# Final Report

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| **Project Name:** | PAMGUARD CODA Field Trial Final Report |
| **Reference:** | MMM.1708.PAM |
| **Project Manager:** | Beth Mackey |

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| **Date:** | Tuesday, 14 April 2009 | |

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# Executive Summary


The primary purpose of the PAMGUARD CODA field trial was twofold:

1. To test PAMGUARD software offshore in order to find bugs and 'Ruggedise' the software.
2. To collect data on the detection efficiency and localisation accuracy for multiple species.

The PAMGUARD software was run at sea both by one of the PAMGUARD developers and by a professional marine mammal observer with experience of other commonly used PAM software packages. It was also used offline by an inexperienced operator. All three operators found the system user friendly and were able to track sperm whales and dolphins with ease. The professional MMO reported that:

> "…it was clear that this particular system (hardware/software combination) was more stable and user friendly than the systems currently provided on the market by the major PAM providers".

The hydrophone used was not sensitive to the low frequency sounds of baleen whales. Several odontocete species were sighted (including Common dolphin, striped dolphin, bottlenose dolphin, pilot whales, sperm whales and three beaked whale species). Whistle and click train detection efficiency has been calculated for all but beaked whales. Efficiency varied both by species and vessel but the overall detection efficiency for all species of using combine click and whistle detection is 84%. This compares with a sighting efficiency of around 30 %.

The complexity of the visual data, often comprising groups of many animals, often of more than one species made a direct comparison of visual and acoustic localisations impossible. An indirect measure of localisation accuracy based on predicted errors on measured bearings to clicks and whistles shows that localisation accuracy varies considerably depending on where the animals are relative to the array and increase with distance. Errors of several hundred metres can be expected for animals in line with the array, but these decrease substantially as animals come abeam of the hydrophone. Multiple clicks detected from individuals can be used to localise sperm whales to an accuracy of 10's of metres after 2 to 3 minutes of tracking.

A total of 30 bugs were discovered. These varied in severity from those which would render PAMGUARD inoperable to minor issues with the placement of graph axis. Fixes to all but two of the most minor bugs have been incorporated into the latest PAMGUARD releases.



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# 1 Introduction

The Coda Survey, coordinated by the Sea mammal Research Unit (SMRU) at the university of St Andrews, was a combined visual and acoustic survey for marine mammals in the Eastern Atlantic from the European shelf break to the limits of the 200 mile Exclusive Economic Zone (EEZ) of participating countries (Figure 1). The survey took place between 30 June and 30 July, 2007. Teams of eight visual observers on each vessel used distance sampling methods (Buckland & Turnock 1992) to assess cetacean population densities in the surveyed region. The survey was divided into three regions, referred to as the British, French and Spanish sectors. The British sector was surveyed by a single vessel, the Mars Chaser. Two vessels were used in the French sector and two in the Spanish, although only one vessel was ever operational in each sector at a time, the survey teams switching vessels roughly half way through the survey.

As well as the visual observers, each vessel was equipped with a towed hydrophone array. In the British and French sectors, data were recorded to hard drives and a high frequency click detector, RainbowClick (Gillespie & Leaper 1996), was used to detect ultrasonic harbour porpoise vocalisations. In the Spanish sector, data were collected in exactly the same way as in the British and French sectors, but an additional acoustic observer was accommodated on board each vessel in order to run PAMGUARD software (Gillespie et al. 2008) on an additional computer connected to the same hydrophone array.

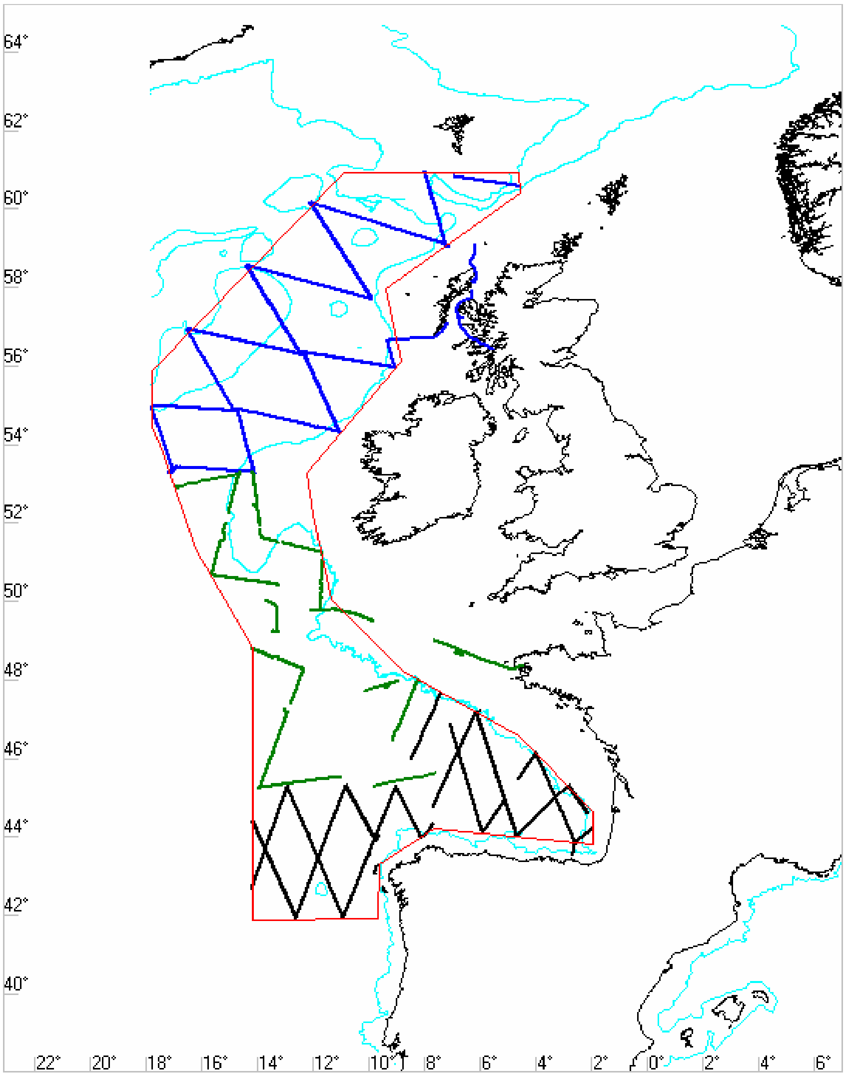


**Figure 1. The CODA Survey area and completed survey tracks.**

**Table 1. Odontocete species encountered during the CODA survey.**

| | Species | Code | Vocalisation Type |
|---|---|---|---|
| Small and medium sized odontocetes | Common dolphin | CD | Clicks and Whistles |
| | Striped dolphin | SD | Clicks and Whistles |
| | Common or striped dolphin | CS | Clicks and Whistles |
| | Bottlenose dolphin | BD | Clicks and Whistles |
| | Pilot whale (long or short finned) | PW | Clicks and Whistles |
| Large odontocetes | Sperm whale | SW | Clicks only |
| Beaked whales | Cuvier's, Sowerbie's or Mesoplodon species. | BW | Clicks only |
| Others | Unidentified "Small" cetacean (might not be an odontocete) | S? | ? |
| | Unidentified dolphin | U? | ? |

From a PAMGUARD perspective, the main purposes of the trial were to:

1) Test the PAMGUARD software at sea in order to 'Ruggedise' the software and provide a list of bugs.
2) Collect data on the detection efficiency and localisation accuracy of PAMGUARD detectors.

During the survey, the odontocete species listed in Table 1 were encountered. These have been grouped into four main categories: Small and medium sized odontocetes which produce both clicks and whistle; sperm whales (which only click); beaked whales (which only click at high frequency) and other sightings of unknown species.

## *1.1 Data collection*

The hydrophone arrays deployed from each vessel were purchased from Seiche Measurements Ltd, UK and each contained five hydrophone elements at distances of 200, 203, 400, 400.25 and 403m from the vessel. The two hydrophone pairs at 200/203m and 400/403m were used as input to PAMGUARD and to make broadband (192 kHz sample rate) recordings to hard drives for offline analysis. Signals from the elements at 400 and 400.25m were used for high frequency porpoise click detection (500kHz sample rate) using the RainbowClick software. A schematic diagram of the acoustics setup is shown in Figure 2. On the Spanish vessels, a second Fireface soundcard was added in parallel to the one shown in Figure 2, and an additional computer used to run PAMGUARD software in real time. The computer used in the trials was a laptop with a Pentium IV, 3.2 GHz processor and 2Gbytes RAM running Windows XP Pro Service Pack 2. The Java environment was the Java JDK 6.

As well as being run online in real time on the Spanish vessels, PAMGUARD was also run offline on the 192 kHz recorded data following the cruise.

At the time of the CODA trial, PAMGUARD was not capable of using data from high frequency data acquisition cards so analysis of high frequency click data is not considered in this report.

