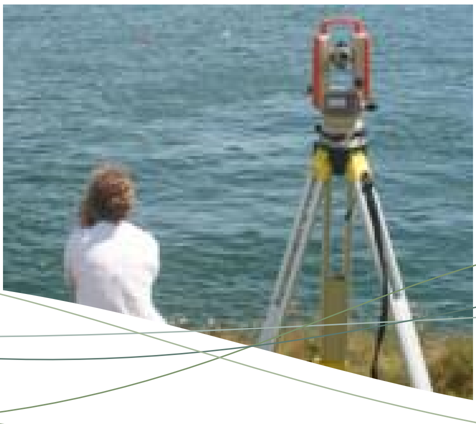
Marine Research Sub-Programme
(NDP 2007–'13) Series

Sea Change
Casadh na Taoide

Marine Mammals and Megafauna in Irish Waters - Behaviour, Distribution and Habitat Use. *Developing Acoustic Monitoring Techniques*

Project-based Award

Lead Partner: Galway Mayo Institute of Technology



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Transforming Ireland

An Roinn
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Project-based Award

Marine Mammals and Megafauna in Irish Waters - Behaviour, Distribution and Habitat Use *(PBA/ME/07/005(02))*

WP 2: Developing Acoustic Monitoring Techniques

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PREFACE

Irish waters are internationally important for cetaceans (whales, dolphins and porpoises), with 24 species recorded to date (Berrow, 2001). These range from the harbour porpoise, the smallest species in European waters, to the blue whale, the largest animal to ever have lived on Earth. Some species are relatively abundant and widespread while others are extremely rare and have never been sighted in Irish waters, only known from carcasses stranded on the Irish coast. At least 12 cetacean species are thought to calve within the Irish Exclusive Economic Zone (EEZ)[1] (Berrow, 2001). Marine mammals, including cetaceans and seals, represent almost 50% of the Irish native mammal fauna, and thus Ireland has a significant conservation obligation towards them and their habitats. In 1991 the Irish government recognised the importance of Ireland for cetaceans by declaring all Irish waters within the EEZ a whale and dolphin sanctuary (Rogan and Berrow, 1995).

This diversity of cetacean species in Ireland reflects the range of marine habitats, which extend to 200 nautical miles (nmls) (370km) offshore and comprise an area of 453,000km^2. This is a little over six times the area of the land of Ireland. These habitats range from shallow continental shelf waters to shelf slopes, deep-water canyons, offshore banks, carbonate mounds and associated deep water reef systems and abyssal waters.

Legal Framework

All cetaceans and their habitats are protected under Irish and international law. The Wildlife Act[2] and Wildlife (Amendment) Act[3] entitle all cetaceans and their habitats up to 12nmls from the coast to full protection, including from disturbance and wilful interference. All cetacean species occur on Annex IV of the EU Habitats Directive[4], and are thus entitled to strict protection, including prevention of deliberate capture or killing, prevention of deliberate disturbance, prevention of deterioration of breeding or resting sites and prevention of capture for sale. There is also a requirement to monitor the incidental capture or killing of these species. Two species, the harbour porpoise and bottlenose dolphin, are on Annex II, which requires the designation of Special Areas of Conservation (SACs) to protect a representative range of their habitats. To date, two candidate SACs have been designated for the harbour porpoise - Roaringwater Bay, Co Cork, and the Blasket Islands, Co Kerry - and one for the bottlenose dolphin - the Lower River Shannon. The European Court of Justice (ECJ) ruled in

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[1] EEZ: a seazone in which a state has special rights over the exploration and use of marine resources.
[2] Wildlife Act (1976)
[3] Wildlife (Amendment) Act (2000)
[4] Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora

February 2009 that the Irish government had failed to 'put in place a comprehensive, adequate, ongoing monitoring programme for cetaceans that could enable a system of strict protection for those species to be devised'.

Under Article 17 of the Habitats Directive, each member state must report on the status of all species and habitats listed under the Habitats Directive which occur within the state. The first reporting round was completed in 2007 and covered the period 2000– 2007. A conservation assessment requires information on range, habitat, population, and future prospects. The conservation assessments for cetacean species were considered very inadequate due to a significant lack of data on range, habitat, and population estimates for nearly all cetacean species in Irish waters. The next reporting round will be completed in 2013, and the National Parks and Wildlife Service (NPWS) must ensure that available data are adequate to make a proper conservation assessment, at least for the most abundant and widespread species.

In December 2009, the National Parks and Wildlife Service (NPWS) published its Conservation Plan for Cetaceans in Irish Waters[5]. This plan lists 41 actions. These include conducting further research to determine the distribution, relative abundance, and habitat preferences of cetaceans (Action 1); identifying breeding ecology, movements, and migration routes (Action 2); devising a programme to effectively monitor cetaceans inside and outside designated areas (Action 3); encouraging the development of passive acoustic monitoring (Action 4); exploring the possibility of using static acoustic monitoring to provide data for monitoring cetaceans (Action 9); including cetacean surveys on fisheries cruises to collect information on the possible relationships between fish and cetacean abundance (Action 18); and carrying out spatial monitoring using GIS to explore the relationship between cetacean distribution and fisheries (Action 19).

The Irish government also has legal obligations to protect cetaceans and other marine megafauna, and their habitats, under a range of other legislation. These include the Convention on the Conservation of Migratory Species[6] (Bern Convention) and the Convention on the Conservation of European Wildlife and Natural Habitats[7] (Bonn Convention). Under the OSPAR Convention[8], Ireland is obliged to address recommendations on the protection and conservation of species, habitats, and ecosystems that make it not only relevant to marine mammals and turtles but also to basking sharks.

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[5] Conservation Plan for Cetaceans in Irish Waters (2009). Department of Environment, Heritage and Local Government.

