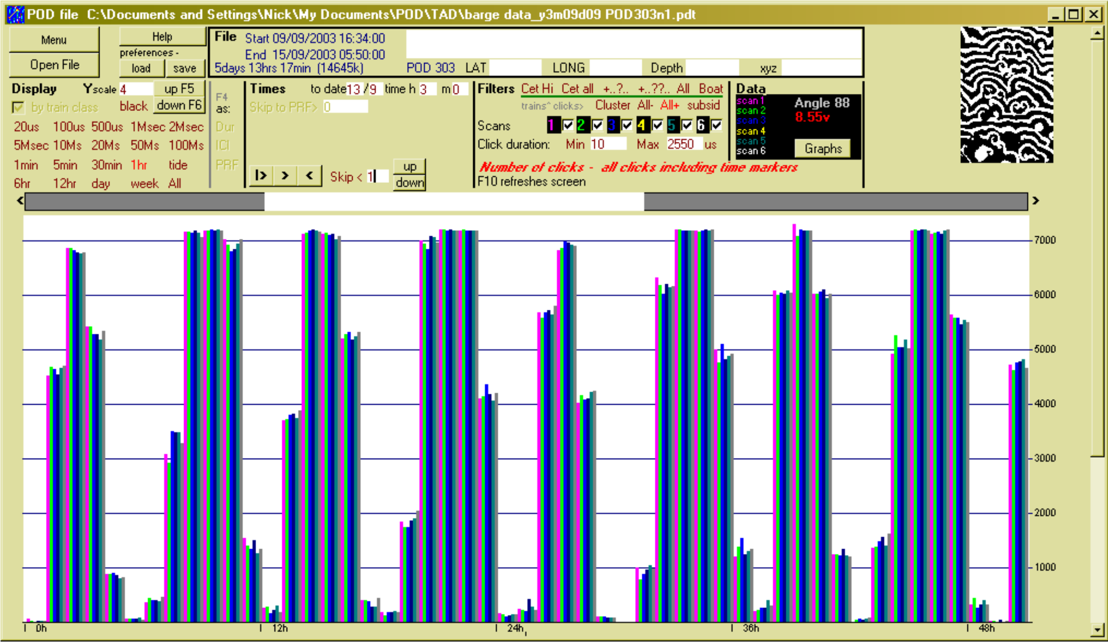

Figure 6. Rate of logging of clicks over 48 hours showing tidal pattern.

The number of clicks logged is capped for successive 10second ‘scans’. Most clicks were logged at rates of 100 to 320 clicks per second, masking the detection of porpoise clicks during periods of peak current flow, i.e. porpoise click detection was only possible from the barge only during the ‘quieter’ periods, ± 2 hours around slack water using this POD configuration. The high level of non-porpoise clicks also increases the rate of false detections in classes below ‘CetHi’ reducing the volume of useful data.

After modification of the hydrophone to allow it to trail like a towed hydrophone array

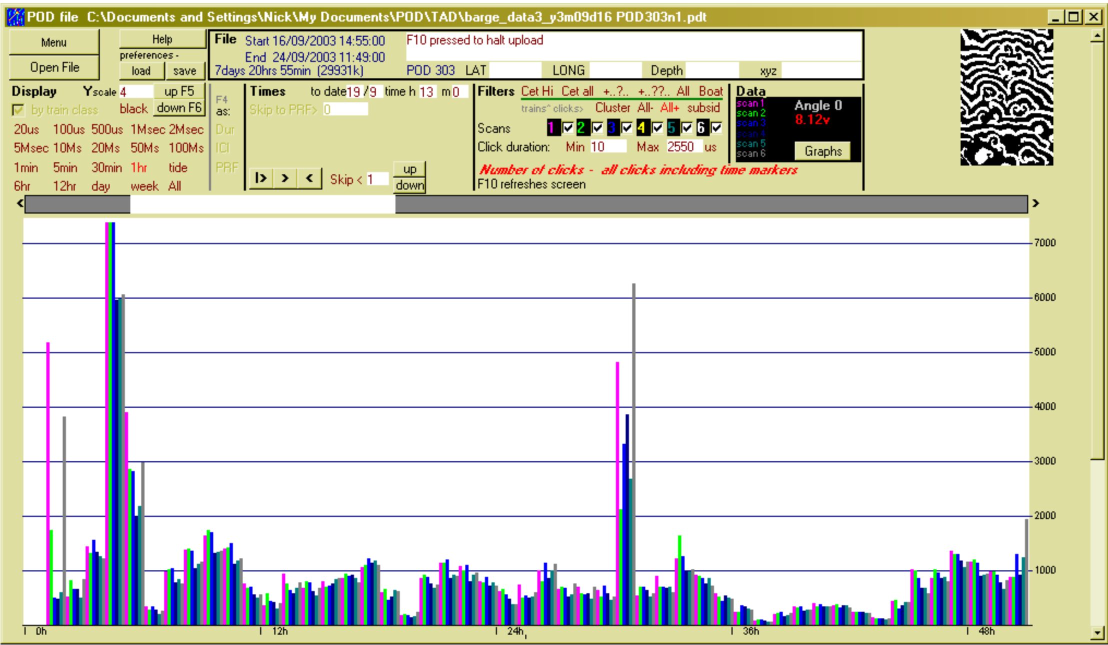

Figure 7. Rate of logging of clicks over 48 hours with hydrophone trailing freely with the current.

the number of clicks detected per scan generally fell below 150/second. The tidal cycle is still evident. The pod sensitivity was set higher than had been used in the fixed hydrophone configuration: filter ratio of 5 and minimum intensity 6 respectively, instead of 6 and 7, indicating a considerable improvement in the reduction of false positive clicks.

With this configuration porpoise detections at the barge are shown in Figure8.

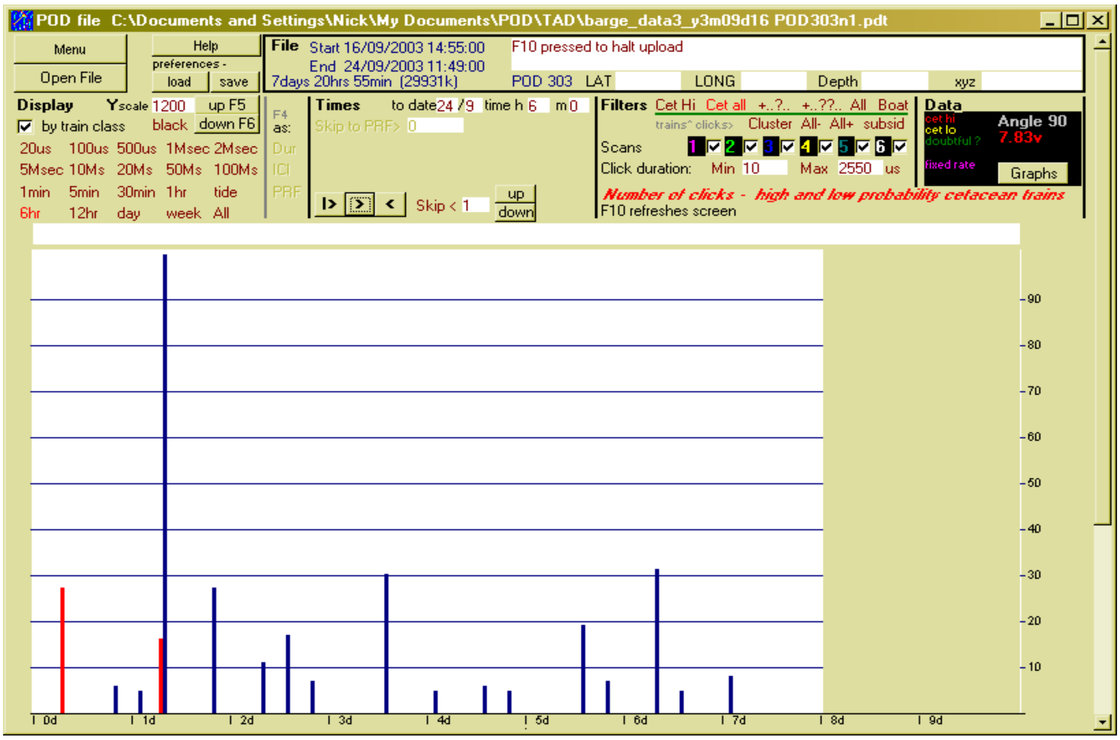

Figure 8.   Porpoise detections from the barge

The tidal pattern in detections is shown in Figure 9 below. Porpoises were detected on the flood and ebb tide with five of the ten porpoise detections at or within one hour of slack water, and the remaining five detections within two hours of slack water. These detections were logged when the current speed was less than 110 cm per second. No porpoises were detected during the period of peak current velocity at c. 170 cm per second, approximating to three hours after slack water.

The acoustic data from the Stingray site was limited greatly by the faulty memory chip, the flow noise before the hydrophone modifications, and the loss of the sea-bed PODs. No before/after comparison is possible because monitoring was only possible when the barge was in place, and the number of detections obtained are not sufficient for assessment of any relationship to periods of activity of the Stingray generator.