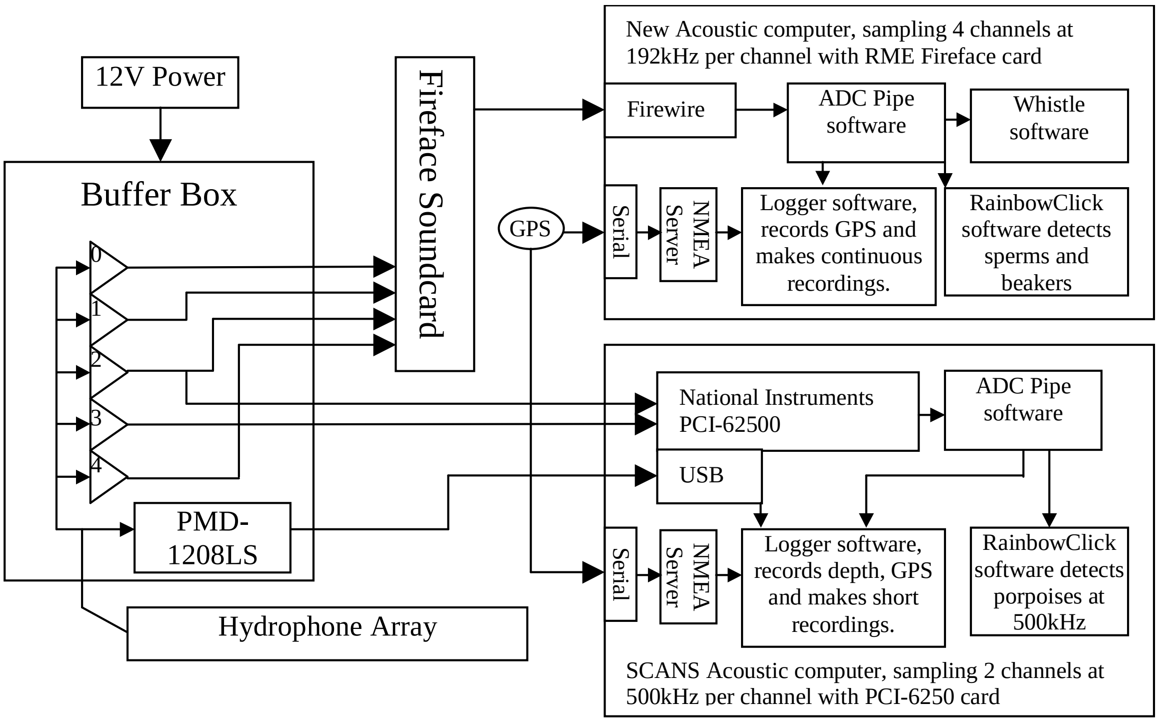


**Figure 2. Schematic diagram of the acoustic detection system**

**Table 2. Vessels and personnel used during the survey.**

| Sector | Vessel Name | Vessel Type | PAMGUARD Operator | Dates | Hours::Minutes acoustic data* |
|---|---|---|---|---|---|
| British | Mars Chaser (MC) | Former Icelandic fisheries research vessel. Now privately operated. | - | 4 July to 29 July | 249:11 |
| French | Rari (RA) | French Navy Tug | - | 2 July to 12 July | 64:35 |
| | Germinal (GE) | French Navy Frigate | - | 16 July to 25 July | 90:45 |
| Spanish | Investigador (IN) | Private research vessel | David McLaren | 30 June to 16 July | 144:14 |
| | Cornide de Saavedra (SC) | Private research vessel | Sebastian von Luders | 17 July to 30 July | 102:57 |
| Total | | | | | 651:42 |

* Hours of data refers to the quantity of 192 kHz recordings saved to hard disk

## 1.2 Vessels and personnel

Vessels and personnel are summarised in

Table 2. David McLaren (DMC), one of the PAMGUARD developers from Heriot Watt University participated on board the vessel Investigador from 30 June to 16 July. Sebastian von Luders (SVL), a professional MMO, with experience of acoustic monitoring using the IFAW software participated on board the Cornide de Saavedra from 16 to 30 July. SVL was trained in PAMGUARD operation during a single day immediately prior to the cruise. The rational between the divisions of labour being that DMC could test and debug the software during the first leg of the cruise and the SVL could concentrate on running the software and testing its performance during the second leg.

## 1.3 On shore analysis

Analysis of recorded data was conducted at SMRU by Eva Hartvig (EH) and Doug Gillespie (DG). A modified version of PAMGUARD was developed specifically for this reprocessing of data which will analyse recorded sound files in real time, playing the sound back over the computer sound card, while, at the same time, reading in GPS data from the databases of GPS data collected during the cruise. The overall PAMGUARD experience from the operator's perspective was therefore identical to that experienced at sea and the correct vessel track and speed were used when estimating the locations of animals. A comparison of PAMGUARD detector and operator output was then completed using specially written Matlab software to compare the content of the PAMGUARD database with data from the Visual and Acoustic output of the CODA survey.

## 1.4 Bug fixing

Post cruise bug fixing was conducted by Doug Gillespie following the cruise. As well as bugs identified during the cruise, a number of bugs were identified during reprocessing of data on shore.

# 2 Ruggedisation and bug reporting from sea trials

Both DMC and SVP successfully detected and tracked sperm whales and other cetacean species on a number of occasions using both the automatic and semi automatic tracking features of PAMGUARD. For example, Figure 3 shows the PAMGUARD click detector display in which click trains from at least six individual sperm whales are being detected simultaneously. Figure 4 shows the PAMGUARD map overlaid with bearings to clicks from a single sperm whale, being used to localise that animal. SVL, who has extensive experience of working with the old IFAW software system reported that "…it was clear that this particular system (hardware/software combination) was more stable and user friendly than the systems currently provided on the market by the major PAM providers."

A summary of modules tested and bugs reported by DMC and SVP is given in Table 5 in Appendix 1. All sound processing and detection modules were tested during the trial apart from the Ishmael modules, which were not functional at the time. A number of modules not used for sound processing or detection were not tested during the trial; these were the AIS processing modules, the simulator, and the Terella depth readout system.

Of 18 tested modules, 13 (72%) contained bugs. 26 bugs were reported during the sea trial, EH and DG found four more significant bugs during offline analysis.

There are currently only two outstanding bugs reported from the cruise. These are:

1. The placement of the x (South) axis on a plug in part of the spectrogram display,
2. The Sound Acquisition dialog is slow to appear.

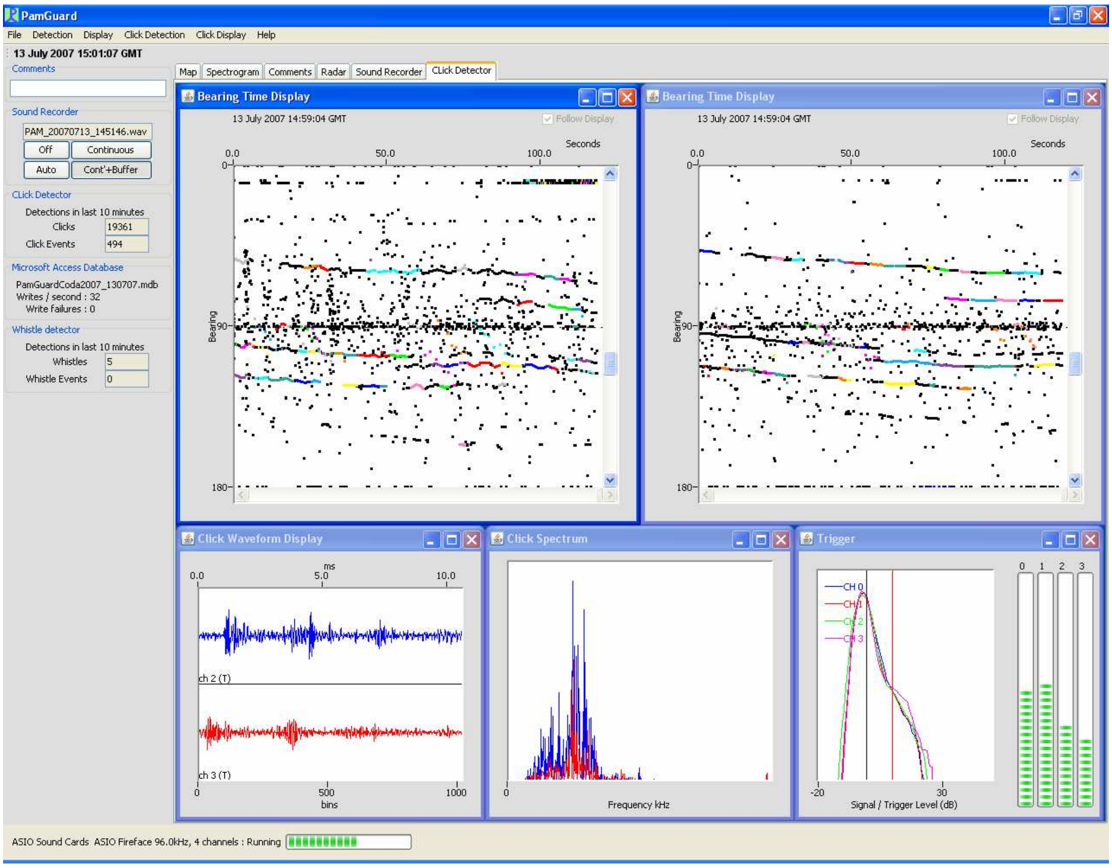


**Figure 3. Automatic sperm whale click and click train identification of at least six individual sperm whales.**

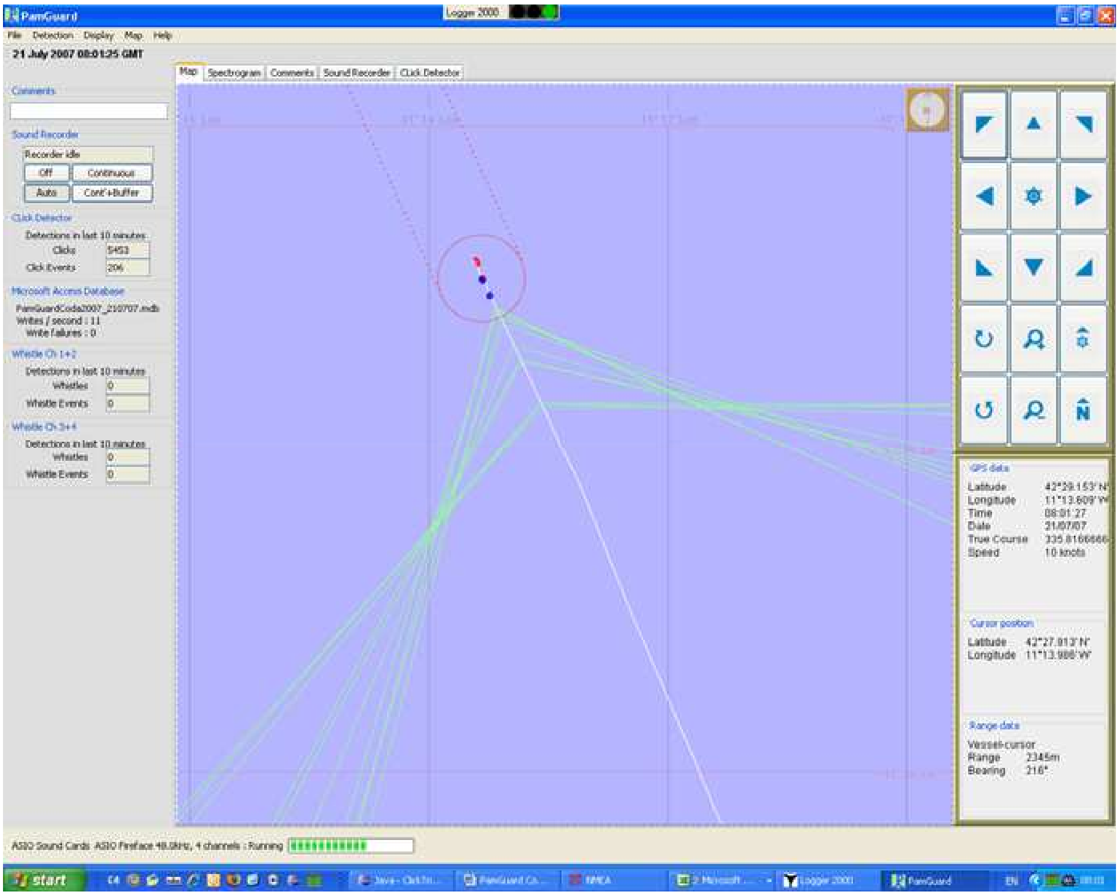


**Figure 4. Crossed bearing tracking of a sperm whale by SVP.**

The former requires some reprogramming of how display windows nested within one another within the spectrogram display, the second results from a number of checks the acquisition dialog makes on all available ASIO sound cards when it first opens. Neither bug has any effect on PAMGUARD performance. Both bugs remain listed in the sourceforge 'open' bugs list to be dealt with by the PAMGUARD guardians should time allow.