[6] Convention on the Conservation of Migratory Species of Wild Animals (1979)

[7] Convention on the Conservation of European Wildlife and Natural Habitats (1979)

[8] Convention for the Protection of the Marine Environment of the North-East Atlantic (1992)

The National Biodiversity Data Centre recently established a marine mammal database. The data collected during this project will be used for this database in order to make the data available for a range of assessments, including Environmental Impact Assessments, Strategic Environmental Assessments and Appropriate Assessments.

Amendments to the EU Common Fisheries Policy require an Ecosystem Approach to Fisheries Management (EAFM). This requires data on the predators as well as the fish prey, and the drivers linking the different ecological systems. This presents a great challenge and member states are exploring how such an approach can be implemented.

The development of a sustainable marine tourism industry has been identified as a national priority by both the Marine Institute and Fáilte Ireland. While marine wildlife tourism has great potential as a high spend product for peripheral coastal regions, the species targeted are usually protected and populations often depleted through over-exploitation. Information on the distribution, abundance, and status of these species is essential for responsible development of this resource.

Marine Mammals and Megafauna in Irish Waters – Behaviour, Distribution and Habitat Use

The research termed *Marine Mammals and Megafauna in Irish Waters – behaviour, distribution and habitat use* attempted to address some of these issues. The project was delivered under six Work Packages. Work Package 1 attempted to increase coverage of offshore waters using platforms of opportunity (both ship and aircraft) to map the distribution and relative abundance of marine megafauna within the EEZ, and to provide recommendations on how best to meet monitoring obligations for these species. Work Package 2 attempts to develop static and passive acoustic monitoring techniques in order to use these techniques to monitor Annex II species within SACs. Under Work Package 3, we intended to develop experience and capacity in the biotelemetry of marine megafauna through satellite tracking of fin whales (*Balaenoptera physalus*). In Work Package 4, results from eight years of cetacean and other marine megafauna surveys concurrent with the Celtic Sea Herring Survey organised by the Marine Institute were used to create a GIS in order to explore ecosystem links.

Thus, the deliverables under this project will provide data which could be used to address a wide range of issues, and will contribute to developing policy advice on meeting Ireland's statutory obligations.

EXECUTIVE SUMMARY

The present study was aimed at assessing acoustic monitoring techniques as a means of addressing statutory monitoring obligations under the EU Habitats Directive for Annex II species (harbour porpoise and bottlenose dolphin). In addition, a protocol of best practice for *Static Acoustic Monitoring* (SAM) was developed. Three commercially available SAM devices were compared and assessed for their suitability in long-term SAM programmes. *Passive Acoustic Monitoring* (PAM) was carried out from *Platforms of Opportunity* (POPs) and this method was also assessed for its suitability in detecting cetaceans. An appropriate best practice protocol was developed. Furthermore, a long-term deployment of a Deep C-POD was carried out offshore, from the M6 weather buoy, at a depth of 500m.

All SAM equipment was calibrated in the field and detection ranges generated for harbour porpoise (441m) and bottlenose dolphin (797m). Long-term deployments of up to two years took place at three locations along the west coast of Ireland: in Galway Bay, the Blasket Islands and the Shannon Estuary. The Blasket Islands is designated as a candidate Special Area of Conservation (cSAC) for harbour porpoises and the Shannon Estuary, a cSAC (Lower River Shannon cSAC) for bottlenose dolphins. Galway Bay was chosen as it is a site with both harbour porpoise and bottlenose dolphin present and it was the site of a previous long-term SAM study.

All SAM data were further explored across temporal trends in order to identify peak times of presence for the target species. Temporal trends, such as season, diel and tidal influences, were investigated. To identify sites of significant habitat importance for specific behaviours, click train data from all sites were analysed. Deep C-POD deployments resulted in the longest data acquisition from a single deployment of 211 days. The M6 mooring buoy proved a successful means to deploy units at depth. PAM from platforms of opportunity also served as a successful mean of data collection and can supplement visual observations, especially by acquiring data during the night-time hours and in adverse weather. To conclude, a detailed protocol of best practice for inshore SAM as a monitoring method was generated.

1. DEVELOPING ACOUSTIC MONITORING TECHNIQUES

1.1. Introduction

Cetaceans live in an acoustic world and increasingly attempts have been used to develop acoustic monitoring techniques rather than using visual methods, whose efficiency is hugely dependent on light weather conditions and sea-state, especially for species such as the elusive harbour porpoise or deep diving species such as *Ziiphids*. Increasingly, acoustic monitoring is being carried out in tandem with or as an alternative to visual surveys. Several areas have been the target of seasonal acoustic monitoring on the west, south and east coasts of Ireland (O'Cadhla *et al,* 2003; Ingram *et al,* 2004; Englund *et al*, 2006; Coleman *et al*, 2008; Berrow *et al,* 2008; Berrow *et al,* 2009a), but only a few studies have focused on an area for more than six consecutive months. These include O'Brien (2009), who focused on a single site in both Galway Bay and Clew Bay, and Anderwald *et al* (2011), who have been continuously monitoring Broadhaven Bay in Co Mayo since 2009. Acoustic monitoring can be carried out in a passive (PAM, e.g. towed hydrophone) or static (SAM, e.g. C-PODs, and AQUAclicks) mode. PAM was carried out during the present project from Platforms of Opportunity (POPs) when appropriate (Chapter 7), while SAM was carried out in shallow coastal waters using C-PODs, T-PODs and AQUAclicks (Chapter 5). Some of the first deployments in the offshore waters of Ireland's EEZ also took place using a Deep C-POD, capable of withstanding increased pressures at depth (Chapter 8).

Echolocation is the ability to emit high intensity signals of short duration with exponentially decaying pulses (Au, 1997), and odontocetes can do this with varying degrees of complexity and composition. Most cetacean clicks are produced in trains. Therefore, the ability to record or recognise a click train can enable us to monitor their presence and identify species. Click trains can come from many sources in the sea and the C-POD.exe software will categorise them into the five categories based on mathematical computations of the detected sounds. For example, harbour porpoise clicks are characterised as being narrowband, high frequency, while dolphin clicks trains are usually broadband and at mid frequency. Boat sonar and other sources of noise can produce click trains but are of different cycles, duration, frequency and source level.