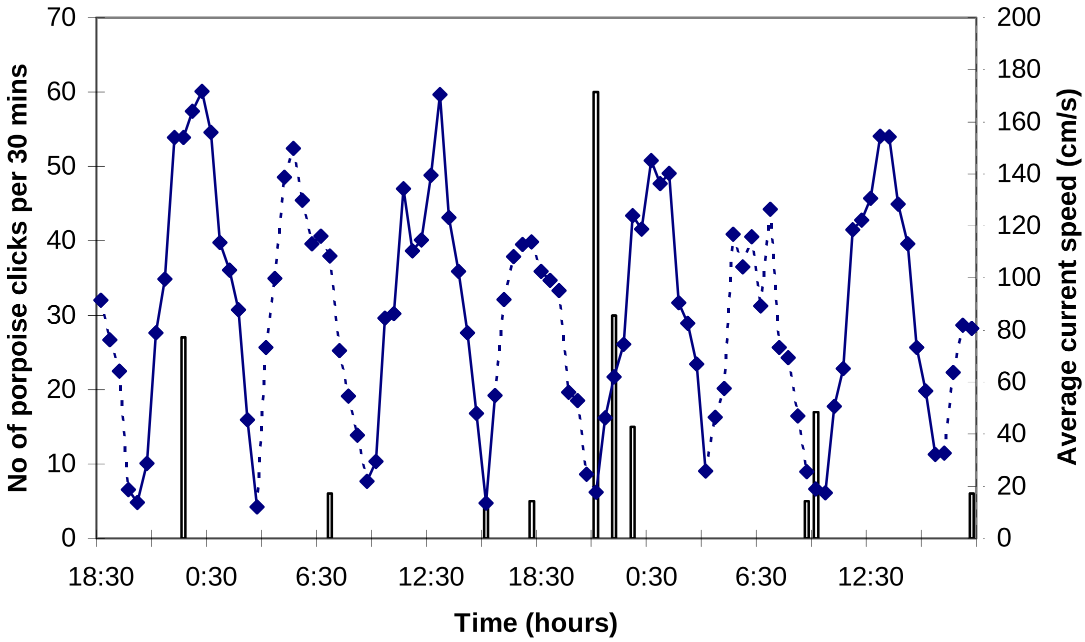

Figure 9. Porpoise click detections vs. current speed from aft ADCP-Stingray barge 16th-18th September. Curve shows current speed, solid lines=flood, broken line=ebb current. Bar: white=porpoise

3.2 Hamna Voe

The longest POD data-logging period was 21 days and 9 hours which was terminated by retrieval of the unit from the seabed. This period was consistent with the manufacturer's specification of a 40day period using six alkaline batteries. The PODs used can hold 12 alkaline or lithium batteries, increasing the logging duration to up to 80 or 240days respectively. Long logging durations may exceed the capacity of the memory in noisy locations or those with many cetaceans, and more frequent data collection was undertaken to ensure that the PODs were still present and functioning.

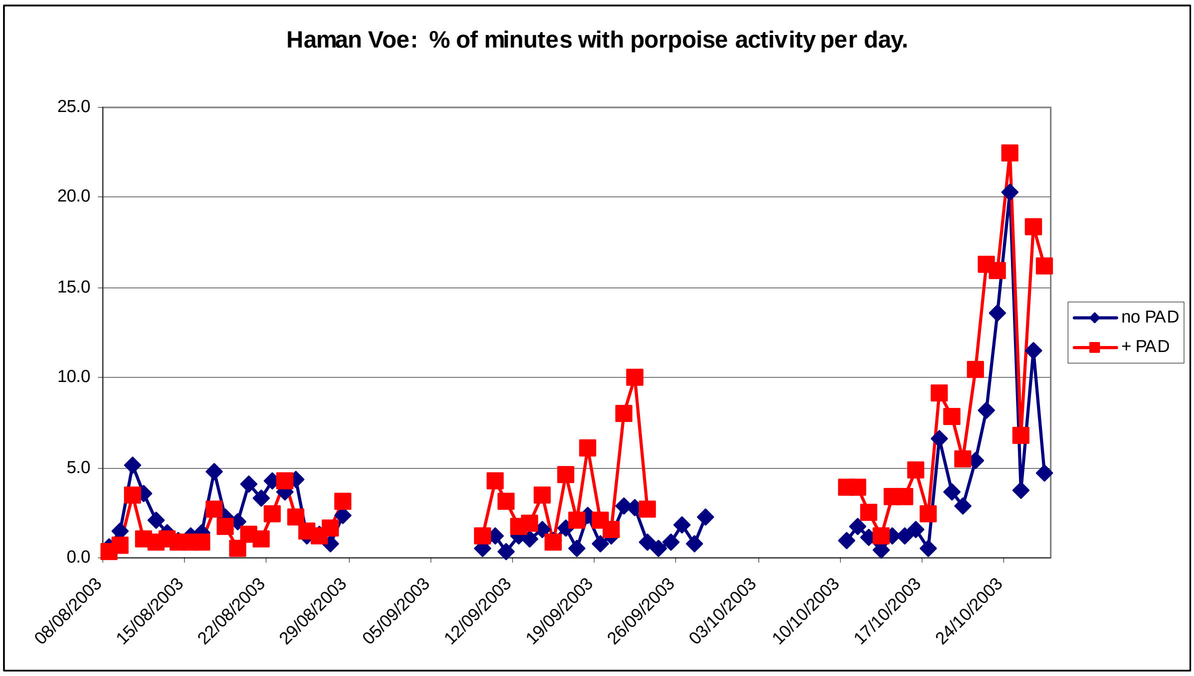

Figure 10. Hamna Voe: train positive minutes; all data.

Figure 10 shows the very marked increase in porpoise activity in the second half of October. The PAD was attached to POD 262 in August. This was the less sensitive of the two PODs and this appears to be the major factor in the shift from lower to higher detection rates with the PAD compared to without it.

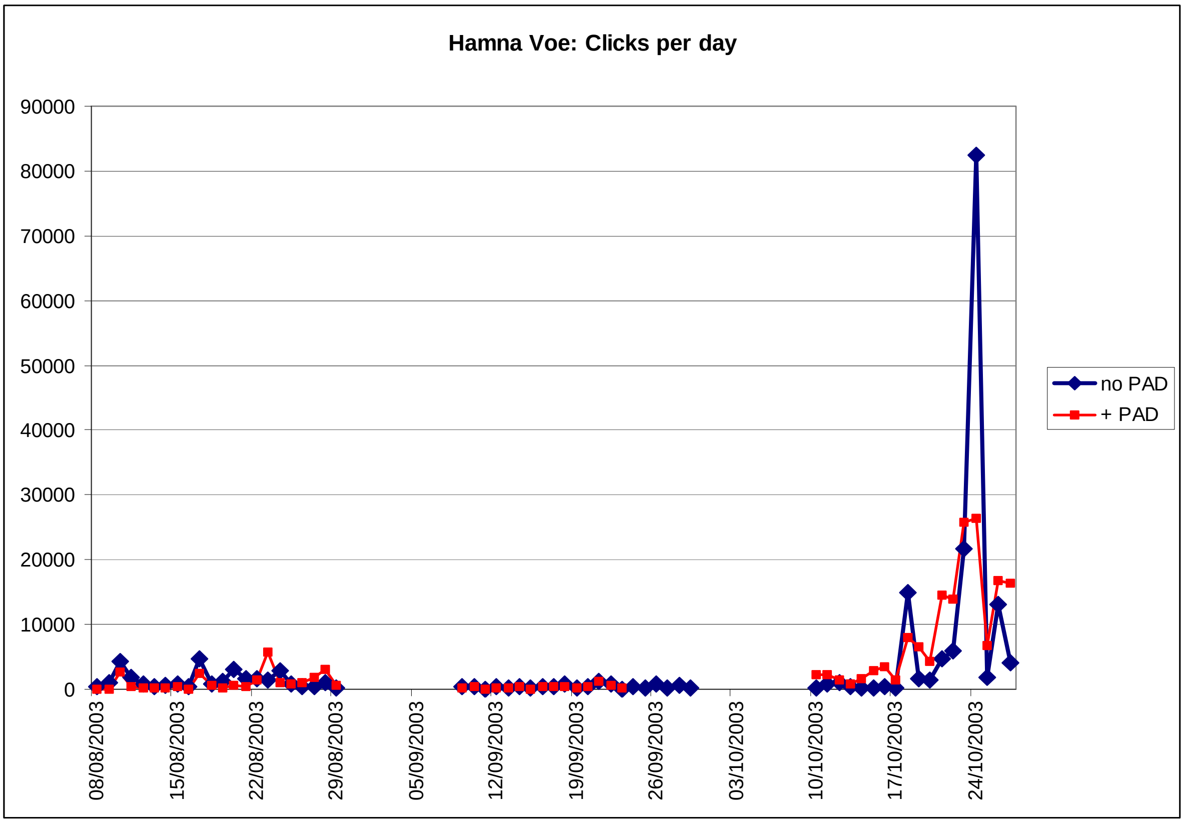

Figure 11. Hamna Voe: clicks per day; all data.

Figure 11 shows the same period using clicks per day (click rate) as the statistic. The comparison shows that the October peak represents a change in behaviour, which is likely to be more intense feeding activity, as well as in usage of the area. The gaps in the graphs are periods during which the PODs were out of the water.