In addition to testing each module, the operators suggested a number of features which would enhance the software, these are summarised in Table 6 (Appendix 1). No time was allocated for the implementation of new features into the code, although two of the features (overloading of the map and angle vetoes in the click detector) have been implemented since they affected the overall performance of the system.

# 3 Software enhancements

A number of enhancements were made to the PAMGUARD software either to aid offline analysis, or more generally, to provide better tracking methods than those already existing in the code. These enhancements were all identified by DG during the offline analysis of the CODA data conducted by EH.

## *3.1 Offline analysis mode*

A modified version of PAMGUARD was developed specifically for the reprocessing of data which will analyse recorded sound files in real time, playing the sound back over the computer sound card, while, at the same time, reading in GPS data from the databases of GPS data collected during the cruise. The overall PAMGUARD experience from the operator's perspective was therefore identical to that experienced at sea, and the correct vessel track and speed was used when estimating the locations of animals. Note that this pseudo real time operation is very different to the type of offline analysis conducted on the CODA data using the IFAW RainbowClick software in which the operator can scroll back and forth through the data, lingering over complicated sections where many animals are present, calling colleagues for a second opinion, etc. During the PAMGUARD offline analysis, the operator made all decisions 'on the fly' just as they would have done at sea in a 'real' monitoring situation.

## *3.2 Sound playback module*

So that the operator viewing data in offline mode could hear the sounds over headphones as they would have done by directly monitoring the hydrophone during real time operation, a sound playback module was added which played selected channels (the operator could select any two of the four channels in each recording) back through the computers sound card.

## *3.3 Numbered whale tracking*

Clicks to be sent to the map are selected by the operator by right clicking on the click detector bearing time display and releasing the mouse over the click of interest. Prior to, and during the field trial, the operator would select clicks that appeared to form part of a train and the bearings to those clicks would be displayed on the map as is shown in Figure 4. When many whales are present, such as in Figure 3, bearing to clicks overlaid on the map rapidly become impossible to interpret as in the simple case in Figure 4.

The code was modified, so that if the operator clicks with the right (as opposed to the left) mouse button, a menu pops up allowing the operator to assign a whale number to each tracked click. Each numbered whale appears in a different colour on the map, making the locations on the map easier to interpret.

## 3.4 Map Comments

Prior to, and during the field trial, PAMGUARD would plot bearings to detected sounds on the map and it was up to the operator to decide where the bearing lines crossed. During the trial DMC added a function so that if the operator clicked on the map at the crossing location, that location would be copied into the clipboard from where it could be copied into a comments form. During the offline analysis, this feature was taken a step further by DG. If the operator clicks on the map, a comment input box will pop up. The entered comment will be stored along with the lat long of the click in the database and a symbol will appear at that location on the map. The entered comment will appear in a text window when the mouse is hovered over the map symbol.

## 3.5 Automatic location calculation for numbered whale tracking

Code was developed which took multiple clicks marked by the operator as being from one individual (Section 3.3) and performed a least squares fit in order to estimate the most likely crossing point of the bearing lines on each side of the track. Localisations are first computed when a minimum of two clicks, on different bearings, are selected for each track. The location is updated as each additional click is added to the track. The fit also estimates errors on the fitted position both parallel and perpendicular to the vessel track-line.

## 3.6 Crossed bearing whistle localisation

Prior to the trial, the whistle detector would estimate bearings to detected whistles based on time of arrival differences of a whistle arriving on two closely spaced hydrophones. The CODA hydrophone contained two pairs of hydrophones spaced 200m apart. Code was added to search for whistles detected simultaneously in each hydrophone pair. In the event of a whistle being detected on each pair, a bearing would be calculated to the whistle from each pair and the same localisation function used for click tracks (Section 3.5) used to estimate a crossing point of the two bearing lines.

# 4 On shore data analysis

Re-analysis of the CODA data on shore allowed for:

1. Analysis of a greater dataset, including data from the French and British sector as well as from the Spanish vessels.
2. Re-analysis of all data using the latest versions of PAMGUARD as bugs were fixed and new features added to the software.
3. A comparison to be made with the visual survey data.
4. A comparison to be made with detailed offline tracking of sperm whales using the IFAW RainbowClick software.

During analysis of the CODA data, it was clear that data from the Mars Chaser, used in the British sector were suffering from high levels of vessel propeller cavitation noise. Analysis therefore only used data from the Spanish and French vessels.

All offline data analysis was conducted by Eva Hartvig, working under the supervision of Doug Gillespie. Although experienced in bioacoustics, Eva had no prior knowledge of PAMGUARD or older PAM software such as the IFAW software or Ishmael and was trained by Doug Gillespie in PAMGUARD operation.

## 4.1 Sightings Data

The total number of sightings on acoustic effort from the Spanish and French vessels is shown in Figure 5. In all, six species of Odontocete were sighted, including sperm whales, pilot whales and four dolphin species. There were also a number of unknown species sighted, some of which (the S? category) may not have been odontocetes.

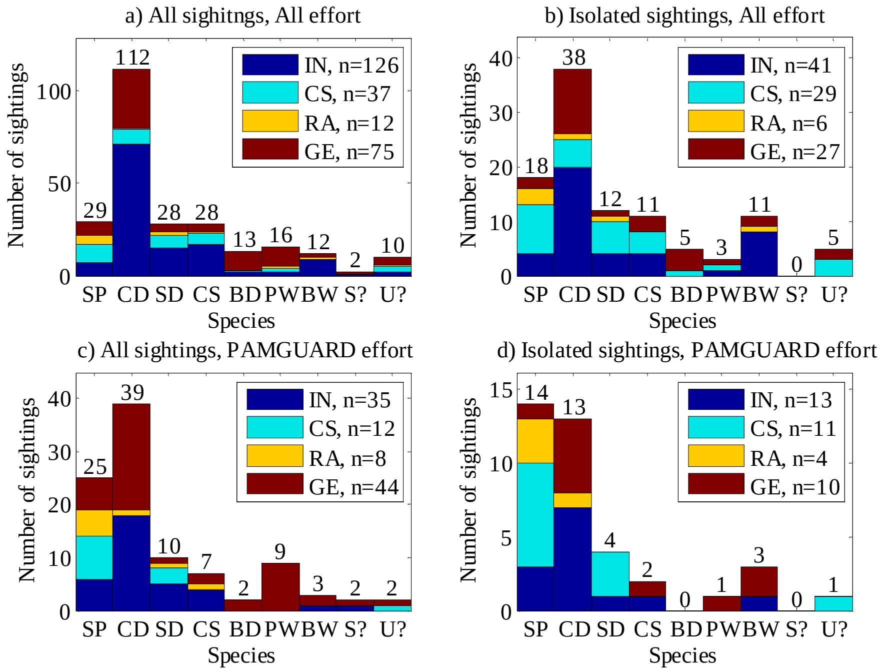


**Figure 5. Number of sightings from the Spanish and French vessels. CD=Common Dolphin; SD=Striped Dolphin; CS=Common or Striped Dolphin; BD=Bottlenose Dolphin; LF=Pilot Whale; SP=Sperm Whale; BW=Beaked Whale; S?=Unidentified small cetacean; U?=Unidentified Dolphin.**

## *4.2 Tests*

### 4.2.1 Whistle detection and localisation

The whistle detection and tracking process is 100% automatic and has therefore been run on all data using standard detection parameters and the crossed bearing localisation method described in section 3.6. Single whistle detection has a low but significant false alarm rate (which depends on the vessel noise). Generally during PAM operations, operators look at whistle events – defined as a minimum number of whistles occurring in a set time span. The default whistle event detection settings require a minimum of 10 whistles within a 1 minute time frame.

### 4.2.2 Odontocete tracking using semi automatic methods

Sperm whale and small odontocete click tracking is a semi automatic process requiring real time input from an operator in order to identify click trains so that bearings to multiple clicks from a single animal can be crossed in order to calculate a location. Click analysis therefore concentrated on sections of data when animals were known to be present from the visual survey. Following examination of the sightings databases, sections of acoustic data approximately 1.5 hours long were identified, bracketing each visual encounter and only these sections of data were analysed. These sections were selected by a different person (Marjolaine Caillat) and only the times to be analysed were given to the operator (EH). A number of time periods in which there were no visual sightings were also selected. Throughout the analysis, the operator was kept ignorant of the sightings within each analysis period.

The operator listened on headphones and selected clicks that appeared to be from the tracks of single whales using the new tracking methods described in Section 3.5. These locations were written to the PAMGUARD database, a new record being written and cross referenced to the previous record for that track (i.e. the record containing one less click and a slightly different and less accurate location) each time a new click was added to each track. A total of 77.6 hours of data were re-analysed in this way. This encompassed all sightings of sperm whales, an approximately equal number of small odontocete sightings and some periods with no sightings.

### 4.2.3 Sperm whale tracking using 3-D localisation methods

The PAMGAURD 3-D localisation methods (Thode 2005) are fully automatic and could therefore have been run on all data. However, time did not allow this, so the 3-D methods were only run on the sections of data identified for semi-automatic odontocete tracking. Three different tracking methods were tried, all working on output from the PAMGUARD click detector, and these were:

1. Cross Bearings. This is the simplest of the localisation methods. It searches for clicks from each pair of hydrophones which are close in time, takes the bearing measurement from each hydrophone pair and calculates where the bearing lines cross. No depth information is calculated to the whales location is assumed to be at the surface, which will always be an overestimation of range to a whale at depth.
2. "TOA and rear bearing, simple TOA estimate". This estimates a slant angle from the detected echo on the rear hydrophone pair and combines it with bearing information to estimate a location in three dimensions. Closest clicks from the two pairs of hydrophones are combined to generate each localisation.
3. "TOA and rear bearing, estimate TOA using ICI". As above, except that inter click interval (ICI) information is used to better match clicks between the two hydrophone pairs.