The Timed Porpoise Detector (T-POD) has been used during a number of studies for various purposes, including environmental impact assessments (EIAs) (Carstensen *et al,* 2006), interactions between cetaceans and fisheries (Cox *et al,* 2001; Leeney *et al,* 2007; Berrow *et al,* 2009b), monitoring population trends (Verfuß *et al,* 2007; Berrow *et al,* 2009a), and behaviour including diel and tidal trends in vocal activity (Carlström, 2005). Initially the POD or porpoise detector, designed and manufactured by Chelonia Ltd (www.chelonia.co.uk) in the UK, was intended specifically to detect harbour porpoises, while more recent versions (T-PODs) were designed to detect both harbour porpoises and dolphins.

The latest digital version of the C-POD (Figure 1.1) is a fully automated, static, passive acoustic monitoring system which can detect porpoises, dolphins and other toothed whales by recognising the trains of echolocation clicks these species make in order to detect their prey, orientate themselves and interact with one another. These units are designed and manufactured by Chelonia Ltd and they are the only commercially available instruments, accompanied by click train recognition software which produce fully automated, accurate data on the behaviour and identification of cetacean species (see www.chelonia.co.uk). SAM can be carried out independently of weather conditions once deployed and, thus, ensures high quality data is collected, but only at a small spatial scale. At present, however, it cannot reliably distinguish between dolphin species, but the application is constantly evolving. The AQUAclick 100 (Figure 1.2) is a porpoise click logger (PCL), which can detect high frequency harbour porpoise echolocation clicks. It is designed and manufactured by Aquatec Group Limited, based in Hampshire in the UK.

In order to evaluate the importance of an area, it is fundamental that the presence of small cetaceans at a site is fully understood and this requires monitoring over time scales of at least years. An evaluation of a site must be underpinned through scientific research from dedicated survey effort. Visual monitoring of cetaceans can provide numbers for density and abundance estimation but will be biased due to factors such as observer effect and unfavourable sea conditions. Therefore, a complete dataset cannot be gathered, necessitating the requirement of *Static Acoustic Monitoring* (SAM). Through SAM, informative datasets, robust enough to detect distinctive trends in presence across a range of factors, can be achieved much more rapidly than visual means. This could contribute towards meeting EU obligations economically.

The aim of this study was to assess the efficacy of various SAM devices and to develop a protocol of best practice. SAM was reviewed under various headings to fully evaluate this technique. A cost estimate for 12 months SAM to fulfil statutory requirements was generated and compared with the cost of carrying out visual methods over the same timescales. This project was funded under the Sea Change Initiative, in which the government aimed to drive the development of marine resources in Ireland in a manner that contributes to the knowledge economy.

1.2. Materials and Methods

1.2.1. *T-PODs*

T-PODs are no longer in production but are still used to monitor cetaceans in the wild. The echolocation characteristics of porpoises and dolphins differ, but an overlap in frequencies can make the discrimination between species difficult. When using T-PODs where porpoises and dolphins co-exist, using filter settings of 50kHz with a reference of 70 or 90kHz will eliminate detections of porpoises in those channels. Echolocation clicks are projected from an odontocete's head in a highly directional beam. Intensity decreases with increasing angular distance off centre. The beam width is commonly expressed as the angle within which the level is within 3dB of that at the centre of the beam. For example, a bottlenose dolphin has a 3dB beam width and is 10-11.7° at an angle 5° above the body axis (Au, 1993). Directionality causes problems when detecting animals in the wild as it can only be recorded when the beam is directed at the recording equipment. Therefore, all SAM devices are subjected to this constraint. One study using T-PODs showed that porpoises were detected at any orientation at a range of about 20m (Chelonia *pers comms.*).

A dolphin's ability to echolocate across a wide range of frequencies (200Hz to 150kHz, Evans, 1973) requires setting a lower click bandwidth (for example, four) to reduce the number of dolphin clicks in the porpoise categories (*Tregenza pers comms*.). The use of such settings makes the automated detection and discrimination between porpoise and dolphin species by the T-POD achievable (Table 1.1). However, it is not possible to discriminate between dolphin species using POD data. As a monitoring tool, the T-POD essentially provides information on the presence of animals and gives a measure of vocalization activity and behaviour. However, these data are non-quantitative in relation to showing how the number of clicks detected by a unit relates to the number of animals present (Ingram *et al,* 2004). A study by Tougaard *et al* (2006) generated a measure of absolute density by assuming that sampling an area *n* times through SAM is equivalent to sampling *n* sub-areas, for example, during an aerial survey, and found that the estimate they generated from acoustic data was similar to that determined as part of an international SCANS (Small Cetacean Abundance in the North Sea) project survey conducted in July 1994. However, this method of analysis is novel and has not been widely adopted.

The T-POD is equipped with a hydrophone element which is connected to two band pass filters, a comparator/detector circuit and a microprocessor which has memory capability to store information logged from the target species (Kyhn, 2006). All electronics are contained within a waterproof PVC housing (Figure 3.0). The dedicated software T-POD.exe is used to download the data from the logger, which identifies and classifies click trains of cetacean origin. A T-POD runs six successive scans each of 9.3 seconds duration, and selects only tonal clicks and logs the time and duration of each click. However, sensitivities between units differ and tank calibration tests are recommended prior to their deployment. These tests should determine the detection threshold of each unit as this is directly related to detection range (Kyhn *et al,* 2008). In addition, field calibrations are also recommended prior to employment of the devices in monitoring programmes in order to facilitate comparisons between datasets collected in different areas using multiple loggers (Dähne *et al,* 2006). A detection distance of over 1,000m for T-PODs and bottlenose dolphins was generated in the Shannon Estuary by Philpott *et al* (2007) using version three T-PODs, but it is likely that this may differ with more recent versions. Detection distances for the harbour porpoise using T-PODs were generated by Tougaard *et al (*2006) (200m) and Villadsgaard *et al (*2007) (300m to 500m).