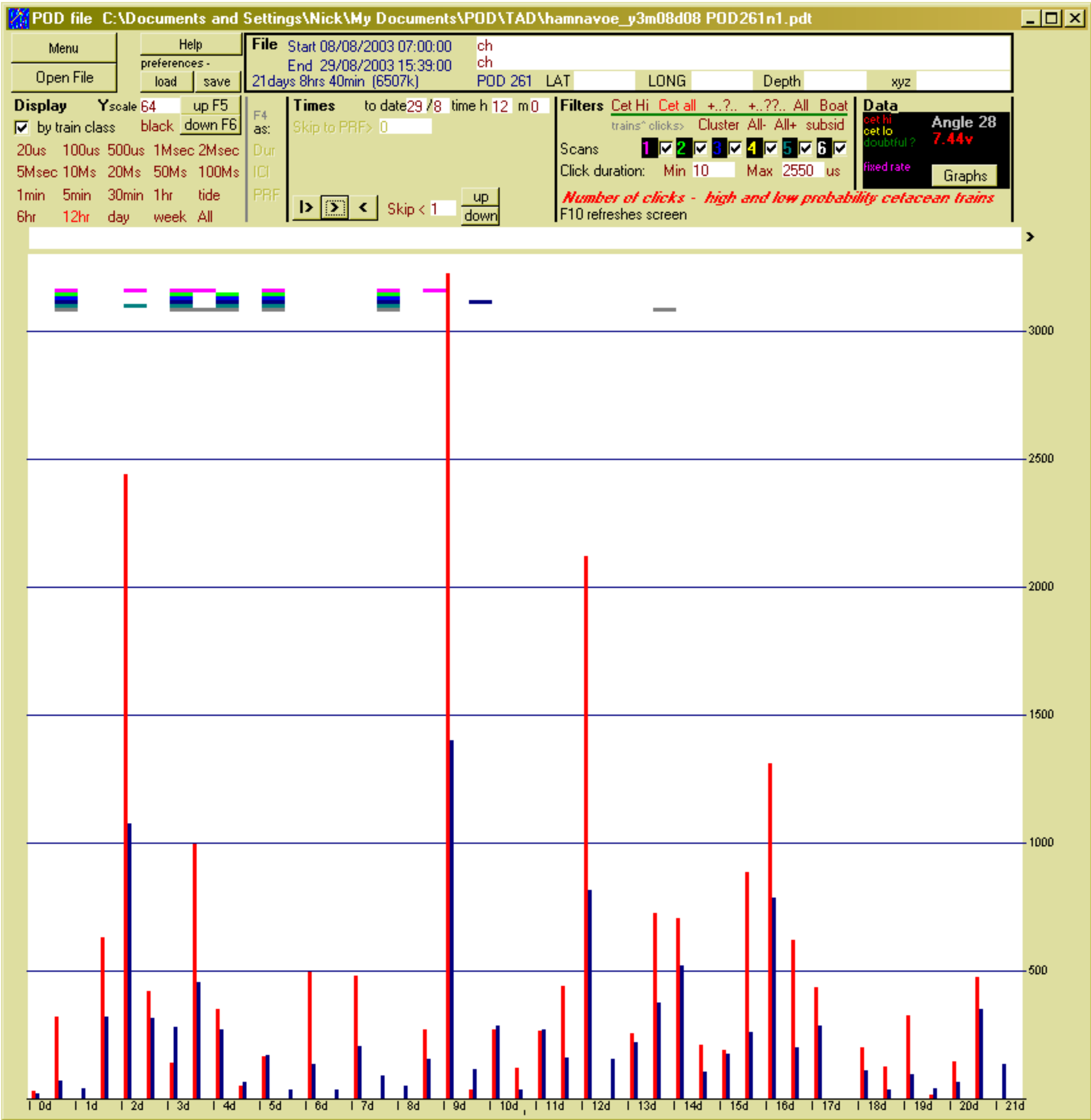

Figure 12. Porpoise clicks per 12hrs and boat sonar detections at Hamna Voe, August. Data is aggregated into 12 hour periods.

Figure 12 shows more detail – 12 hourly click totals - for August. The horizontal bars indicate the detection at some time in that 12 hour period of a boat sonar.

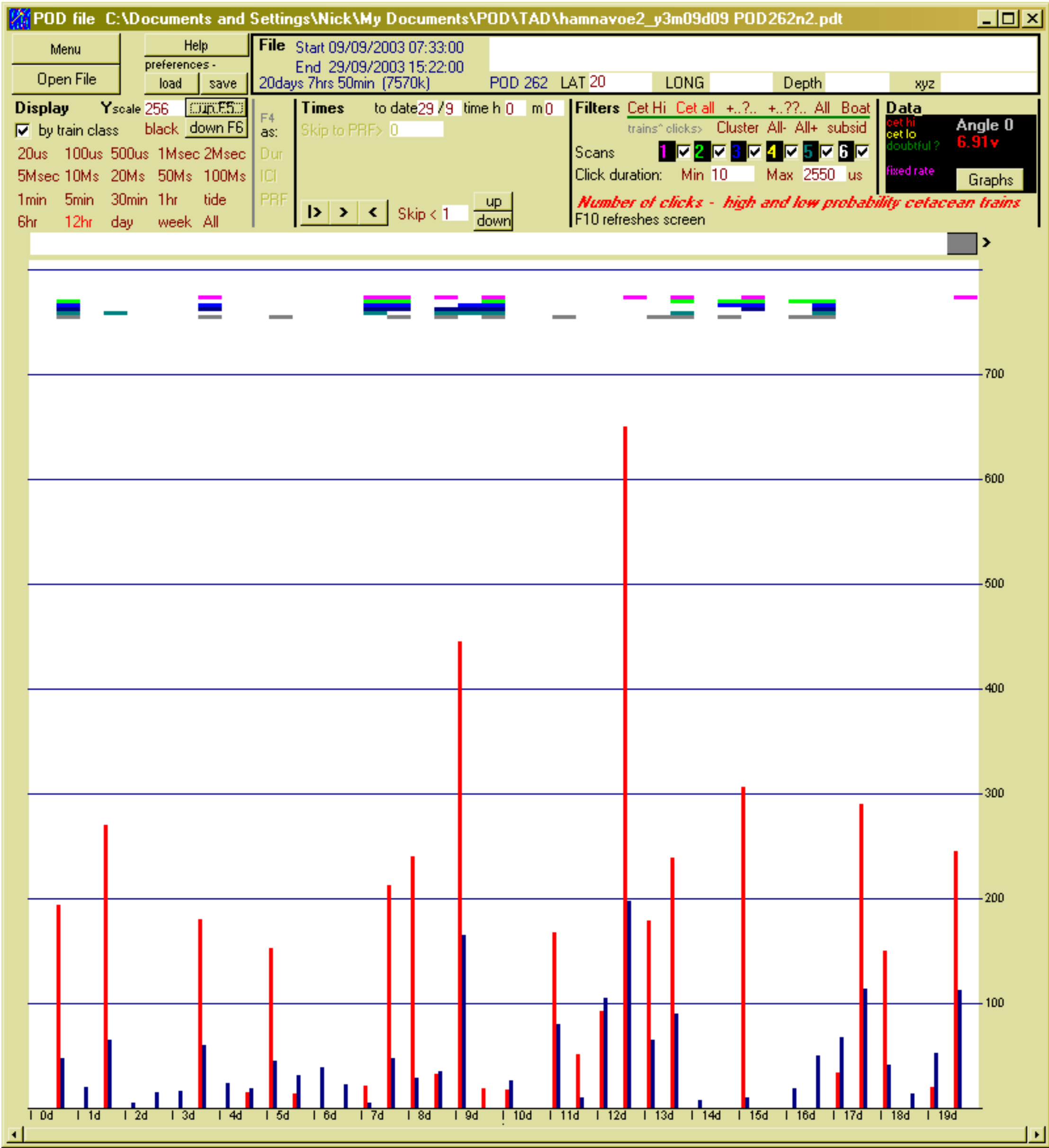

Figure 13. Porpoise clicks per 12hrs and boat sonar detections at Hamna Voe, September. Data is aggregated into 12 hour periods.

Activity is a little lower in September.

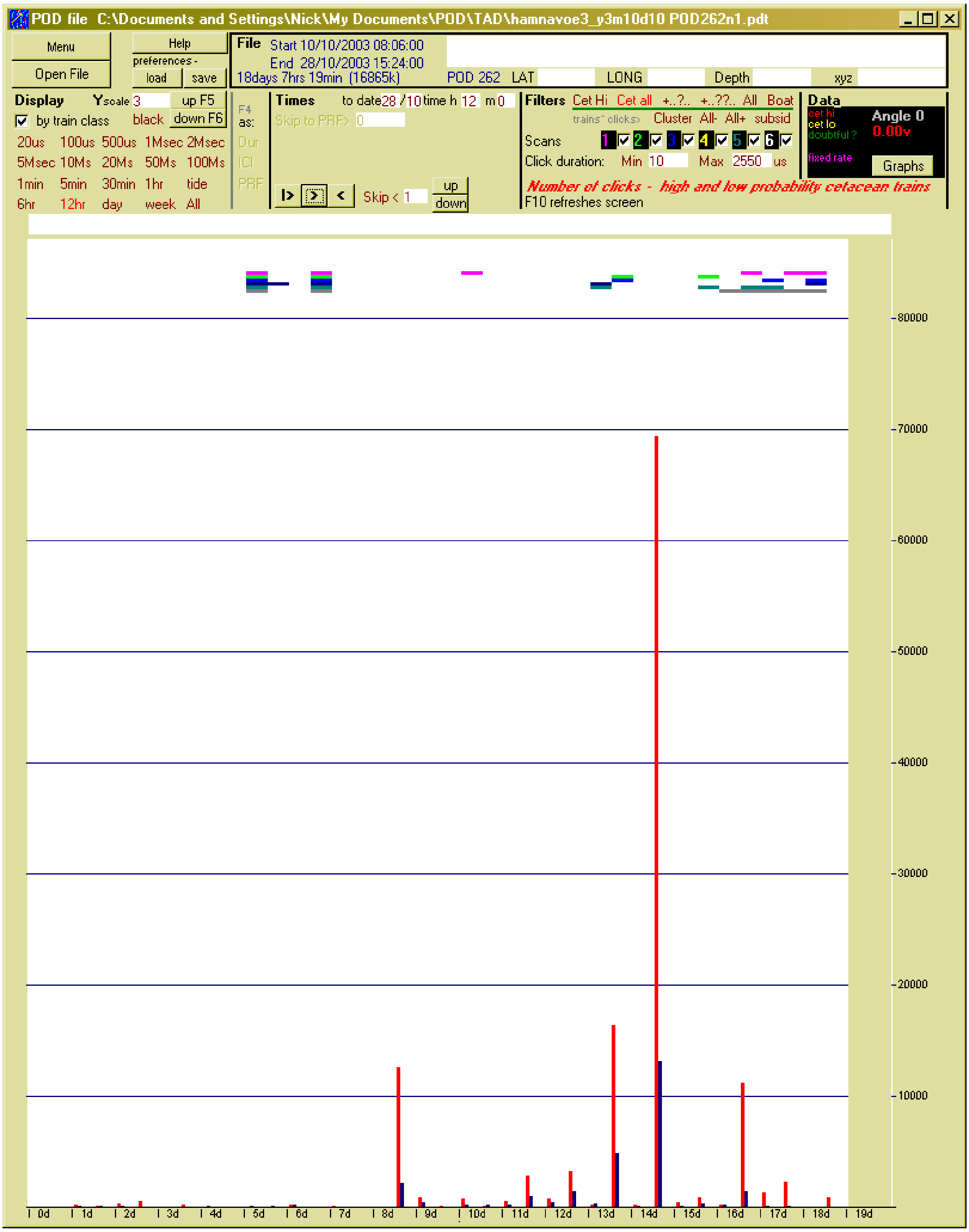

Figure 14. Porpoise clicks per 12hrs and boat sonar detections at Hamna Voe, October. Data is aggregated into 12 hour periods.