Further information on these methods is available from Thode, 2005 and from the PAMGUARD online help.

Accurate hydrophone depth information was not available for all of the survey, so nominal depths of 15m for the front hydrophone pair and 30m for the rear hydrophone pair were used.

## *4.3 Results*

A comparison of PAMGUARD detector and operator output was completed using specially written Matlab software to compare the content of the PAMGUARD database with data from the Visual and Acoustic output of the CODA survey. Figures 6 and 7 show the times of automatically detected whistle events and click trains tracked in real time using PAMGUARD overlaid with visual survey sightings from the primary platform observers. It can be seen that although there are detections which match well with times of sightings, and some that don't, there are many times when animals were seen and heard within tens of minutes of each other, so the questions arises as to what counts as a visual / acoustic match.

Analysis of the data is further confounded by multiple species being present at any one time. For instance, on the vessel Investigador, in the analysis period starting at 13:29:10, Common dolphin were sighted and a sperm whale a short time later. There was a single acoustic detection between the two. Is this a detection of the dolphins or the sperm whale? Pilot whales and bottlenose dolphin were sighted from the Germinal soon after 05:10:04 on 18 July. Are the detected whistles those of the pilot whales or the dolphin? For the sperm whales sighted from the Rari in the analysis period starting at 06:26:49 on 8 July, should this count as one missed detection or three? Therefore, for efficiency analysis, only isolated sightings have been used. An isolated sighting is one which is either separated from all other sightings by 20 minutes OR, in the case of multiple sightings of the same species, is the first sighting, and then subsequent sightings separated from the first by 20 minutes and still separated from sightings of other species by 20 minutes. Sightings which pass these criteria are shown ringed with a black circle in Figures 6 and 7.

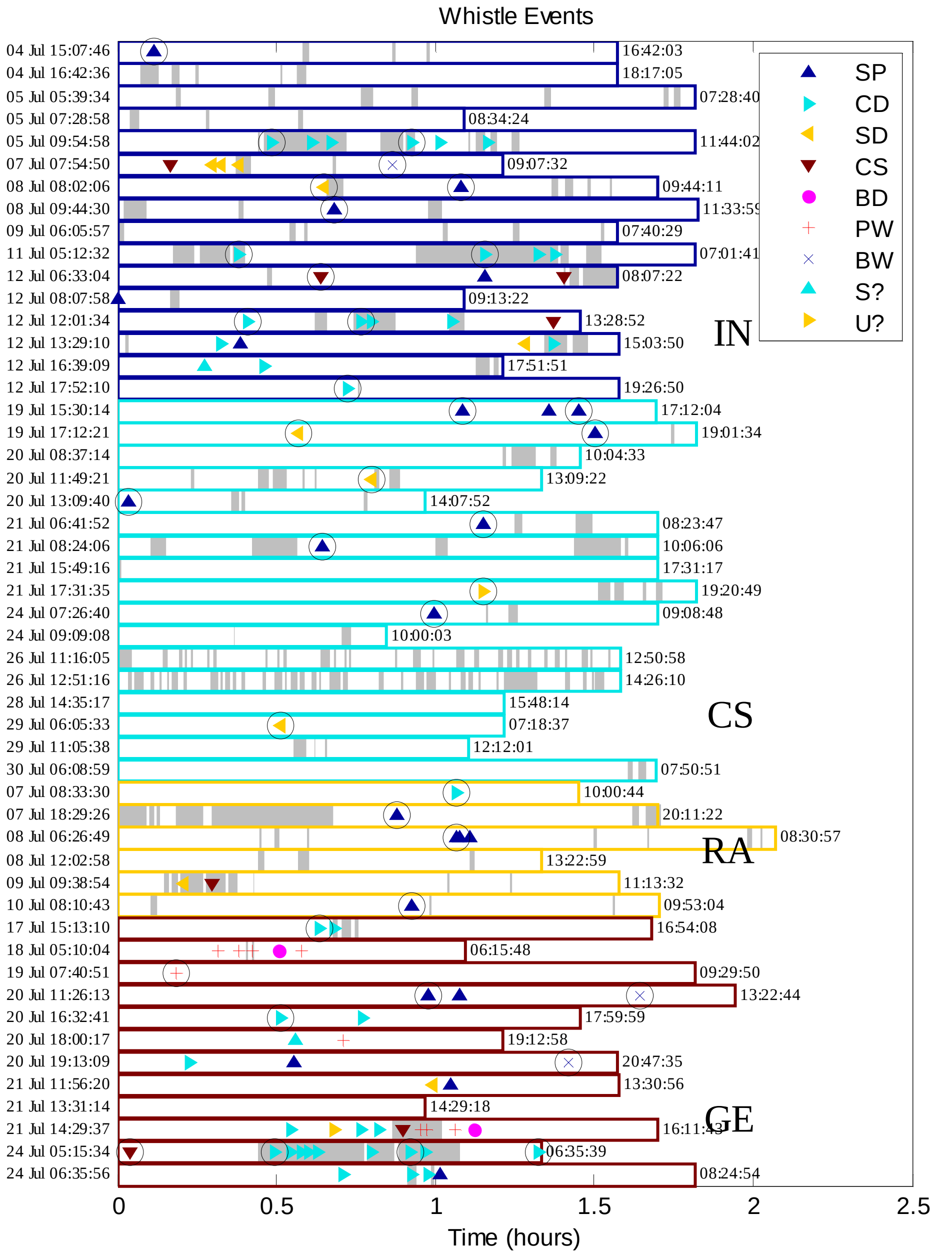


**Figure 6. Times of Odontocete sightings and whistle events during the survey. Each open rectangle represents one monitoring period by the PAMGUARD operator. Cetacean sightings are shown as symbols as per the legend in the figure and Table 1. Periods of whistle identification are shown as grey rectangles. Isolated sightings are shown with a black circle around them.**

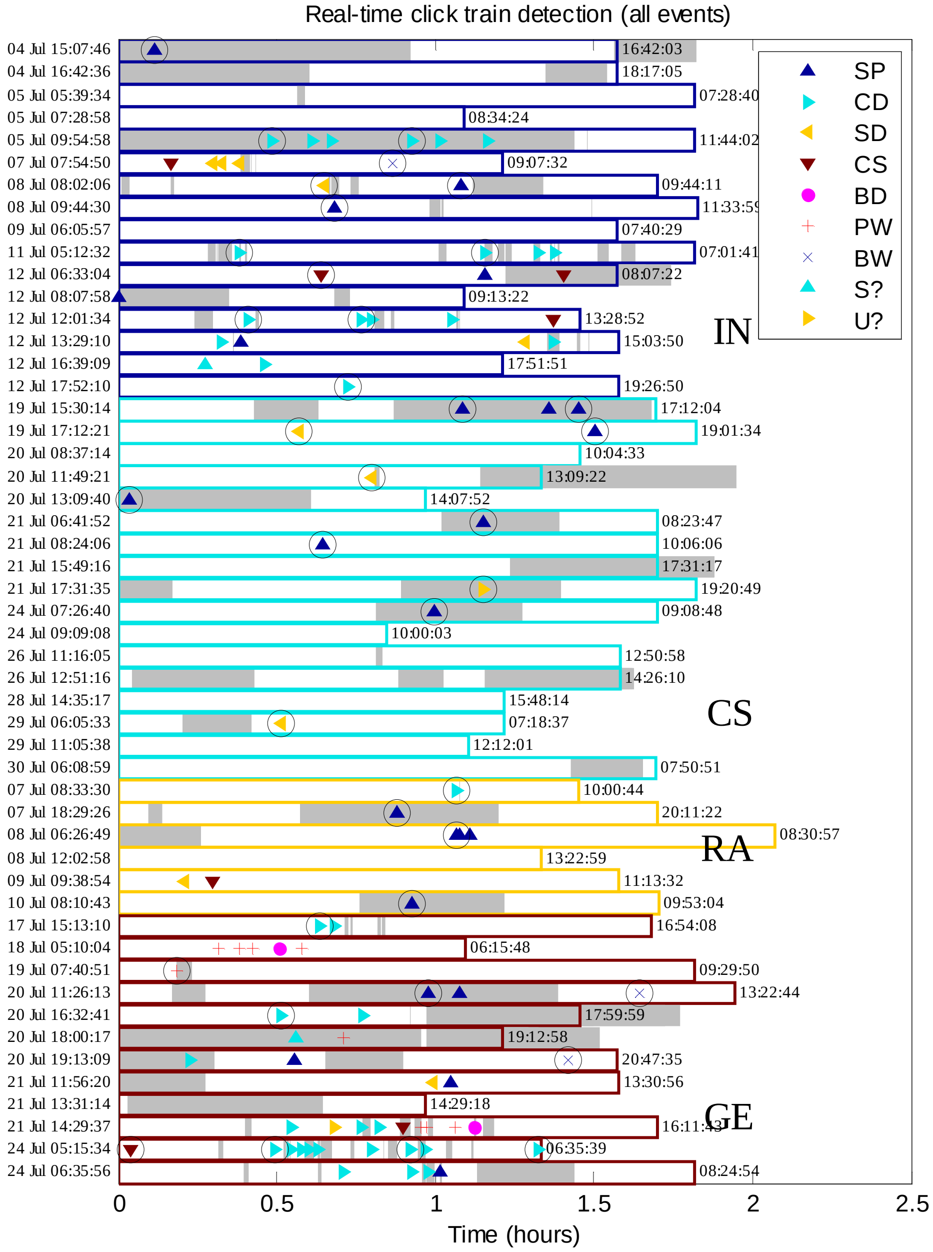


**Figure 7. Times of Odontocete sightings and real time click train detections during the survey. Each open rectangle represents one monitoring period by the PAMGUARD operator. Cetacean sightings are shown as symbols as per the legend in the figure and Table 1. Periods of whistle identification are shown as grey rectangles. Isolated sightings are shown with a black circle around them.**

### 4.3.1 Small Odontocete detection efficiency

Acoustic detection efficiency was assessed by comparing the times of isolated sightings, from the Primary observation platforms of the CODA vessels with the times of acoustic detections. Since there will rarely be an exact match between the times of visual and acoustic detections acoustic visual matches are searched for in a time window surrounding each sighting. Obviously, a narrow time window will lead to results indicating a low efficiency and as the time window increases, the efficiency will also appear to increase. For this analysis we consider a time window starting 20 minutes before each sighting and plot the increasing efficiency over time as more animals are detected acoustically in an expanding time window. Tabulated efficiency values in Table 3 are taken as the number of sightings with an acoustic detection within a 20 minute window either side of each sighting.