Table 1.1: Generic settings for T-PODs as recommended by Chelonia Ltd

T-POD generic settings						
SCAN	1	2	3	4	5	6
A filter (kHz)	50	130	50	130	50	130
B filter (kHz)	70	92	70	92	70	92
Click bandwidth	5	4	5	4	5	4
Noise adaptation	++	++	++	++	++	++
Sensitivity	6	6	6	6	6	6
Scan limit	240	240	240	240	240	240

Figure 1.1: T-POD, version 5 unit by Chelonia Ltd

1.2.2. *C-PODs*

Once deployed at sea, the C-POD operates in a passive mode and is constantly listening for tonal clicks within a frequency range of 20 to 160 kHz. When a tonal click is detected, the C-POD records the time of occurrence, centre frequency, intensity, duration, bandwidth and frequency of the click (Chelonia Ltd). Internally, the C-POD is equipped with a Secure Digital (SD) flash card, and all data are stored on this card. Dedicated software, CPOD.exe, provided by the manufacturer, is used to process the data from the SD card when connected to a PC via a card-reader. This allows for the extraction of data files under pre-determined parameters, as set by the user. Additionally, the C-POD also records temperature over its deployment duration. It must be noted that the C-POD does not record actual sound files, only information about the tonal clicks it detects. The C-POD detector is a sound pressure level detector with a threshold of 1Pa peak to peak at 130 kHz, with the frequency response shown below:

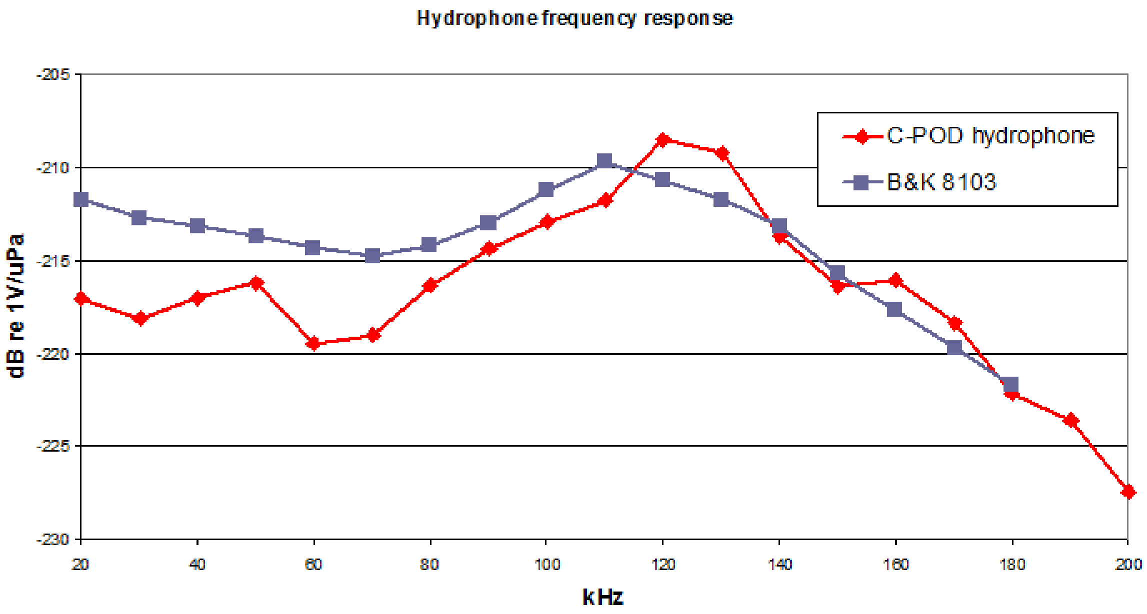


Figure 1.2: Threshold for detection across various frequency bands between 20 and 200 kHz for the C-POD (note 1Pa p-p is the SI unit for pressure and correctly represents the threshold) © Chelonia Ltd

Calibration of equipment is important in order to compare results across units. Chelonia Ltd calibrates all units to a standard prior to dispatch. These calibrations are carried out in the lab under controlled conditions and thus Chelonia highly recommends that further calibrations are carried out in the field prior to their employment in monitoring programmes instead of further tank tests (Nick Tregenza *pers comms*).

Figure 1.3: C-POD unit by Chelonia Ltd

1.2.3. *Deep C-POD*

The deep C-POD works on the same principals as the C-POD. The only difference between the two is that housing structure of the Deep C-POD is composed of a heavy anodised aluminum, allowing it to be deployed to depths of over 3,000m, and thus making the unit negatively buoyant. This has implications for deployment, and moorings are usually designed so that the hydrophone element faces the sea floor, the opposite to the C-POD used in inshore monitoring.

Figure 1.4: Deep C-POD unit by Chelonia Ltd

1.2.4. *AQUAclick 100*

The AQUAclick 100 (Figure 1.5) is a porpoise click logger (PCL) which can detect high frequency harbour porpoise echolocation clicks and is designed and manufactured by Aquatec Group Ltd, based in Hampshire in the UK. The unit comprises tough delryn housing, and the electronics are housed inside the unit. The battery consists of 4 C-cell nickel metal hydride batteries, which require recharging approximately every 12 to 14 days. Acoustic signals are detected through a high sensitivity transducer, and the device filters signals to remove unwanted noise. Further analogue and digital signal processing occur, and Aquatec's AQUAlogger technology is used to log the click events in non-volatile storage. The parameters stored are click occurrence time, click duration, and click sound level. After deployment the logged data can be uploaded via high speed USB, allowing it to be analysed by the ClickView software provided by the manufacturer. Generic settings as recommended by the manufacturer were used (Table 1.2). More recent versions of the AQUAgclick have longer battery durations. However, the conversion of older models to increase battery life is costly - in the region of £700 - and, hence, was outside the scope of this project.