The Y axis scale has been reduced by a factor of 10 to accommodate the very high click rates on 24th October.

Table 3. Summary of POD data acquisition in Yell Sound.

POD	303+PAD	303+PAD	261	262+PAD	262	261+PAD	262	261+PAD
LOCATION	Barge	Barge	H'voe-offshore	H'voe-inshore	H'voe-offshore	H'voe-inshore	H'voe inshore	H'voe offshore
	Sept	Sept	Aug	Aug	Sept	Sept	Oct	Oct
Start	3/9/03 16:34	16/9/03 14:55	8/8/03 07:00	8/8/03 12:03	9/9/03 7:33	9/9/03 7:31	10/10/03 8:06	10/10/03 7:08
Finish	15/9/03 5:50	21/9/03 12:00	29/8/03 15:39	29/8/03 11:11	29/9/03 15:22	24/9/03 10:44	28/10/03 15:24	29/10/03 14:25
Duration (minutes)	7998	7026	30761	30190	29271	21807	26360	27799
Ratio ; Click Intensity	6 ; 7	5-6 ; 7	5 ; 6	6-7 ; 4-5	6-7 ; 4-5	6-7 ; 4-5	6-7 ; 4-5	6-7 ; 4-5
PORPOISE ACTIVITY								
Train Positive Minutes	*	26	763	497	409	776	1284	2334
% TPM		0.4	2.5	1.6	1.4	3.6	4.9	8.4
% fast clicks (range over 6 scans)		0-46	25-41	7-27	4-25	2-12	51-54	23-27
CLICK RATES								
Total no. of CetHi clicks		43	19935	17266	5231	19096	127228	113077
Total no. of CetLo clicks		220	10800	6595	4020	11910	29104	54624
Mean click / minute		0.04	1.0	0.8	0.3	1.4	5.9	6.0
Standard Error		0.01	0.06	0.07	0.03	0.11	0.29	0.23
Max. no. of clicks / minute		35	550	596	433	649	1209	1137
Max PRF	59	280	869	793	943	781	800	1000
Peak PRF	94	531	934	833	1010	800	934	1041
ENCOUNTER RATES								
Total no. of encounters		20	257	231	234	226	231	346
Mean duration in minute		1.9	5.3	3.7	3.0	6.0	8.1	11.9
Standard Error		0.45	0.27	0.34	0.23	0.59	1.65	1.51
Max. duration in minutes		8	45	34	24	51	280	310

Note. Data from POD deployments with PADs at Hamna Voe are shaded in grey.

3.3 Discussion: Comparison between sites

Table 3 gives a comparison.

Click rates/day

The mean click rate per minute was calculated from the total number of clicks logged for CetAll train classification. The mean click rate at the barge was 0.04 clicks (±0.01 S.E.) / min with a maximum count of 35 clicks in one minute. The mean click rates from the two PODs at Hamna Voe were all higher, with 1.0 and 0.8 clicks (S.E. ±0.06 and 0.07) in August, 0.3 and 1.4 clicks (S.E. ±0.03 and 0.11) in September and 5.9 and 6.0 clicks (S.E. ±0.29 and 0.23) in October. The maximum click counts per minute for each month were 550 and 596; 433 and 649; 1209 and 1137.

Train Positive Minutes

The % of minutes with porpoise detections each day at Hamna Voe during the period of the Stingray monitoring was up to 4.2%, with 3.3% at the Stingray site itself.

Encounter durations

During September the mean duration of porpoise encounters at the Stingray barge was 1.9 minutes (s.e.±0.45, n=4 encounters per day) and the longest encounter was 8 minutes. At Hamna Voe the mean duration of porpoise encounters was 3.0 (s.e.±0.45, n=12 encounters per day) and 6.0 minutes (s.e.±0.45, n=15 encounters per day), with a maximum encounter of 24 and 51 minutes respectively.

Encounter durations at Hamna Voe increased in October; with successive deployments of PODs without PADs recording 5.3, 3.0 and 8.1minutes, while PODs with PADs recorded 3.7, 6.0 and 11.9 minutes. The longest encounter durations logged increased from 51 minutes in August to 310 minutes in October.

Porpoise click repetition rates (PRF)

The peak PRF recorded for CetAll click was 531 clicks per second at the Stingray barge. At Hamna Voe the peak was 1041 clicks per second. Both these values are in the range known to be used during prey capture.

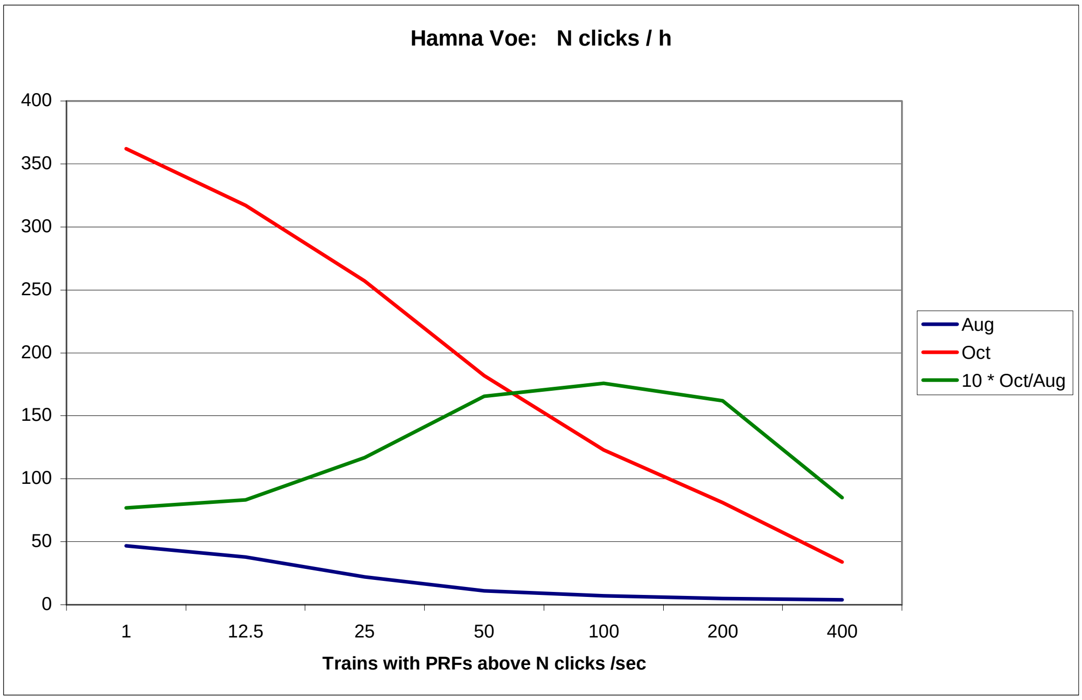

Figure 15. Level of porpoise sonar activity v. PRF

Figure 15 compares August with October and breaks the data down into PRF classes. It shows that October has much more activity, and that this is most marked in trains with PRFs from 50 – 200 clicks/second. This fits the observed feeding behaviour in October. The two months provide a useful basis for identifying how the porpoise alerting effect may vary with level of activity and behaviour.

3.4 Porpoise Alerting Device: Results

The effect of the porpoise-alerting device (PAD) on the porpoise train detection rates was investigated using the PODs with the PAD attached to the side of the POD at Hamna Voe, and on 5 days of data from the barge after the revision of the hydrophone reduced non-cetacean clicks to satisfactory levels.

The PAD signal is logged by any POD nearby and the characteristic low PRF can be used to identify these detections using a specific detection function in the POD software. This allows analysis even where there is some drift of the PAD clock relative to the POD clock. The PAD switches on for alternate 30minute periods so that the 30minute OFF periods can be used as a control. This avoids confusion with differences between sites or PODs.

However the acoustic conduction pathway between PAD and POD is variable as it passes through seawater and is sensitive to the relative positions of POD and PAD. Consequently detections are not entirely consistent and data from September in Hamna Voe has been omitted, as the PAD detection rate was low, probably because it was positioned too low on the POD housing. The frequency of Click Train +ve and Click Train –ve periods in Table 3.2 are summarised per five-minute period.

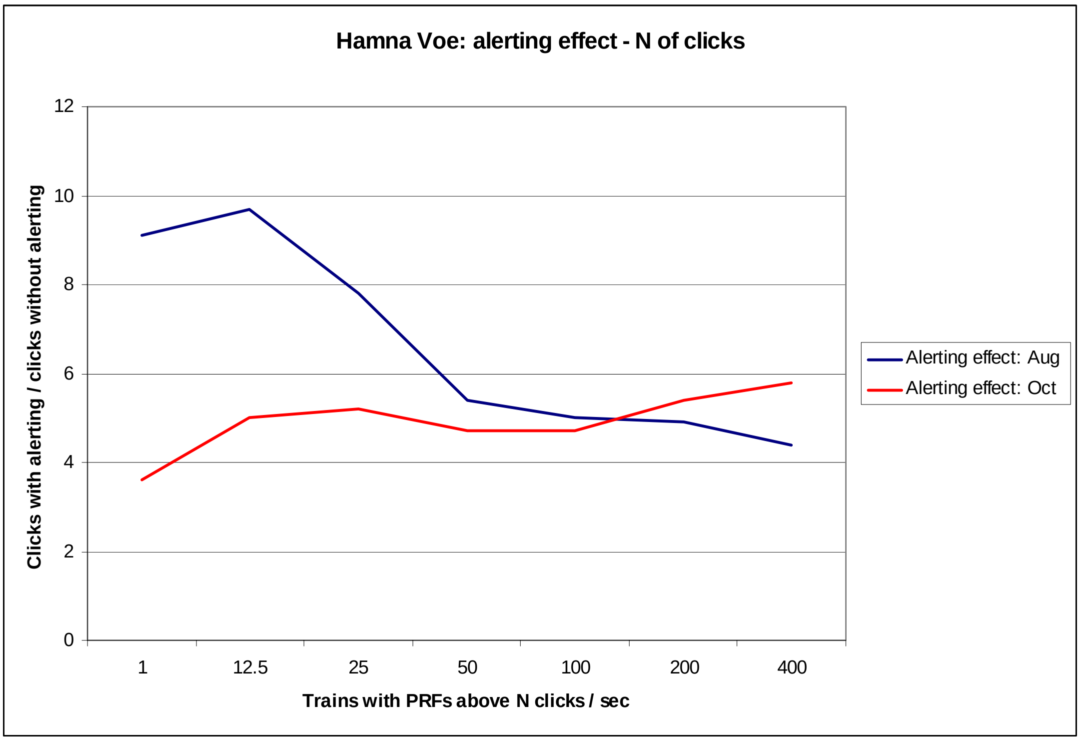

Figure 16. Alerting effect v. PRF in August (lower porpoise density) and October (higher porpoise density)

Figure16 shows how the alerting effect varies across PRF rates in August and October. The alerting effect is the ratio of number of clicks logged when the PAD is active to the number logged when it is silent.