**Table 3. Summary of detection efficiency by species, vessel and detection method. Only isolated sightings have been used. Numbers in each field represent the detection efficiency as a percentage (and the number of sighted animals in parentheses). Whistle Event (WE) efficiency measures use all survey data, Click Train (CT) and combined Whistle Events and Click Train (WE+CT) use only PAMGUARD click trains and whistle events from the periods of data analysed offline by Eva Hartvig. Note that many sample sizes are small, so results have little statistical meaning.**

| | | | Vessel | | | | |
|---|---|---|---|---|---|---|---|
| | | Detection Method | All vessels | IN | CS | RA | GE |
| Species or species group | All Small Odontocetes | WE<br>CT<br>WE+CT | 65.2 (69)<br>85 (20)<br>90 (20) | 89.7 (29)<br>89.9 (9)<br>100 (9) | 52.9 (17)<br>100 (3)<br>100 (3) | 50 (2)<br>0 (1)<br>0 (1) | 42.9 (21)<br>85.7 (7)<br>85.7 (7) |
| | Common Dolphin | WE<br>CT<br>WE+CT | 81.6 (38)<br>84.6 (13)<br>84.6 (13) | 95.0 (20)<br>100 (7)<br>100 (7) | 80.0 (5)<br>- (0)<br>- (0) | 0 (1)<br>0 (1)<br>0 (1) | 66.7 (12)<br>80 (5)<br>80 (5) |
| | Striped Dolphin | WE<br>CT<br>WE+CT | 66.7 (12)<br>100 (4)<br>100 (4) | | | | |
| | Common or Striped Dolphin | WE<br>CT<br>WE+CT | 36.4 (11)<br>50 (2)<br>100 (4) | | | | |
| | Bottlenose Dolphin | WE<br>CT<br>WE+CT | 40 (5)<br>-<br>- | | | | |
| | Pilot Whale | WE<br>CT<br>WE+CT | 0 (3)<br>100 (1)<br>100 (1) | | | | |
| | Sperm Whale | CT | 85.7 (14) | 100 (3) | 85.7 (7) | 66.7 (3) | 100 (1) |

### Whistle Detection

Detection efficiency for small cetaceans that whistle as a function of time window plotted by vessel and by species is shown in Figure 8. There are clearly large differences in efficiency both between vessels and between species. For example, whistle detection is over 90% efficient on the Investigador, but below 50% on the Germinal. Pilot whale and bottlenose dolphin detection is less efficient than the detection of the smaller species. Figure 9 shows whistle event detection efficiency for small cetaceans by group size and by the estimated radial distance to the initial sighting. There is no strong relationship between either sighting distance or group size.

### Click Detection

Click trains were detected both offline using the IFAW RainbowClick software which allows the operator to scroll backwards and forwards through the data, and also in real time using PAMGUARD. Click train detection efficiency for small odontocetes using both these methods is shown in Figure 10. As with whistles, the detection efficiency varies by vessel. It can also be seen that the detection efficiency for online click detection is higher than for offline detection. This latter difference is probably due to the operator listening for clicks as well as searching for them visually on the screen.

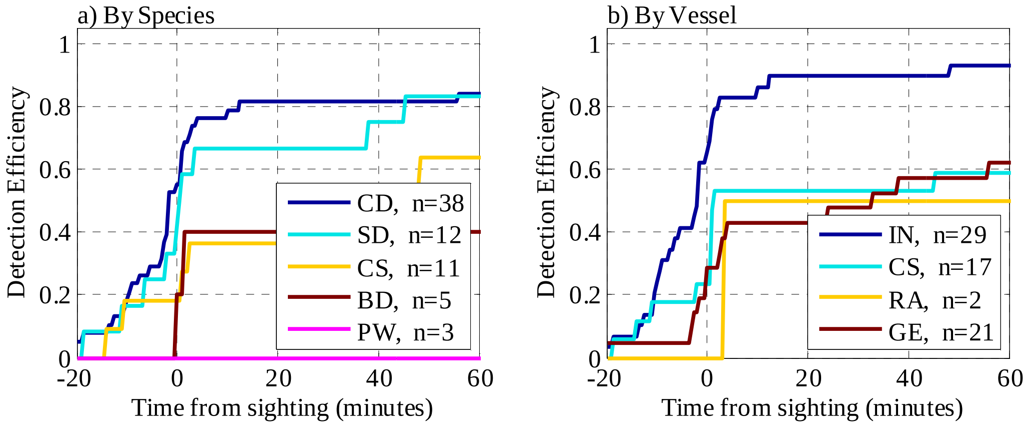


**Figure 8. Acoustic detection times relative to sighting times for whistles events.**

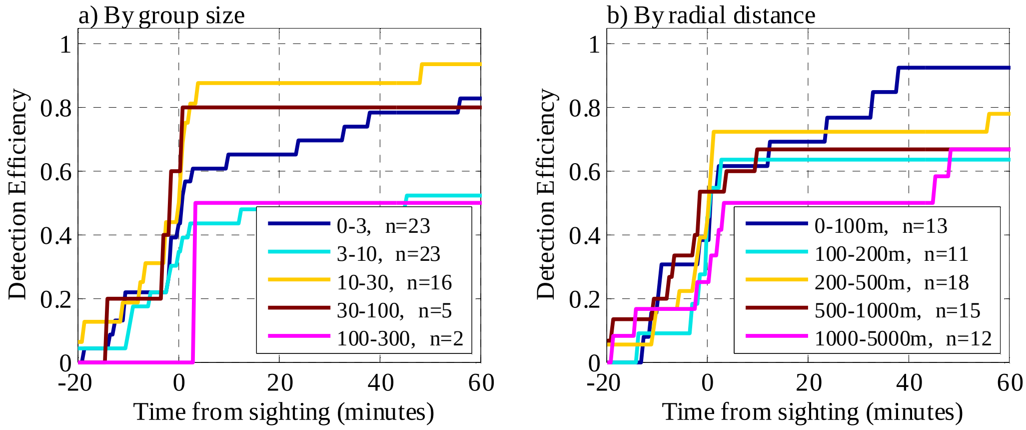


**Figure 9. Detection efficiency of whistle events as a function of group size and estimated radial distance.**

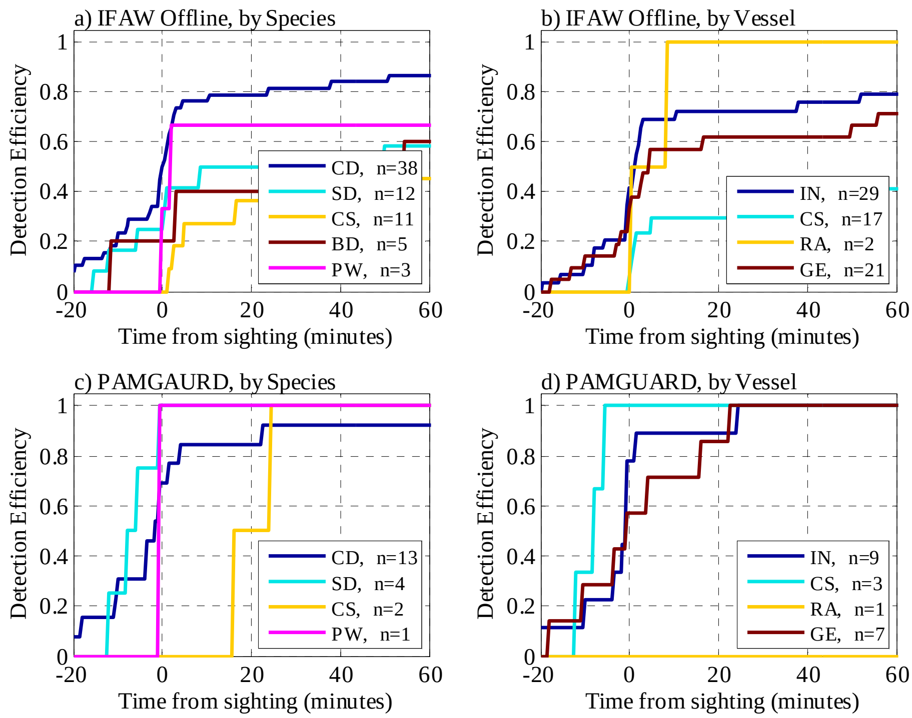


**Figure 10. Click detection efficiency for small odontocetes.**

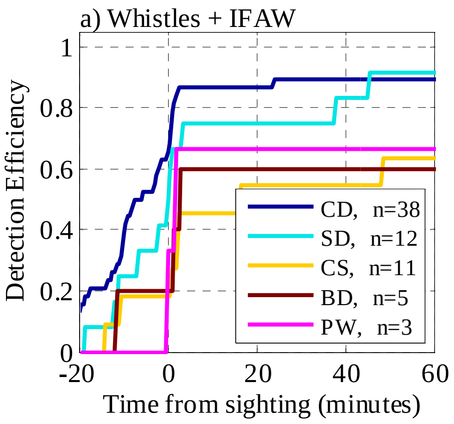


**Figure 11. Small cetacean detection efficiency using combined click and whistle event detection.**

**Combined click and whistle detection**

Many small odontocete species produce both whistles and clicks and it is normal during PAM operations to run both click and whistle detectors. Figure 11 shows the detection efficiency for small odontocetes using combined click and whistle event detection. In both cases, whistle detection is the fully automatic process, click detection was either offline or online, as described above.

Combined detection efficiency must always be higher than just click or just whistle detection efficiency as is borne out by the data presented in Figure 11 compared to that in Figure 10. Using combined whistle event detection and online click train detection, detection efficiency is 100% for three species and over 90% for a fourth.

### 4.3.2 Sperm Whales

Detection efficiency for sperm whales is shown in Figure 12. As with small odontocetes, click train detection is more efficient when processing online using PAMGUARD than offline using the IFAW RainbowClick software, presumably because the operator can listen to the clicks as well as see them on the screen.