Figure 1.5: AQUAclick unit by Aquatec

Table 1.2: Recommended settings for AQUAclicks by Aquatec Ltd. Settings used during all deployments

AQUAclick settings	
SETTING	**VALUE**
Variable gain	6dB
Threshold level	3
Automatic threshold	Turned off
Trigger (for use on porpoises)	130kHz filter
Minimum click length	30μ seconds
Maximum click length	1000μ seconds
Minimum inter-click-interval	2 milliseconds
Maximum inter-click-interval	500 milliseconds
Do not log clicks outside click length	Turned on
Do not log clicks outside filter ratio	Turned on
Do not log clicks with invalid inter-click ratios	Turned off
Format prior to deployment	Yes

1.2.5. *Towed Hydrophone*

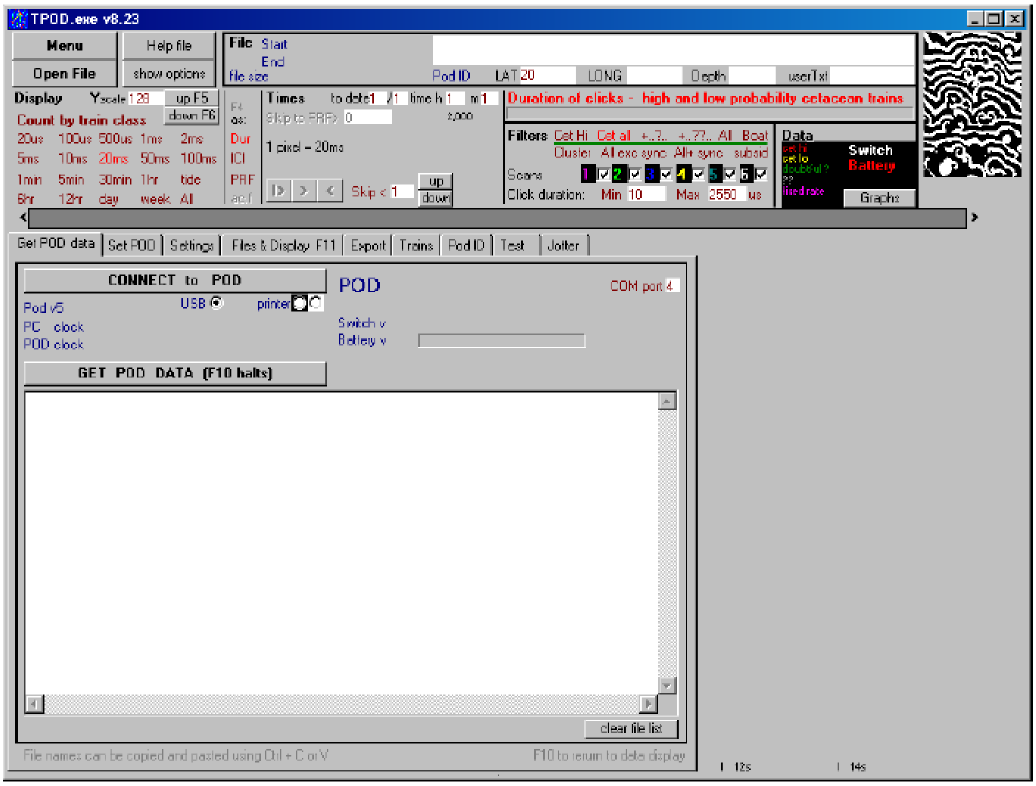
A towed hydrophone array was also deployed as part of the present study (Figure 1.6). This array consists of a 200m cable with two hydrophone elements (HP-03) situated 25cm apart in a fluid-filled tube towards the end of the cable. The hydrophone connects to a MAGREC HP-27 buffer box which runs through a laptop computer. This is connected to a National Instrument DAQ-6255 USB soundcard. This allows for the detection of sounds outside the capability of the computers soundcard (i.e. harbour porpoise high frequency echolocation clicks). Detection software used during all surveys includes PAMGUARD (freely available at www.pamguard.org) and IFAW's Logger and Rainbowclick (freely available at www.ifaw.org). The acoustic survey track line is recorded via an external GPS receiver linked to the Logger software. PAMGUARD is a fusion of the IFAW suite and Ishmael and, therefore, has applications such as click detectors, tonal whistle detectors, capability to calculate bearings on maps, record a track log, spectrogram viewer, and detection energy display. It also has built-in filters. The collection of acoustic data during visual surveys adds an extra dimension to the monitoring dataset. Acoustic monitoring can also potentially detect cetaceans which are beyond the visual observers' view and can be carried out during darkness and increasing sea state, thereby increasing the capacity of the survey.

Figure 1.6: Towed hydrophone deployment and real time monitoring

1.3. Software

1.3.1. *T-POD.exe (www.chelonia.co.uk)*

The T-POD.exe software is required for setting and downloading T-PODs, either through the use of a printer port cable or more recently, USB. The T-POD trains used to process .pdc files for trains and the filter is based on an algorithm that uses a 38% increase or decrease in an interval as the constraint. The true value for small odontocete trains is occasionally much higher but cannot be implemented in practice without very complex processing and/or a high level of false positive trains (Chelonia Ltd). Train selection is categorised by the probability of a train being of cetacean origin. Data can be exported under various parameters and displayed on text or .csv files (Figure 1.7).