The alerting effect is maximal for low PRFs in August when porpoise densities are lower. This could be interpreted as porpoises responding at a greater distance from the source of a sound, that is similar to a porpoise's click, when there are less porpoises around. Also a porpoise investigating the PAD from a distance is forced to use low PRFs to give time for the echo to return and be heard before the next click is made. The two-way travel time alone requires a porpoise at 15m to use a PRF of below 50/s to investigate the source of the alerting sound.

The small excess of alerting effect assessed on high PRF trains only in October is less easy to interpret plausibly and could be a sampling error arising from the smaller volume of data at these high PRFs. Overall the range of alerting effects varies by a factor of nearly 3.

To investigate this further we can look at the alerting effect assessed using train positive minutes as in Figure 17. The range of alerting effect now comes down to just under 2, but the greater effect on high PRF trains in October is now shown more strongly with TPM as the test statistic. This suggests that when porpoise densities are high most of the alerting effect detected is due to animals quite close to the source of the alerting signal and consequently using higher PRF trains to investigate the source. Perhaps for more distant animals the PAD signal is actually lost in a background in which porpoise sounds provide an ever-present rattle and buzz of click trains.

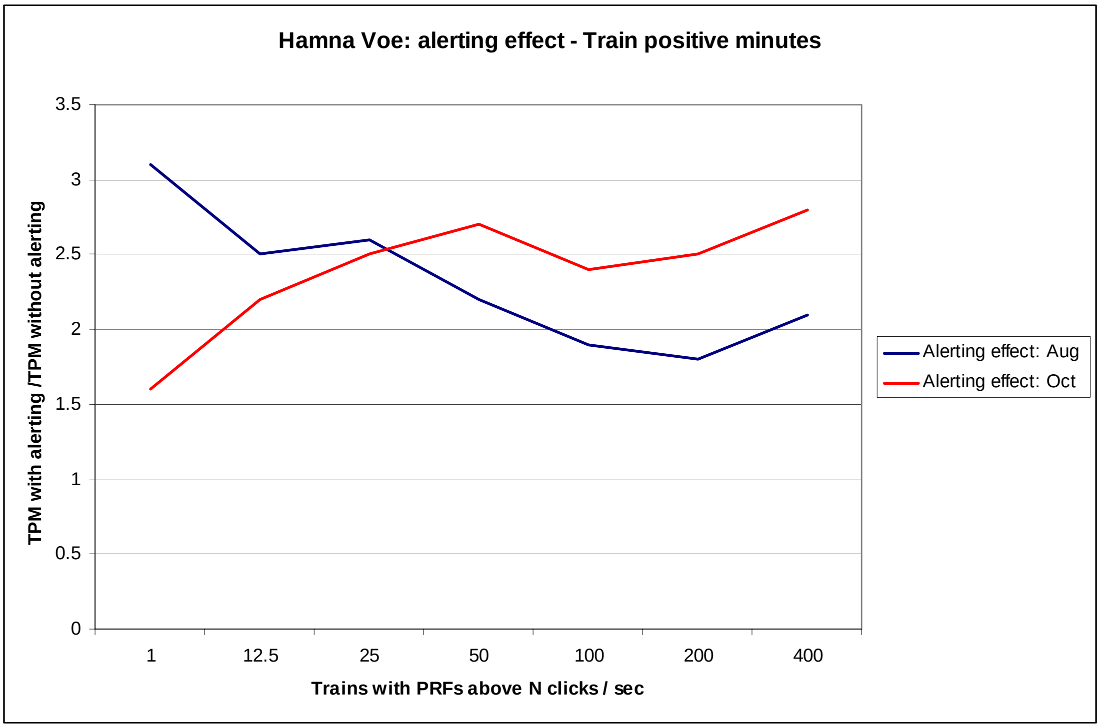

Figure 17. Level of porpoise sonar activity v. PRF

To examine that further we plot the prevalence of fast trains logged at PODs with and without PADs. Overall the percentage of 'fast trains' with high PRFs (>100/s) detected for PODs with the PAD was approximately half compared to PODs without the PAD.

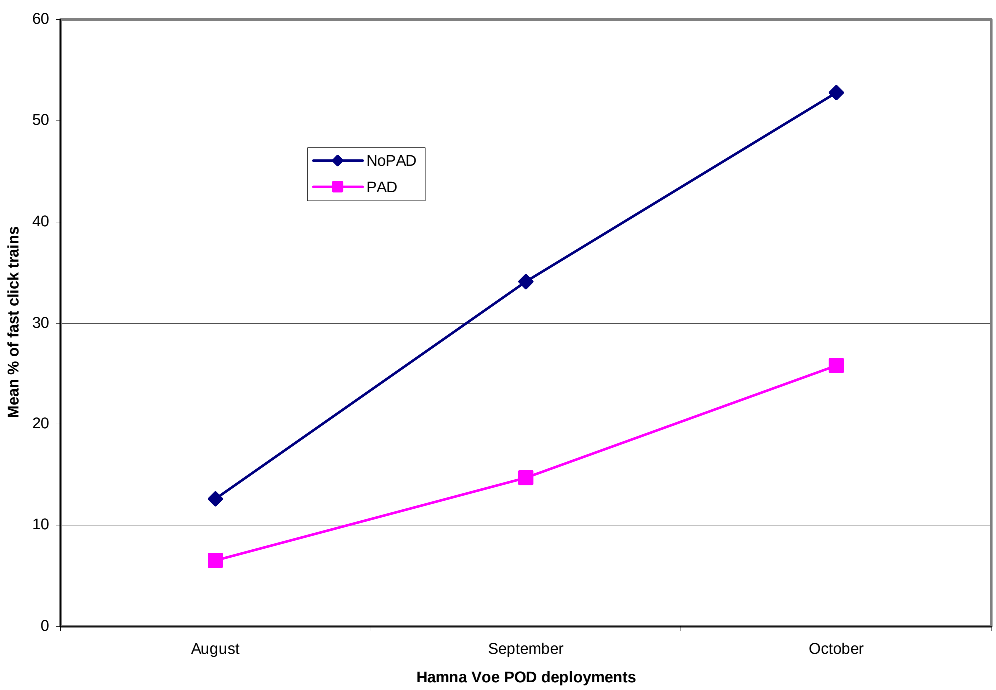

Figure 18. Variation in percentage of clicks that are in fast trains. Data from PODs deployed at Hamna Voe with and without alerting devices.

This clear relationship suggests that the PAD induces low PRF trains, which may represent porpoises acoustically responding to the PAD from a greater distance than their current focus of sonar attention. As noted before this is expected as the PRF of a train is related to the distance between the porpoise and the potential acoustic targets of interest to it, by the time it takes a click to travel from the porpoise to the target and back again, plus the ‘processing time’ in the porpoise’s nervous system.

The September data with PAD in place is less reliable as the PAD positioning did not allow very accurate logging of its active periods, but the data does show the same pattern – the alerting effect on click totals gives 12 times those without while train positive minutes are 3.4 times those without the PAD activity. Both figures are likely to err on the high side because of the method used to identify PAD active periods, but they do support the evidence that Train Positive Minutes is a better statistic than click rates to use in comparing data sets collected with use of a porpoise alerting device.

At the barge the alerting effect was very much smaller, around 26% for click rates. This may be due to the higher levels of ambient noise or the presence of boat sonars, or to changes in porpoise behavioural response associated with differences in porpoise activity such as transiting, or to the presence of some non-porpoise trains in the data as previously discussed. We have not analysed this aspect of the barge data further as the overall data volume and quality from the barge would seriously limit the reliability of the results.

3.5 Boat Sonars

Boat sonars have long narrowband (tonal) pulses that can be at a wide variety of frequencies and have pulse repetition frequencies of under one pulse / second up to around 20 pulses per second. Frequencies at or above porpoise frequencies are detected by the POD, which becomes less sensitive as the frequency is further above the 130kHz used by porpoises. 200kHz sonars may be detected. The waveform of the start of a sonar pulse is shown below.