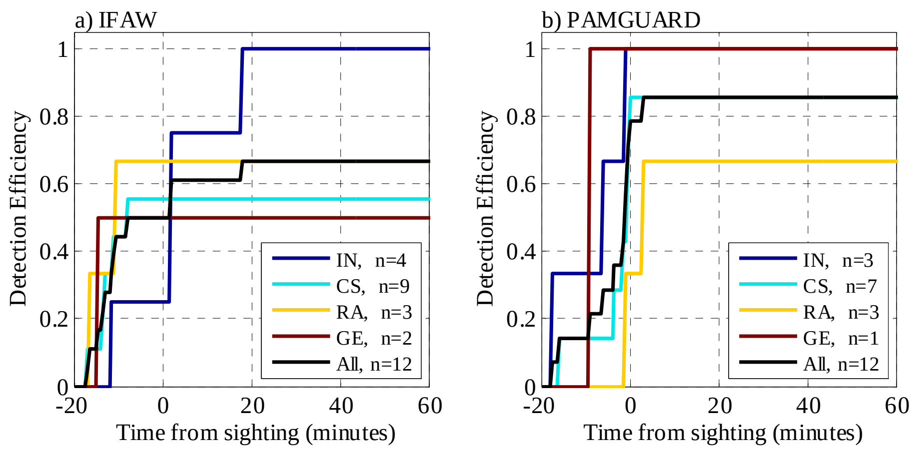


**Figure 12. Sperm whale detection efficiency**

### 4.3.3 Beaked Whales

As part of a separate JIP funded project on odontocete classification we are in the process of developing detectors and classifiers for beaked whales. These have not yet been implemented in PAMGUARD and applied to the CODA data. It is known from other studies of beaked whales that they are generally silent at the surface, only vocalising during long foraging dives ((Tyack, Johnson, &

Madsen 2005; Johnson et al. 2004). It is therefore extremely unlikely that a beaked whale would be detected while visible at the surface. From these data, we are therefore unable to assess detection efficiency for beaked whale species.

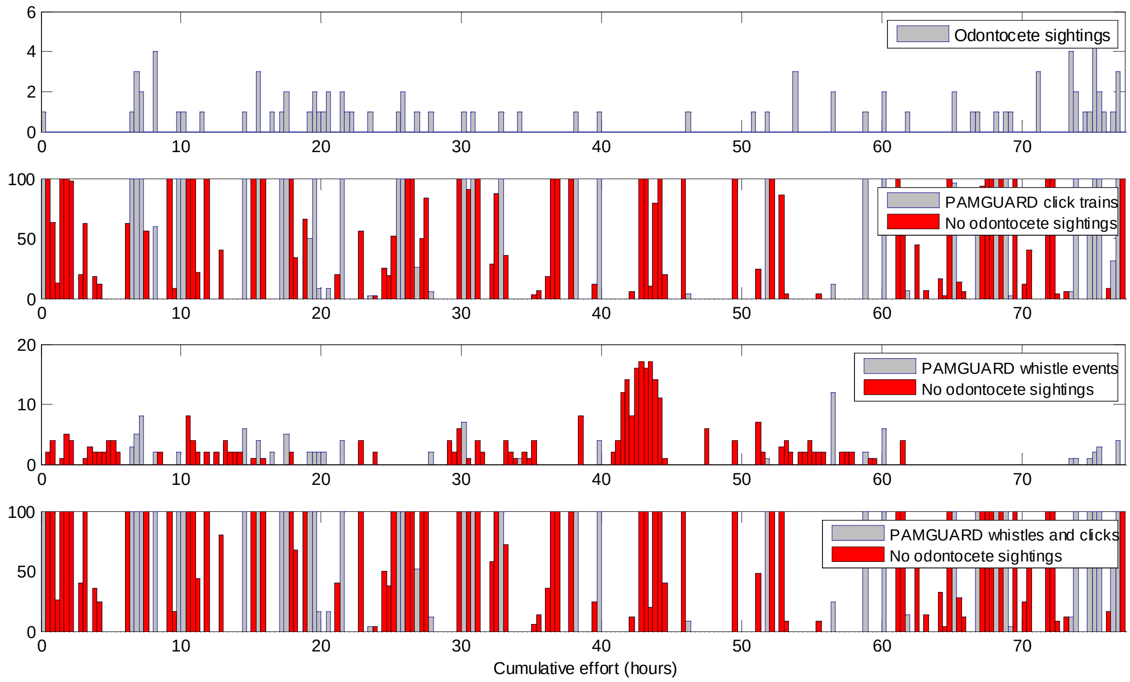


**Figure 13. Numbers of sightings and acoustic detections in 20 minute windows.**

**Table 4. Sighting and acoustic detection efficiencies.**

| **Sighting Efficiency** | **Periods with acoustic detections** | **Period with match to a sighting** | **Efficiency** |
|---|---|---|---|
| Re. PAMGUARD click trains | 127 | 44 | 36 % |
| Re. PAMGUARD whistle events | 100 | 28 | 28 % |
| Re. Combined PAMGUARD whistle events and click trains | 167 | 47 | 28 % |
| **Acoustic Detection Efficiency** | **Periods with sightings** | **Periods with match to acoustic detections** | |
| PAMGUARD click trains | 56 | 44 | 79 % |
| PAMGUARD whistle events | 56 | 28 | 50 % |
| Combined PAMGUARD whistle events and click trains | 56 | 47 | 84 % |

## 4.3.4 Overall sighting and acoustic detection efficiency

During mitigation exercises, observers, whether acoustic or visual generally monitor for a fixed time period of 20 minutes prior to the start up of a noise source. The simple question then arises as to what the overall efficiency for detecting cetaceans within a 20 minute period is. To answer this

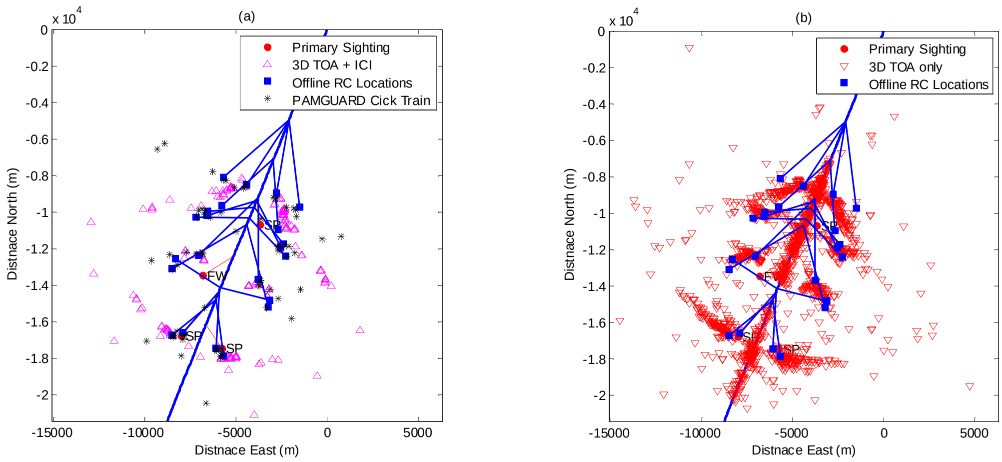


**Figure 14. Visual and acoustic localisations of sperm whales using multiple online and offline tracking methods.**

question, all periods of offline data analysis with PAMGUARD were concatenated into a single 77 hour long sections. A count was then made of the number of sightings and acoustic detections in 20 minute periods during those 77 hours as shown in Figure 13. Acoustic efficiency can then be calculated by taking the number of sightings which do and do not associate with an acoustic contact. Conversely, sighting efficiency can be calculated from the number of acoustic detections which associate with a sighting. Sighting and acoustic detection efficiency were measured in this way for manually selected PAMGUARD click trains, automatically detected PAMGUARD whistle events and the combination of the two. Results are shown in Table 4. It can be seen that when compared to any of the acoustic detection methods, sighting efficiency is low at around 30 %. Acoustic detection efficiency however is high, reaching 84 % when click train and whistle detection are used together.

### 4.3.5 Localisation accuracy through comparison with visual data

Odontocetes were localised using several different methods during offline data analysis using PAMGUARD:

1. Sperm Whale Localisation using crossed bearings from manual click train detection
2. Localisation of individual sperm whale clicks (three different methodologies).
3. Whistle Localisation

Localisations of sperm whales from offline data analysis using the IFAW RainbowClick software were also available.

The problems of assessing localisation accuracy through comparison with the visual data are highlighted in Figure 14. This shows an hour of survey data, during which time there were three sperm whale sightings and one fin whale sighting. The plot also shows reconstructed sperm whale locations from offline analysis using RainbowClick, which found a total of 11 individual animals. Figure 14(a) shows locations derived from manual click train selection in PAMGUARD and the 3D TOA and ICI localisation method for single clicks. Figure 14 (b) shows an overlay of the 3D TOA only single click localisations. The presence of multiple animals, and the fact that the animals had probably moved between being sighted and being located acoustically, makes a direct measurement of localisation accuracy impossible. From the plots it can be seen that there are clear clusters of PAMGUARD localisations (both single click and tracked click trains) around the localisations derived offline using RainbowClick. However, some of these clusters of single click localisations are spread over several kilometres.

There are at least four reasons for this discrepancy between the two methods. First of all, both visual and acoustic methods are subject to error and the difference will reflect the combination of these errors. Secondly, the offline RainbowClick location is based on the assumption of a stationary whale and is, to some extent, the mean location of the whale throughout the period for which it was tracked. This mean location will clearly never be the exact location at any one time, as is calculated by the single click localisation methods. Thirdly, two of the single click localisation methods measure a slant angle to the detected sound which gives an estimate depth and a range which will generally be shorter than a range that doesn't take depth into account and assumes that the animal is at the surface. Finally, it is possible that the PAMGUARD methods were picking up whales missed using other methods so there is no reason to expect those clicks to appear close to sightings or IFAW software detections.