LAT 20

Yscale 128

to date 1 / 1 time h 1 m 1

Skip to PRF> 0

1 pixel = 20ms

Skip < 1

1 ☑ 2 ☑ 3 ☑ 4 ☑ 5 ☑ 6 ☑

Click duration: Min 10 Max 2550 us

COM port 4

File names can be copied and pasted using Ctrl + C or V

F10 to return to data display

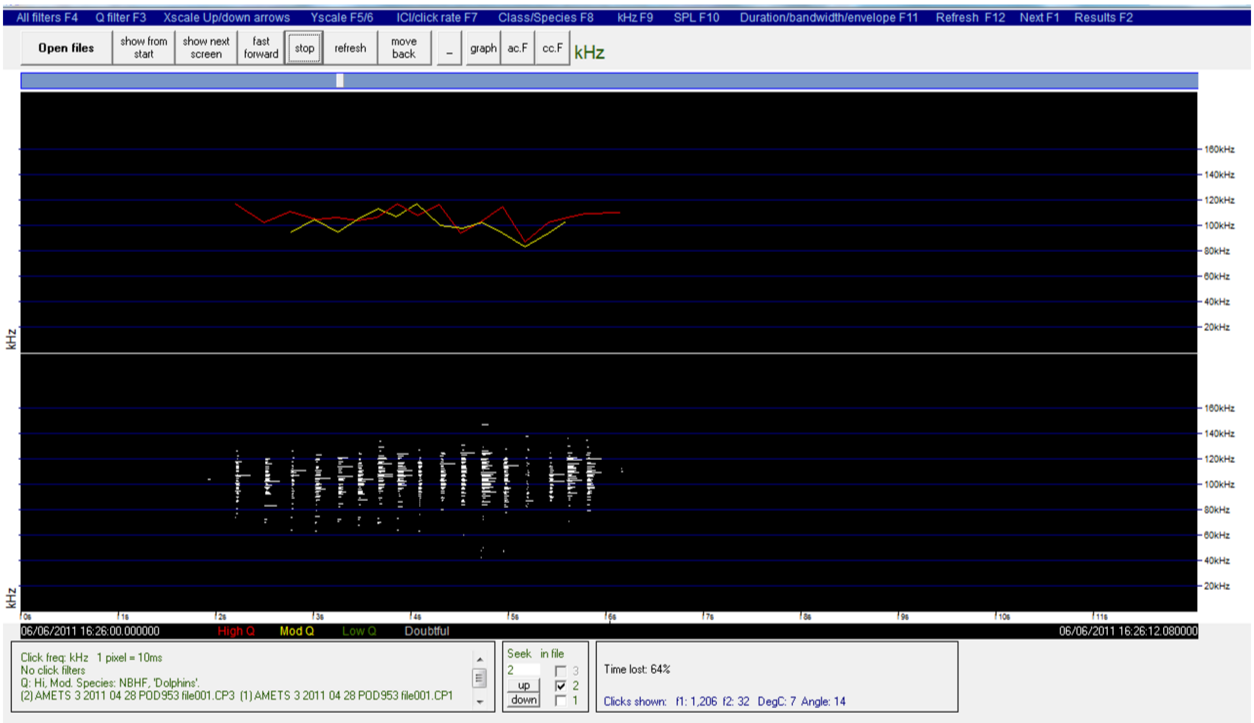
Figure 1.7: Screen grab of T-POD.exe

1.3.2. *C-POD.exe (www.chelonia.co.uk)*

Through the C-POD.exe software, data can be viewed, analysed and exported. Additionally, the software can be used to change settings of individual SD cards. The software includes automatic click train detection, which is continually evolving as Chelonia Ltd receives more feedback from their clients. The C-POD.exe software is very similar to the T-POD.exe but has capabilities beyond its predecessor. C-POD.exe can be run on any version of Windows and requires an external USB card reader, which reads the SD card into the directory. Version 2.013 (June 2011) was used for all analyses. *CP1* files are generated when the data is read from the SD card, while *CP.3* files are generated when the *CP.1* file is processed via the button on the "Trains" page (Figure 1.8. A typical file size for a three-month deployment is approx. 100MB). C-POD.exe software allows the user to extract click trains under five classification parameters:

i) porpoise-like
ii) dolphins
iii) other train sources
iv) unclassed
v) boat sonars.

Harbour porpoise detections are the easiest cetacean species to recognise within an acoustic dataset due to the click characteristics. However, problems can be encountered when trying to decipher between dolphin species and in many instances may not be attainable. Experienced C-POD users should be able to pick out definite species characteristics within a dataset and therefore be able to make more accurate assertions about species presence within an area. C-POD.exe is also used for viewing, analysing and extracting the Deep C-POD data.



06/06/2011 16:26:00.000000

06/06/2011 16:26:12.080000

Click freq: kHz 1 pixel = 10ms
No click filters
Q: Hi, Mod. Species: NBHF, 'Dolphins'.
(2) AMETS 3 2011 04 28 POD953 file001.CP3 (1) AMETS 3 2011 04 28 POD953 file001.CP1