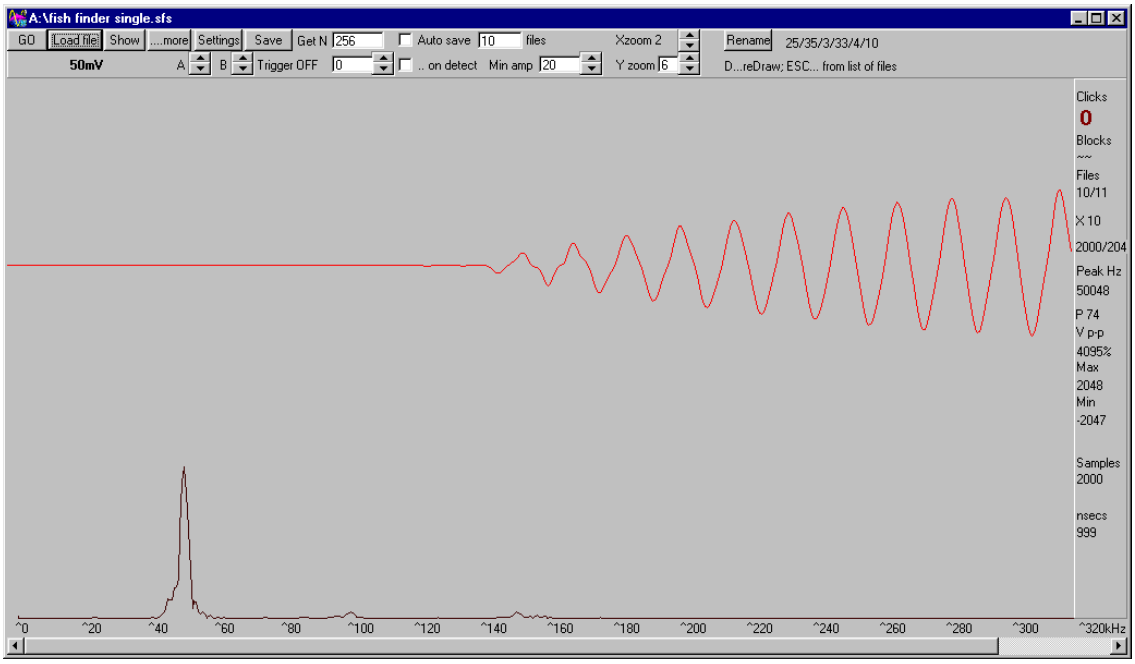

Figure 19.   The waveform of the start of a 50kHz sonar pulse.

Sonar pulses are typically received as clusters of echoes. The graphic below shows echoes logged on the barge from a sonar pulsing at around 15 pulses per second. The modulation of inter-pulse intervals and durations arises from the complex pathway between source and receiver. These complex paths reflect the very high acoustic intensity of modern sonars, which are far louder than the porpoises themselves, or the pingers used in fisheries to drive them away from nets.

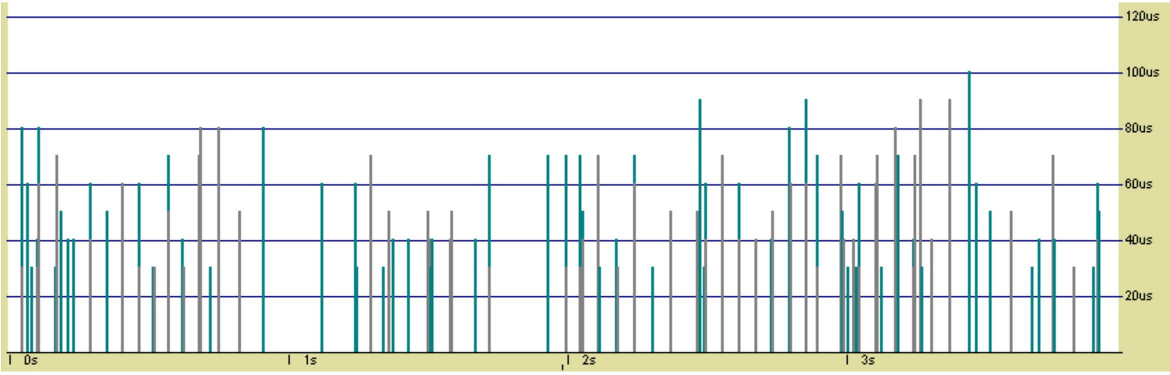

Figure 20. Sonar pulses at 15 pulses per second logged on the barge.

Discrimination of boat sonars is an essential part of the POD software and depends on their regularly repeated duty cycle. Some variability is introduced into the PRF of the boat sonar by the acoustic pathway which can include multiple reflections from sea bed and surface may be involved, and the shape of the sea surface is constantly changing due to surface waves. The TPOD software includes algorithms to identify train characteristics of sonars.

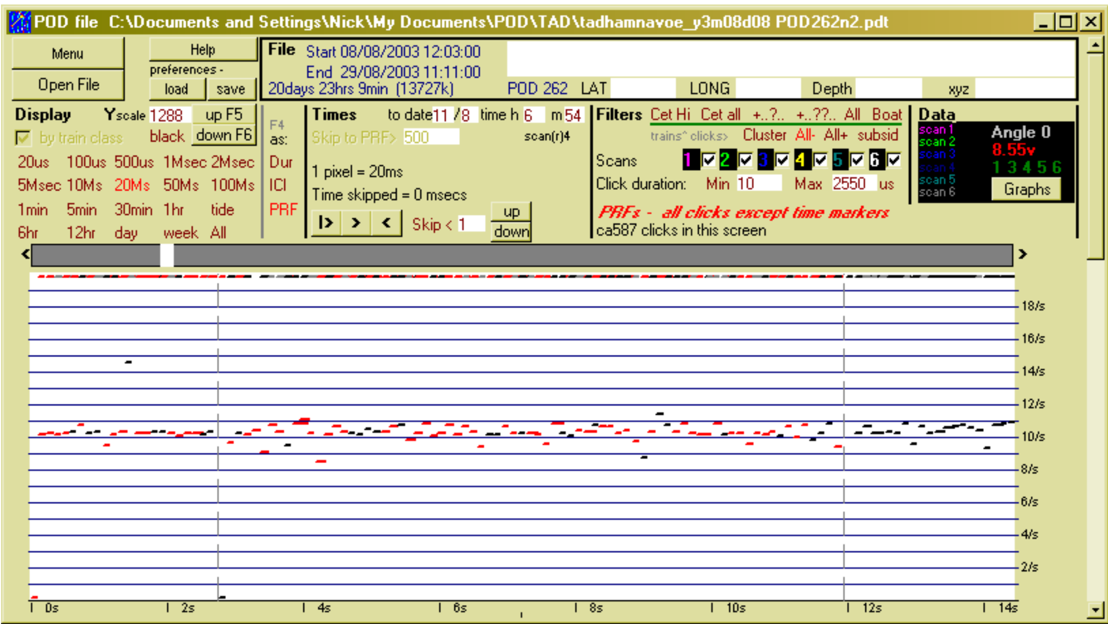

Figure 21.   The fundamentally constant PRF of clicks from a boat sonar, with superimposed pathway variations.

The Stingray barge presented a particular difficulty as the trailing transducer gives enhanced sensitivity to components of marine sound travelling vertically. This enhances boat sonar detection while diminishing sensitivity to the predominantly horizontal sounds from porpoises. This results in the detection of sonar pulses that have been subject to more reflections and are consequently more difficult to identify as arising from sonars. A significant ‘false positive’ rate is evident in the data on inspection of the train structure and context.

To identify and reduce this risk a boat sonar detection algorithm is under development. This uses auto-correlation of smoothed POD data to identify the duty cycle of boat sonars and is both more sensitive and more specific in that role than train detection.

The source of sonars at the barge site may include sonars on the barge, on service vessels moored to, or moving alongside, the barge and other working vessels in the area including ferries and fishing vessels.

In addition to effects on the detection process boat sonars may have a direct effect on the porpoises by introducing very loud sounds into their environment.

The graphic below shows porpoise detections (vertical bars) and boat sonar detections (horizontal bars) from over three days at Hamna Voe. The sonars are identified by the development version of an algorithm for the identification of boat sonars. This algorithm has not previously been available to us, and the results here are of interest as they may indicate a suppression of porpoise activity related to the boat sonar activity at Hamna Voe.

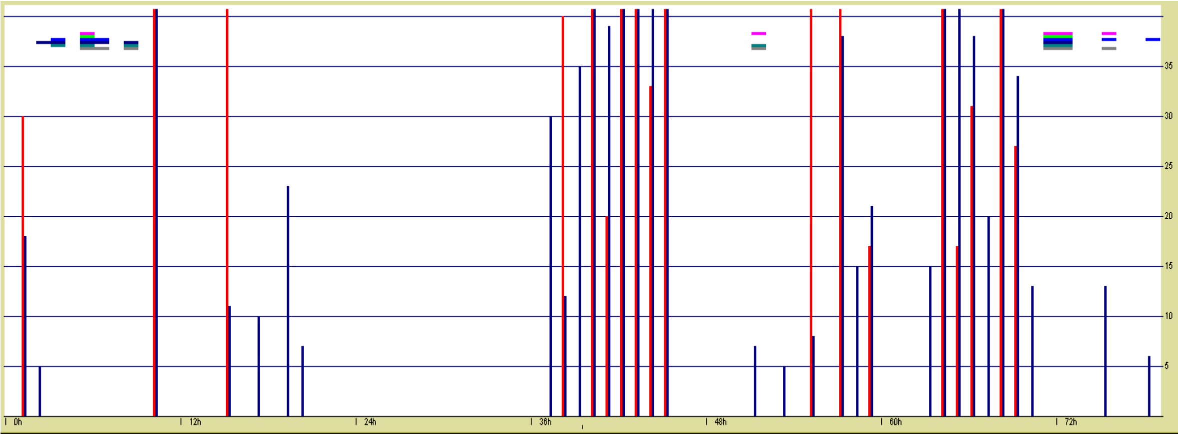

Figure 22.   Occurrence of porpoise and boat sonar detections at Hamna Voe. Data is aggregated into one-hour periods. Vertical bars are porpoise activity, horizontal bars are boat sonars.