Similar problems arise when trying to assess localisation accuracy using crossed bearings to whistles (Section 3.6). Dolphins often occur in large aggregations formed of multiple sub groups which may be fast moving around the vessel. Associating a particular sighting with a particular whistle is impossible. For example, Figure 15 shows visual and acoustic data from a passage through a group of common dolphin. Some of the clusters of acoustic localisations clearly coincide with some of the sighting positions, but there are other clusters of localisations where no animals were seen. As with

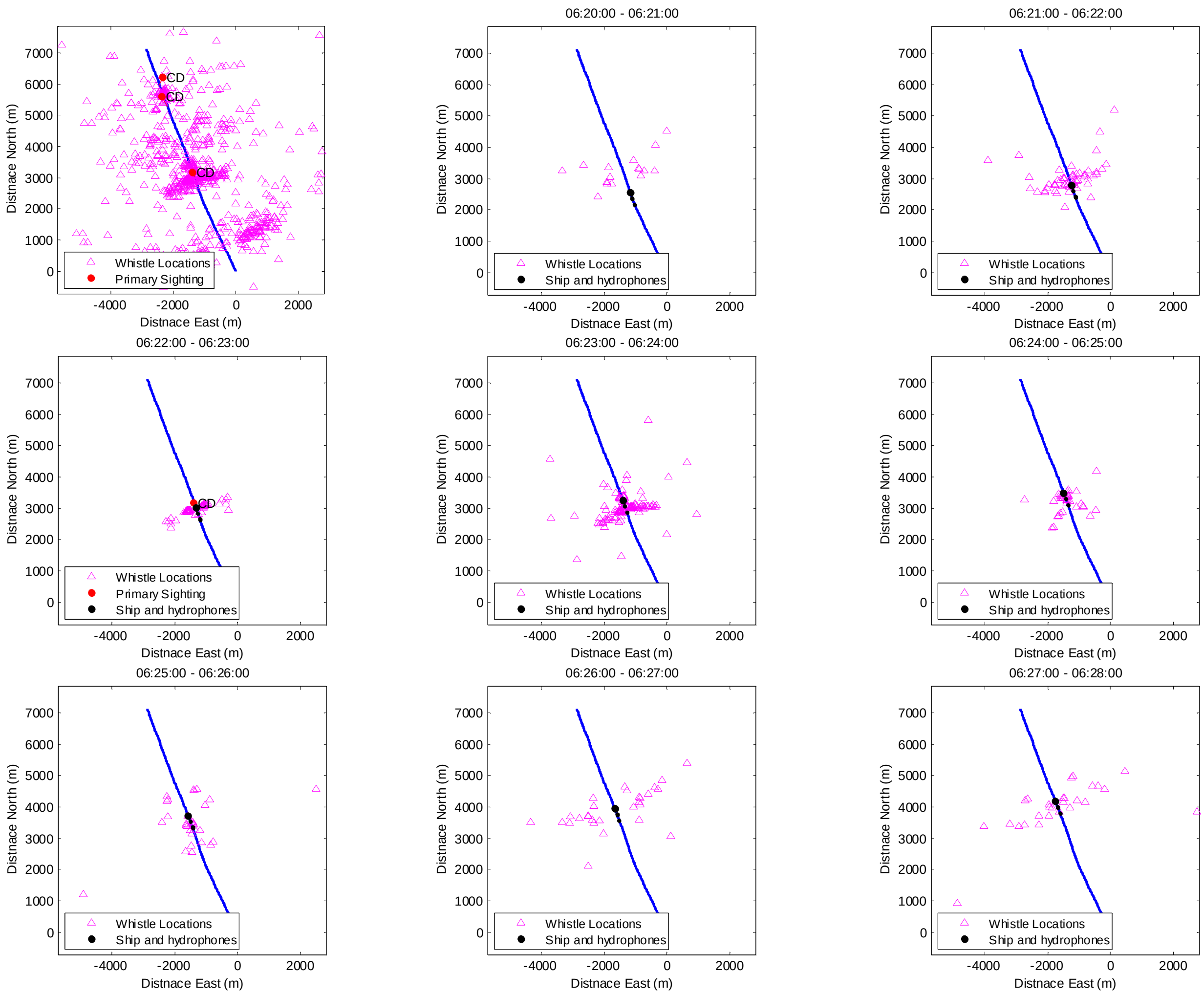


**Figure 15. Common dolphin sightings and PAMGUARD Whistle localisations. The first plot shows 40 minutes of data between 06:00 and 06:40 on 11 July. Subsequent plots show one minute each of acoustic and sighting data as the vessel passes a common dolphin spotted from the Primary Platform.**

the single click localisations of sperm whales, these clusters of acoustic localisations are spread out over 100's of metres and this spread will be in part due to measurement error and in part to animal movement and undetected animals.

### 4.3.6 Localisation accuracy from acoustic data alone.

An alternative method of assessing localisation accuracy is to look at theoretical errors. For whistles, where the location is obtained by crossing two bearings, these are derived from the estimated angle error on the bearing from each hydrophone pair and how an error on that bearing would affect the localisation accuracy both parallel to and perpendicular to the vessel track. For sperm whale tracks, where many clicks are included in the position calculation, the accuracy is derived from how closely the multiple crossing points of bearing lines are grouped.

For both sperm whale clicks and whistles, the estimated error on single bearings was taken at 3 degrees for bearings perpendicular to the array, increasing towards the ends of the array using $1/\sin(\theta)$ where $\theta$ is the angle relative to the array axis (see (Gillespie & Chappell 2002). The nominal 3 degree error is a deliberate overestimate of the theoretical error on individual bearing calculations, which is less than a degree, but has been set high to allow for some uncertainty in array location. In practice the accuracy with which the array can be located will be very much a function of the hardware used, sea state and the accuracy of any array localisation systems.

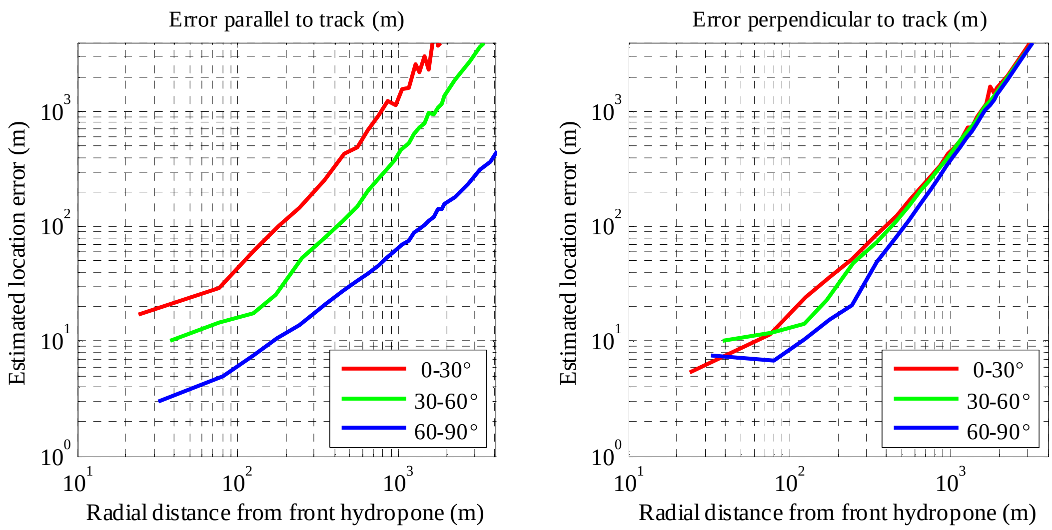


**Figure 16. Whistle localisation accuracy parallel and perpendicular to the array axis as a function of range. Data are grouped by angle relative to the array axis.**

PAMGUARD calculates error components on localisations both parallel to and perpendicular to the array. Estimated errors on whistles from the CODA survey (all vessels) are shown in Figure 16. The magnitude of errors varies as a function of both distance and angle. As distance from the array increases, the angles at which bearing lines cross becomes increasingly small, so small changes in those angles results in large changes in the estimated radial distance. The most inaccurate measurement is the distance to animals directly in front of or behind the array where angle errors are largest. For instance, Figure 16 shows that for animals located within 30˚ of the array end, at a distance of 500m, the error parallel to the array is itself nearly 500m. However, the error parallel to the track for those same animals is around 150m and this error will decrease further as the animals pass abeam. This is important both during surveys and mitigation exercises, where the perpendicular distance from the vessel track is more important than the exact position along the trackline.

When tracking sperm whales using PAMGUARD, as the operator adds clicks to a click train, the location of the click train is updated. Figure 17 shows the evolving error on sperm whale tracks for animals with a final perpendicular distance from the array of < 500m and for animals between 500 and 1000m. Clearly as each animal is tracked for an increasing length of time, its position becomes increasingly accurate. For animals at ranges of < 500m, perpendicular distance errors are generally less than 10's of m after a minute of tracking. For more distant animals, the perpendicular distance measurements usually reduce to 10's of m after 2- 3 minutes of tracking. The few large errors, which increase dramatically during the track, are due to operator error, whereby the operator added a click to a track which did not belong to that track, so the resulting fit to the data was very poor.

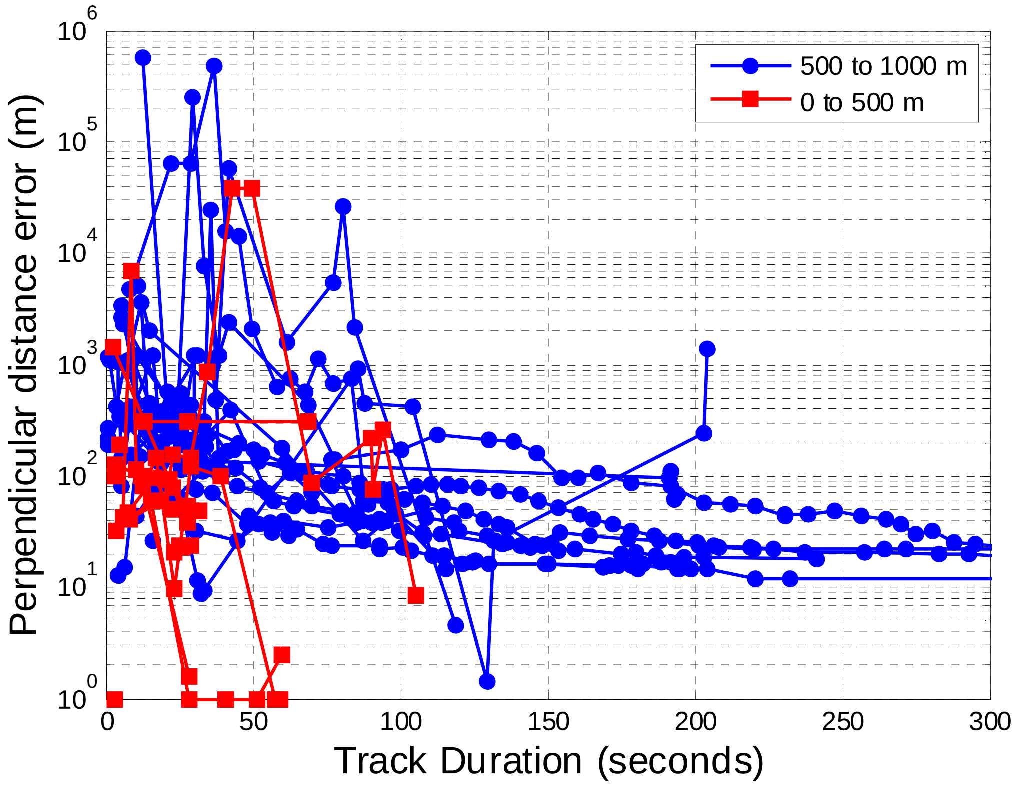


**Figure 17. PAMGUARD Sperm whale click train localisation errors as a function of track time and distance.**

# 5 Summary

## *5.1 Usability*

Two people who were not part of the PAMGUARD development team used PAMGUARD extensively during the trial. Sebastian von Luders, an experienced MMO with PAM experience was trained in PAMGUARD configuration and operation over a single day prior to going to sea and found the system easy to operate, finding it "More stable and user friendly" than previous PAM software. Eva Hartvig had no prior PAM experience either with PAMGUARD or older systems, although she is an experienced bioacoustician; currently studying for a Masters degree in sperm whale acoustic behaviour at the University of St Andrews. Eva was trained in general PAMGUARD operation in a single day, and then required assistance only when new modules were being used for the first time. Both operators successfully tracked animals, whether at sea or running in real time back at the lab.