2
☐ 3
☑ 2
☐ 1

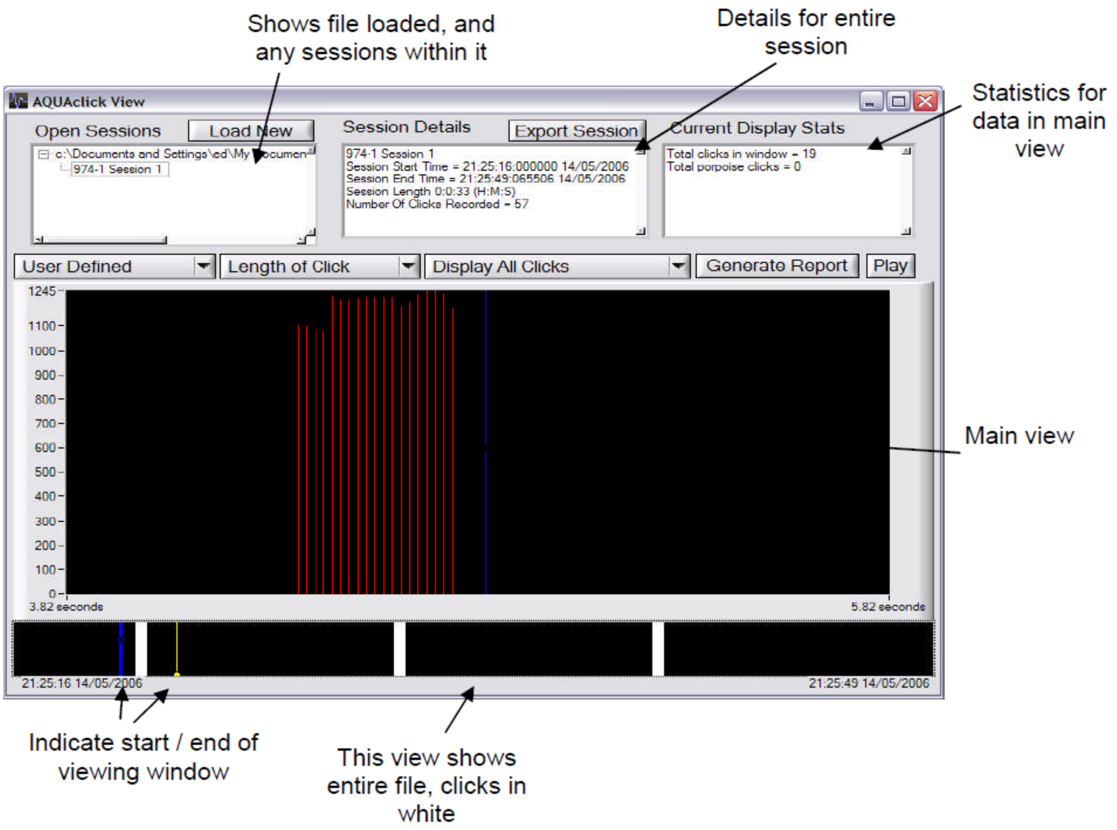
Time lost: 64%

Clicks shown: f1: 1,206 f2: 32 DegC: 7 Angle: 14

Figure 1.8: Screen grab of C-POD.exe, showing a harbour porpoise click train

1.3.3. *AQUAtalk and AQUAview*

The AQUAtalk.exe software is used to set up the unit prior to deployment but also to download data upon retrieval through USB connection. An additional piece of software called AQUAview is used to visualise and analyse the data (Figure 1.9). The settings the software uses to classify clicks are stored in a .ini file. The data can be compiled into a report within the software to determine the amount of propose activity over the duration.



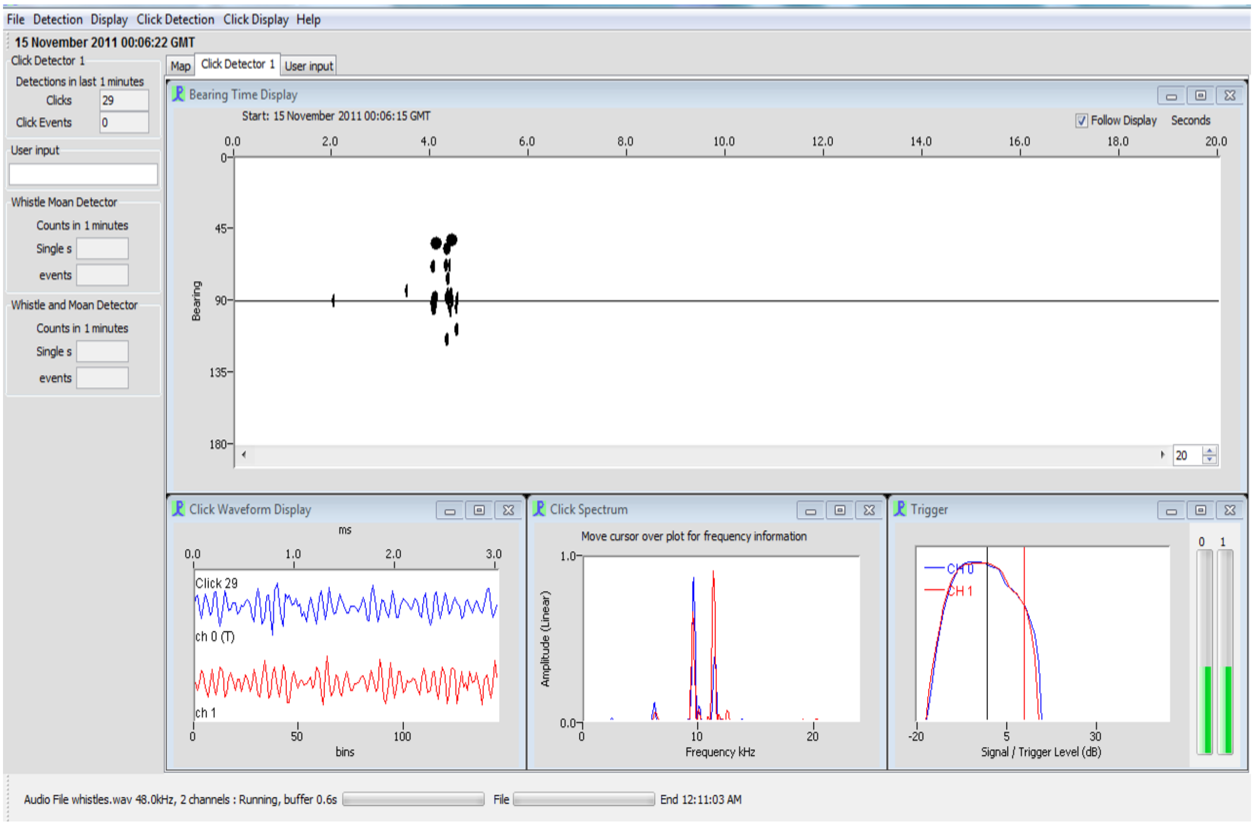
974-1 Session 1
Session Start Time = 21:25:16:000000 14/05/2006
Session End Time = 21:25:49:065506 14/05/2006
Session Length 0:0:33 (H:M:S)
Number Of Clicks Recorded = 57