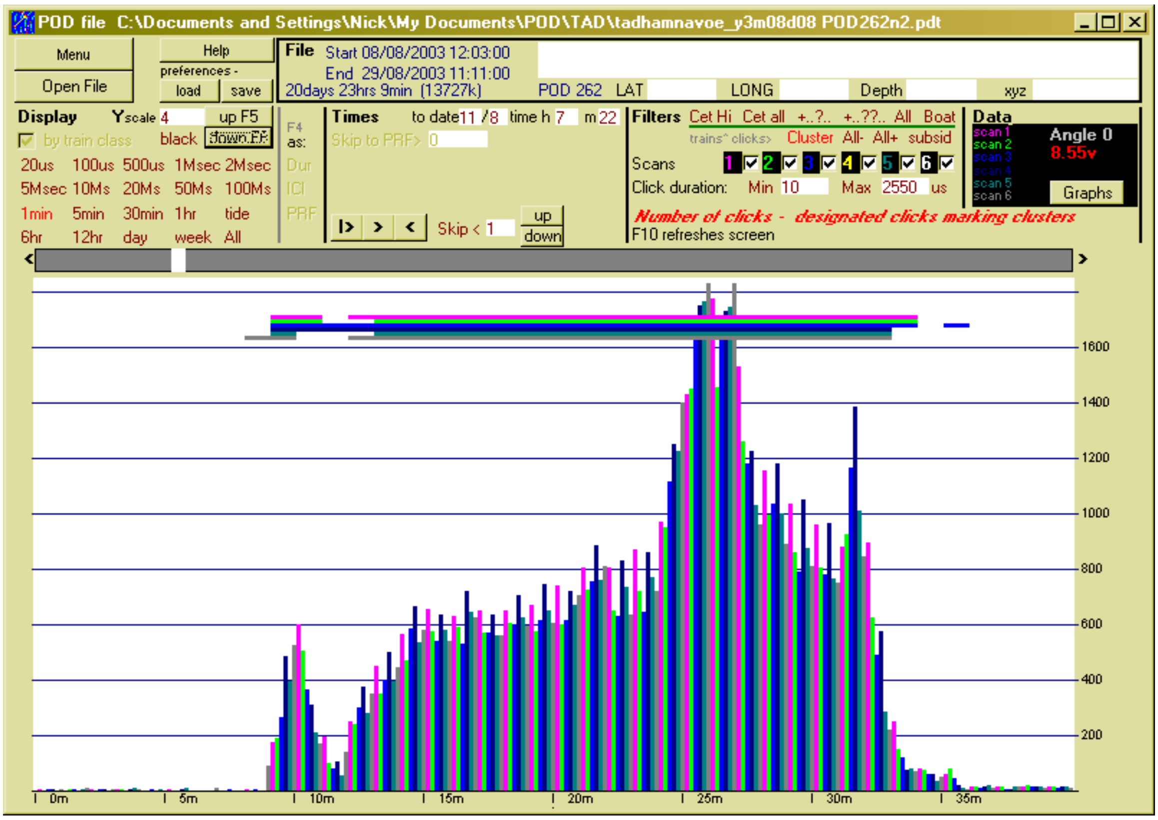

Figure 23. Clicks logged during boat sonar detection at Hamna Voe. Data is aggregated into one-minute periods. Vertical bars are total click counts, horizontal bars are boat sonars.

Figure 23 shows a massive increase in click logging rates from a boat sonar. We have not attempted to quantify any relationship between boat sonars and porpoise activity, but we consider that this relationship is one that should receive priority in the assessment of marine acoustic impacts of anthropogenic sound because it affects those frequencies used by cetaceans for their own sonar, and involves sources much louder than the porpoise itself.

3.6 Visual watches

Harbour porpoise watches were undertaken on 40 days (July:3 days, August:13 days, September:12 days, October:12 days) with 23 days at Hamna Voe and 17 days in the east channel of Bigga from the barge or Ulsta shore. All watches and video filming of porpoises in October were at Hamna Voe. Porpoises were detected on 12 of these days. The day of the month and number of individuals in the group, in parentheses, were -

Barge/Ulsta watches

August: 3 (1), 10(2), 12(1), 13(1), 16(2), 17(2, 5)
September: 1(2), 3(1), 7(3)
9 days, total count: 20 porpoises

During August and September individuals and small parties of up to five porpoises, probably comprising of family groups (mother-calves), were seen in Yell Sound passing the barge during daylight hours. Porpoises were only encountered 1-2 times during a six-hour watch, when sighting conditions were favourable. Sightings of porpoises at various locations in the sound suggested that most porpoises travelled along the east coast of Bigga, out of the main tidal flow and currents. The distances travelled between sightings indicated that porpoises were transiting at speed.

Hamna Voe watches

October: 16 (10), 23(120), 29(100)
3 days, total count: 240 porpoises

During the watch on the 23 October, a group of c. 60 porpoises were seen within 500 m of the offshore POD at 1130 h, corresponding to a count of 140 clicks per hour at noon when the watch ended. At 1400 h on the 23, a count of 7,000 clicks per hour was recorded and 27,000 clicks per hour at 1600 h on the 24 October.

The number of porpoises at Hamna Voe was considerably greater than recorded in Yell Sound from the barge and Ulsta shore with parties of 10 to 30+ porpoises dispersed between Hamna Voe and Fish Holm during watches in October, with the total aggregation numbering over one hundred animals during one watch. No porpoises were seen in late in September and early October because of poor observer conditions from stormy weather. However, train detections from the PODs indicate that porpoises were present in Hamna Voe during stormy sea conditions. The surface activity of porpoises watched was predominantly indicative of feeding (on or close to the seabed); surface dives lasting several minutes, surfacing in various localities. On occasions porpoises were seen porpoising at speed on the surface with gannets overhead, presumably chasing fish prey at the surface. However, porpoises were also noted ‘resting’ and ‘milling’ in the same area on the surface.

Other notable sightings:
A single minke whale was seen north of Hamna Voe off Fish Holm on the 15 August.

A single basking shark was seen from the barge in early September (no date provided) and in Hamna Voe on the 10 September.

3.7 Notes on other findings

Diurnal patterns of acoustic activity were seen on occasion. The greater proportion of porpoise detections occurred during daylight hours and around low water at Hamna Voe in October and may be in response to predator-prey behaviour. A number of fish prey e.g. (saithe *Pollachius virens,* sprats *Sprattus sprattus* and sandeels *Amodytes* sp.) found inshore are known to follow diurnal rhythms, moving in to open water and shoaling during daylight and returning to hide on the sandy bottom or reefs during night.

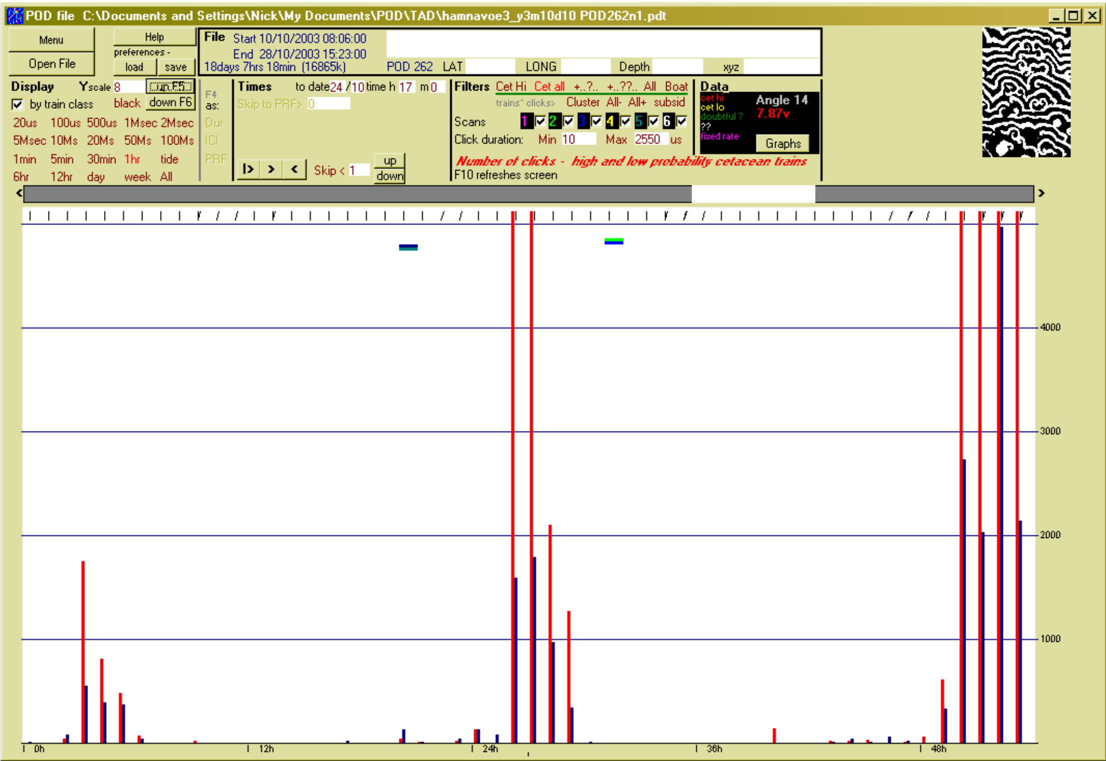

Figure 24. Porpoise click rates during daylight hours in Hamna Voe during October. Low Water is approximately at 1430 h and 0030 each day. Mean angle of the POD to vertical is shown by the short lines at the top of the figure, indicating current velocity during.

4. Discussion

4.1 Habitat use

Previous land-based watches and opportunistic sightings have indicated a greater abundance of porpoises on the east side of Shetland (particularly, Out Skerries, Noss and Mousa Sounds; Evans, 1996). During September and October, aggregations of porpoises include calves, which are dependent on mothers for sustenance. Voes protected from strong tides and currents by islands or headlands might be favoured feeding sites because the ‘sheltered’ conditions provide suitable areas for resting and suckling young.

In this study the higher proportion of fast click trains in Hamna Voe in comparison with the Stingray site suggests that more feeding is done in the Voe. However the comparison between the barge site and the Voe is unreliable because the barge POD is very close to the surface and porpoises commonly feed at the bottom, and the PODs deployed at the bottom at the barge site were lost. The detection of trains produced depends on the animal facing the transducer, so when the animals are feeding at the bottom their fast trains are unlikely to be detected by any POD that is near the surface. There may also be reactions to the large and recent installation itself, but the data available does not provide a basis for any inferences on that.

4.2 Porpoise activity in relation to tidal currents.

Porpoises were present and acoustically active in Hamna Voe at all tidal states.