A number of new features were added to PAMGUARD as a result of feedback from SVL and EH, or due to needs identified by Doug Gillespie or David McLaren. While some of these features were specifically added for offline data analysis, others enhance PAMGUARD usability during normal operation. These additional features include map comments, improvements to the spectrogram display, improved map options and angle vetoes in the click detector.

## 5.2 Software stability

A total of 26 bugs were reported from the cruise, a number of bugs were also identified and resolved during the offline data analysis period. The severity of the bugs ranged from ones which would regularly crash the software or inaccurate measurements on the map to minor issues with the display of axes. All reported bugs have now been fixed apart from two very minor ones which do not affect either stability or performance.

## 5.3 Detection efficiency

Detection efficiency was measured by comparing sightings from the CODA visual survey with output of the click and whistle detectors. Using the somewhat crude comparison of visual and acoustic detection in 20 minute windows, acoustic detection efficiency reached 84% if both click and whistle detectors are used simultaneously. Conversely, sighting efficiency was shown to be only about 30 %.

Detection efficiency has been shown to vary considerably by species and, equally importantly, by vessel. Common sense tells us that a noisy vessel will be a less efficient platform than a less noisy one. Vessel noise is highly variably in nature, the two main sources of continuous noise being low frequency "rumbling" from ships engines and broad band impulsive sounds from cavitating propellers. The effect a particular noise will have on detection will depend on the frequency band noise is in and also on how that noise affects the triggers within a particular detector.

## 5.4 Localisation accuracy

Accurate measurement of localisation accuracy through comparison with the visual data has not been possible for any species due to the complexity of the visual data. Generally, many animals, and often many species were present, and some, such as the sperm whale, are known to vocalise rarely while at the surface. This made it impossible to link acoustic localisations to independently measured whale locations. The results presented in Section 4.3.5 indicate that successive localisations of what are possibly the same animal, are spread out over several 100's of m. This is not entirely surprising given the 200m aperture of the array used. During the survey most of the detections were either directly in front of the vessel or at distances of several 100's of m or several km in the case of sperm whales. The primary tool in estimating location is the crossing of bearings from the two hydrophone pairs (some of the 3-D localisation methods are more complicated than this, but the basic idea is similar). For locations far from the vessel, the angle at which bearings cross becomes increasingly small and any error on the measured angles will translate to a large error on the range. This error is worse for animals ahead of the vessel since the errors on calculated angles increase dramatically when those angles are near parallel to the array axis.

The estimated error for whistle localisations and sperm whale click train localisations have been estimated based on an estimated error on bearing measurements of 3˚. For whistles, the error parallel to the array axis is considerably larger than that perpendicular to the array axis. Errors may be over 100m for animals 500m from the array, although the error will be very dependent on the array geometry. For sperm whale tracks, the error reduces over time as more clicks are added to a particular track. Generally after a few minutes, sperm whales within 1000m of the track-line can be positioned to within 10's of m.

# 6 Publications and conference presentations

A PAMGUARD Presentation was given at the Institute of Acoustics conference on Underwater Noise Measurement, Impact and Mitigation held in Southampton on 14th – 15th October 2008 which included results of the sperm whale semi-automatic tracking detailed in Section 4.3.5.

A paper (Gillespie et al. 2008) was prepared for the proceedings of the conference:

Gillespie, Douglas, Jonathan Gordon, Ron Mchugh, David Mclaren, David Mellinger, Paul Redmond, Aaron Thode, Phil Trinder, and Xiao Yan Deng. 2008. PAMGUARD: Semiautomated, open source software for real-time acoustic detection and localisation of cetaceans . *Proceedings of the Institute of Acoustics* 30, no. 5.

# 7 Software releases

Bug fixes resulting from the trial were released in PAMGUARD version 1.0 on 31 January, 2008 and in version 1.1 on 21 May, 2008. These fixes remain in subsequent releases of both beta and core versions.

All new features described in Section 3, apart from the offline analysis mode, described in Section 3.1 were also released with version 1.1.

At the time of writing, the offline analysis mode, which was developed specifically for the analysis described in this report, was not sufficiently bug free or adequately documented for general release. It is intended however, that a beta release of the offline analysis option will be released in April or May, 2009.

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# 9 Acknowledgements

I'm am most grateful to the coordinators and staff of the CODA survey, in particular Phil Hammond, Kelly Macleod and Rene Swift who enabled access to the visual data from the survey and the standard acoustic analysis using the IFAW software. Thanks should also go to the acoustic 'observers' on the vessels who deployed the hydrophones and collected the data, as well as Sebastian von Luders and Eva Hartvig already mentioned in this report.

# Appendix 1. Module testing and bug report

**Tests conducted on each module during the sea trials are summarised in Table 5, feature requests from the field operators in Table 6.**

**Table 5. Module testing and bug reporting.**

| | Tested | Bugs | Notes |
|---|---|---|---|
| **Maps and Mapping** | | | |
| NMEA Data Collection | Y | N | Additional functionality added after the cruise to read NMEA data directly from PAMGUARD without need for separate server. |
| GPS Data Processing | Y | Y | Bug - incorrect calculation of distances between fixes (Fixed) |
| AIS Processing | N | - | No AIS receiver available |
| Airgun Display | Y | Y | Reported by SVL to be slowing the program down. Have found no evidence of this and the module has been extensively tested during other trials without problems. |
| Map | Y | Y | Bug - Incorrect bearing and range calculations on Map side panel (fixed)<br><br>Bug - Zooming using mouse wheel doesn't always work (Fixed) |
| **Utilities** | | | |
| Simulator | N | - | Purely designed for offline testing, so no point testing at sea. |
| ODBC Database | Y | Y | Bug - Dialog does not always open correct database (Fixed)<br><br>Bug - Need to better handle infinite and null data which crash the system (Fixed)<br><br>Bug – Crashes when trying to use an invalid table or column name, e.g. SVL set up a whistle detector and called it 'Whistle ch 2+3'. The '+' is not a valid character for database table names, so the system crashed when PAMGUARD attempted to create an output database table for that module. (Fixed – have added checks which change all invalid characters into an underscore character, so the output table for the above detector would be 'Whistle_ch_2_3')<br><br>Seems to slow performance, particularly when using MySQL. Better with MS Access. |
| Terrella Control | N | - | |
| **Displays** | | | |

| | | | |
|---|---|---|---|
| User Input | Y | N | McLaren added additional side panel for quick comment entry and also immediate storage of data following carriage return on keyboard |
| User Display Panel | Y | Y | Bug - Spectrogram window crashed if 0 spectrogram panels specified. (Fixed)<br>Bug - Detections not always showing on Radar plot (Fixed) |
| **Sound Processing** | | | |
| Sound Acquisition | Y | (y) | Sound card and ASIO acquisition thoroughly tested.<br>Problems reported from Alaska field trial, No details provided. (this module has since been debugged and extensively tested during other trials) |
| FFT (spectrogram) Engine | Y | Y | Bug - Worked, but identified need to make it easier to tell the difference between FFT data blocks when multiple FFT sources are present. (Fixed – naming of modules and data blocks is now clear through unique naming systems). |
| IIRF Filters | Y | Y | Bug Seems to have crashed click detector. (Fixed – changes to filter parameters are now correctly noted and new filters set up in such a way that they can be changed even during real time operation). |
| Decimator | Y | Y | |
| Sound Recorder | Y | Y | Occasional crashes / Loss of output data stream. (Fixed). |
| Spectrogram smoothing | Y | Y | |
| **Detectors** | | | |
| Click Detector | Y | Y | Ran four channel two hydrophone pair version and was able to track sperm whales rapidly using semi-automatic tracking algorithm.<br>Bug - Crashes if channel configuration altered while running. (Fixed) |
| Whistle Detector | Y | Y | Hard to set up reliably (was improved during Industry field trial and another detector from PW pending)<br>Bug - Crashes if data source is removed. Trouble identifying different FFT data sources (Fixed) |
| Ishmael Energy Sum | N | - | |
| Ishmael Matched Filtering | N | - | |
| Ishmael Locator | N | - | |
| Workshop Demo Detector | Y | N | |

| | | | |
|---|---|---|---|
| 3D Towed Array Localiser | Y | N | |
| **New modules added since field trial, used during offline analysis** | | | |
| Sound Output | Y | N | Used to play back sound to operator when analysing stored data |
| Signal Amplifier | N | N | Can boost signal amplitude prior to playback. |
| Patch Panel | N | N | Useful for mixing together multiple channels of data when monitoring > 2 channels on headphones. |

**Table 6. Feature requests from the field operators.**

| Module | Feature Request | Resolution |
|---|---|---|
| Map | Need to remove old detections when map gets cluttered. | The display time for each different type of data can now be set individually so that data which occur often, or in large numbers (such as individual sperm whale clicks) are only displayed for a short time, whereas data which occur les often (such as the estimated location of a sperm whale based on multiple clicks) can be displayed for longer. |
| Sound Acquisition | 1) Assign 'random' channel numbers rather than always reading out channels 0 to n-1, e.g. may want to read out channels 8,9,12 and 13.<br>2) Level meters for each channel (possibly as a side panel plug in) would be useful. | 1) Implemented following the cruise.<br>2) Not implemented |
| Sound Recorder | Need to support other output formats, e.g. 24 bit | Not implemented |
| Click Detector | SVL identified a need for a forward veto to remove ship noise | Implemented a flexible system for multiple vetoes at any angles so that the veto system can also remove electrical noise (usually appearing on beam), noise from other vessels at fixed positions relative to the survey vessel (e.g. during multi vessel surveys) or to work with alternate hydrophone configurations in which the ship may not be directly ahead of the hydrophone. |
| Things Heard form | The IFAW Logger software contains a form for entry and logging of sounds heard by the operator. | Not implemented.<br>A basic form, but without user control of the species list was added as part of the 2008 industry field trial, but will not be included in any future releases until it's completed. |