The greatest proportion of intervals with porpoise detections in Yell Sound was around slack Low and High Water. Porpoises were observed transiting north and south in Yell sound, generally arriving from the north and travelling with the flood tide and meeting the start of the north flowing ebb tide in the southern approaches of Yell Sound. This contrasts with porpoise behaviour in many tidal races elsewhere in which porpoises clearly feed while moving against the current, sometimes at a speed which keeps them in a constant position relative to the ground. The difference at this site may be due to the high current speeds that exceed normal porpoise swimming speeds so that the porpoise cannot maintain station for feeding in the current without excessive effort. If this interpretation is correct the sites chosen for tidal generators may generally be of lowest foraging value to porpoises at the times that they are of greatest value for power generation.

4.3 Acoustic impacts

Yell Sound is an area of intense human activity with commercial shipping that services Sullom Voe oil terminal plus hourly ferries linking Yell to the mainland. Porpoises frequent both the tidal sound and the sheltered voes of Yell Sound. Noise from boats, and probably from the tidal generator, has most energy at low frequencies with relatively little above 1kHz. This noise arises from machinery, propellers, turbulence etc. and is commonly called ‘pink’ noise in contrast to white noise that has energy spread evenly across the audible spectrum.

The noise from sonars used on vessels as depth and fish finders etc. is very different. These sources are very loud and frequencies are very high – most small vessel sonars use 50kHz, 100kHz or 200kHz. The lower frequencies are in high sensitivity ranges of the cetacean hearing spectrum. These ultrasounds are absorbed much more rapidly during propagation through sea-water e.g. at 3km 50kHz intensity would be approximately –40dB and 130kHz –120dB.

The possible association between boat sonars and reduced porpoise detections noted in this study is consistent with some earlier visual reports of porpoises showing aversion to boats at a distance of 1 mile. We consider that these observations indicate that further evaluation of the impact of boat sonars on cetaceans (in view of their excellent high frequency hearing), is required. It may well be that the introduction of these sonars into marine habitats may often be the major acoustic impact of developments rather than the lower frequency sound sources that are more readily identified with the nature of the development.

In recent years salmon farms in Yell Sound have refrained from using acoustic deterrent devices to scare seals from cages, in compliance with guidelines from Scottish Natural Heritage and the Shetland Islands Council, to minimise acoustic disturbance to 'non-target' marine mammal species. However these sites introduce boat sonars and no framework currently exists for the local council to monitor noise pollution from aquaculture developments, and effective monitoring of cetaceans has not generally been part of environmental impact assessment.

Little is known about typical temporal patterns of response of porpoises to structures like the barge or the generator. Data from POD studies of marine wind turbine foundation installation shows aversive reactions by porpoises to these extremely noisy operations, with re-colonisation of the area approximately 3 hours after cessation.

4.4 Moorings and data retrieval

Before this study PODs were successfully deployed on the seabed in Yell Sound during the first Stingray trials in 2002 using 'low drag' mooring gear (e.g. 10 mm rope and a small buoy) and a mooring anchor (HGV rim) that remained in a stable position on the seabed for sufficient time to accumulate sediment and 'bed' in to the seabed. With this temporary mooring system the surface marker buoy was dragged under the surface during the strongest tidal flow, which restricted the retrieval of PODs to one hour around slack water. The fishing vessel, rigged for creels, was manoeuvrable in relatively shallow coastal waters, which allowed transit to the PODs avoiding the areas with the strongest currents, and passage between islands, and was ideal for lifting the gear. The travel time between the PODs in Yell Sound was ca. 30 minutes at a speed of 2-6 kts, depending on the current strength and direction of travel. Operating from Sullom Voe, the retrieval of data and re-deployment of two PODs took 4 hours. With this in mind, the number and distance between PODs should be considered within the logistical and financial constraints of the project; the size and speed of the vessel, and distance to study sites all being important considerations. A USB interface for PODs in under development and will reduce data download times. The running time of PODs on set of batteries has also increased to 80+ days, but current memory sizes would not allow such a long period of logging in the fastest current sites. Larger memory sizes are also planned for the POD.

4.5 The role of the Porpoise Alerting Device

The strong effect from the PAD in Hamna Voe does indicate that it could be valuable in reducing the total duration of observations required to answer specific questions by acoustic monitoring. However we do not know how much the alerting effect may vary with porpoise behaviour, which is itself partly determined by prey type, habitat type, age/sex structure of the local population etc. To obtain this information specific studies could be undertaken, or the PAD could be employed in a range of other studies to build up a wider base of experience. However the effort required to achieve adequate calibration and data analysis is significant, and may be difficult to incorporate piece-meal into other studies.

5. Conclusions

5.1 Stingray : Conclusions from Acoustic Data

No before/after installation comparison is possible as the monitoring began after installation and ended on removal of the barge. The acoustic data collected shows that:

- Porpoises continue to be active in Yell Sound in the vicinity of the installation (barge and Stingray).
- The vicinity of the installation is used much less by porpoises than the comparison site in Hamna Voe, which was known to be heavily used.
- Hamna Voe showed a much heavier use in October than in August or September, in line with findings from POD monitoring in the previous year.
- Rigorous comparison is not possible but much higher levels of porpoise activity were previously recorded in Hamna Voe in 2002. This difference might have various causes other than the presence of the installation, and the sharp variations within the monitoring period demonstrate this.
- Both the click train PRFs suggest that porpoises are mainly but not exclusively in transit through this part of the Sound.
- Acoustic detection of porpoises using POD technology is possible in this noisy environment.
- Trailing hydrophones are required for acoustic monitoring in the high current speeds required for tidal generators. More costly custom housings could also be used.
- To monitor accurately from a barge with sonar sources close by would require further development of the hydrophones to achieve appropriate directional sensitivity, and further development of the train classification algorithms, but the data would probably still not be of the quality obtained from Hamna Voe, where the fully automated system can be confidently used without any operator inspection or intervention.
- Monitoring from sites a few hundred metres from the barge would be technically much easier in terms of data quality and processing, but deployment would be more difficult.

- If monitoring must be from the barge a preliminary study to find the most acoustically favourable location would be very valuable.

- The Hamna Voe data showed possible reduction of levels of porpoise activity around times when boat sonars were logged.

- It is likely, and certainly possible, that boat sonars (depth finders, fish finders, bottom imaging sonars) have a greater impact on porpoises than the tidal power generator itself.

5.2 Porpoise Alerting Device : Conclusions from Acoustic Data

- The PAD doubled (or more) detection rates at Hamna Voe in line with previous experience, but this was not demonstrated on the barge site.

- Train Positive Minutes is the most stable and useful statistic in the context of PAD use.

- The alerting effect could be very useful in obtaining significant data volumes from sites where un-enhanced detection rates are low.

- The PAD effect in fast current / high noise sites has not been adequately defined by this study, but remains of interest.

- The role of the PAD in acoustic studies is still subject to a range of uncertainties so its application should be considered experimental even though the PAD effect was clear.

5.3 Conclusions from visual data

- The visual data confirm the acoustic findings for calm weather. Visual data sea states above 3 is sparse and at night is, of course, nil.

- The visual data provide information on porpoise group size and the prevalence of calves that is not provided by the POD.

Visual observations undertaken to track porpoise movements in response to the POD and PAD were hampered by the lack of flat calm sea conditions required to detect porpoises. Although watches are labour intensive, they provide an element of validation and identify some features that are not detected by PODs. These are primarily –

- the direction of travel of porpoises

- the proportion of calves present

- the size of porpoise groups

- sometimes information on prey species

6. Recommendations

This study has given very valuable practical experience in evaluating acoustic monitoring for impact assessment. It has shown that PODs can be a cost-effective means of assessing impacts on porpoises; that boat sonars should be identified and evaluated more clearly in the assessment of the impact of developments, and that the PAD has a strongly alerting effects in some or all locations.

To deliver accurate assessments of the impact of an installation such as Stingray a number of modifications would be required:-

1. The study should start well before the installation to provide ‘before’ data.
2. Retrieval of PODs and battery changes can be achieved efficiently by budgeting for a ‘spare’ POD if PODs are to be accessed by boat.
3. Some reserve PODs would also avoid the extensive loss of data that occurred in this study due to the destruction of both seabed units at the Stingray site.
4. The study should go beyond the period of the installation to give ‘after’ data.
5. The technical expertise involved should be deployed on site at the start of the most difficult phase – in this case monitoring from the barge.
6. Trailing hydrophones for fast current areas with boat sonars should be constructed to achieve directionally specific sensitivity in the desired directions.
7. As both the before and after data cannot use the installation itself, we would, in a similar case, now recommend that no monitoring from the installation itself be used, but effort be concentrated on establishing longer-term monitoring locations within the area of interest.
8. The monitoring sites should extend beyond the zone of anticipated impact in two or more directions to allow comparison of trends at impacted and control sites.
9. Assessment of the sonars in use on the installation and associated vessels be undertaken both by enquiry and by broadband sound recording. This is not done by PODs but has become much easier in recent years with high speed analogue to digital converters and PC interfaces.
10. The sonar detection algorithm now available in the POD software should be ground-truthed by visual or acoustic surveys of boat activity around a POD deployment.
11. The acquisition of some fishery data on prevalence of commercial species would be valuable if it is available.

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8. References

We include a brief survey here of papers and conference presentations on the POD as tool for monitoring acoustic impacts on porpoises. There are no publications known to us on alerting devices or tidal power generators.

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(POD and visual data correspond. Narrow porpoise migration pathways can give low detection rates on POD outside the pathway.)

Koschinski, S., Culik, B., Damsgaard, O. (2002) **Reactions of Harbour Porpoises (*Phocoena phocoena*) and Harbour Seals (*Phoca vitulina*) to underwater sound produced by a simulated 2MW offshore windpower generator.** Presentation at European Cetacean Society Conference, Liege, 2002. (Porpoise sonar increased in response to some stimuli, decreased by others. The first report of an alerting effect)

Piper, W., Brock, V., Thomsen, F. **Surfing the POD: the use of a towed porpoise detector in visual and POD surveys on Harbour Porpoises (Phocoena phocoena) in the German Bight.** Poster at European Cetacean Society Conference, Las Palmas, 2003. (POD towed 3m down and >100m behind vessel 'shows promise'.)

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