Total clicks in window = 19
Total porpoise clicks = 0

Figure 1.9: Screen grab of AQUAview.exe software ©AQUATEC Group

1.3.4. *PAMGUARD (www.pamguard.org)*

PAMGUARD is currently funded by the OGP E&P Sound and Marine Life Joint Industry Programme, and has been established to address the fundamental limitations of existing cetacean passive acoustic monitoring (PAM) software capabilities. PAMGUARD seeks to provide open-source PAM software based on a platform-independent (e.g. Windows or Linux), flexible, modular architecture. The open-source aspect of software development is facilitated through the project's presence on SourceForge, where a community of altruistic developers provide extra resources. This community currently includes developers with proven PAM experience from both the UK and the USA. Open development means that the software is free and access to the code is easy and assured. It also allows the code's copyright to be protected in perpetuity so that it cannot readily be closed and commercialised to the detriment of its users. It ultimately means that more people have access for development. This generally speeds up innovations and improves the performance and maintainability of the code (Figure 1.10).



15 November 2011 00:06:22 GMT

Detections in last 1 minutes

Clicks 29

Click Events 0

Counts in 1 minutes

Start: 15 November 2011 00:06:15 GMT

☑ Follow Display

Click 29

ch 0 (T)

ch 1

Audio File whistles.wav 48.0kHz, 2 channels : Running, buffer 0.6s

End 12:11:03 AM

Figure 1.10: Screen grab of PAMGUARD showing cetacean click detections

PAM data can be post processed back in the lab. Data analyses should include the visual inspection of all sound files on spectrograms, using IFAW's whistle detector and porpoise detector or Adobe Audition (latest version CS5.5), (e.g. Figure 1.11, clicks and whistles). All characteristics associated with detections, including inter-click interval of click trains, as well as frequency, shape and outline of whistles can be taken into account when identifying detections to species level. The track of all acoustic monitoring effort can be mapped, with acoustic detections classed as "sightings", and these can be overlain on a track similar to that from visual surveys.

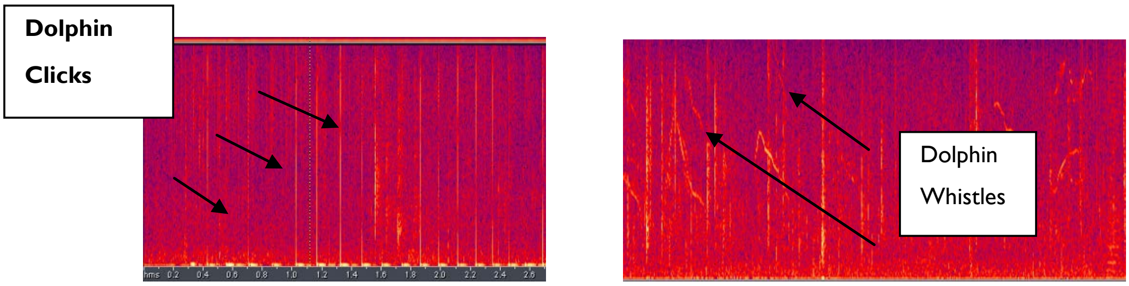
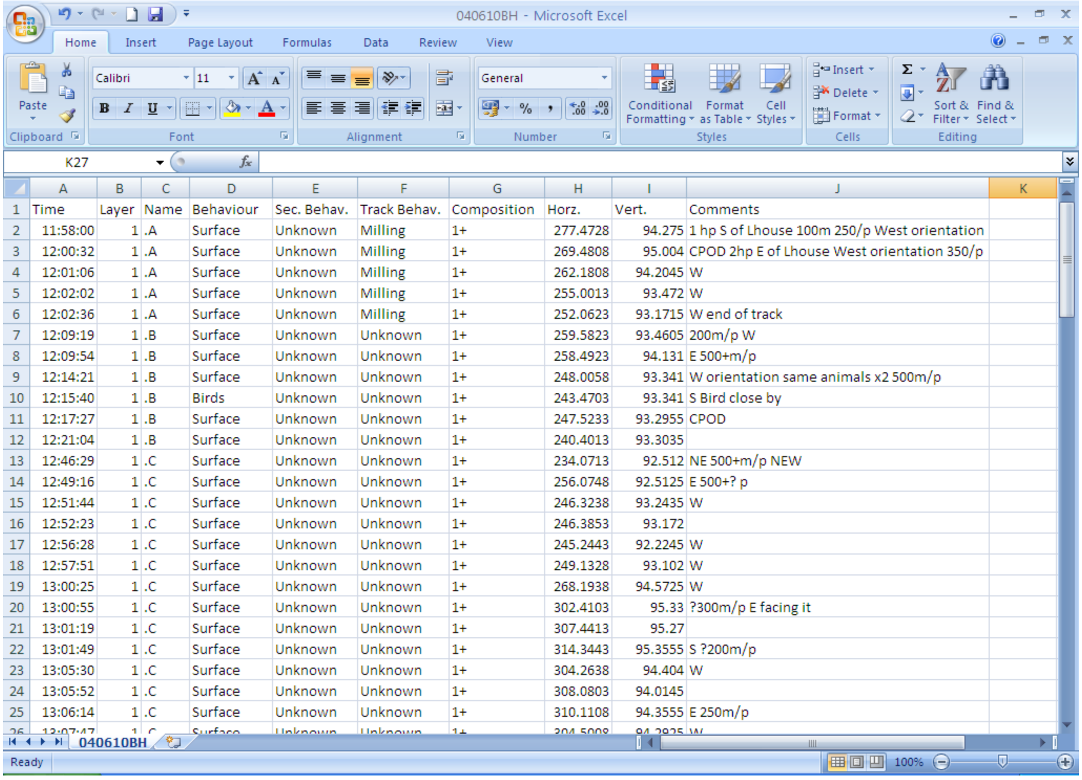


Figure 1.11 Screen grab of spectrogram showing clicks and whistles in Adobe Audition

1.3.5. *Cyclops Tracker*

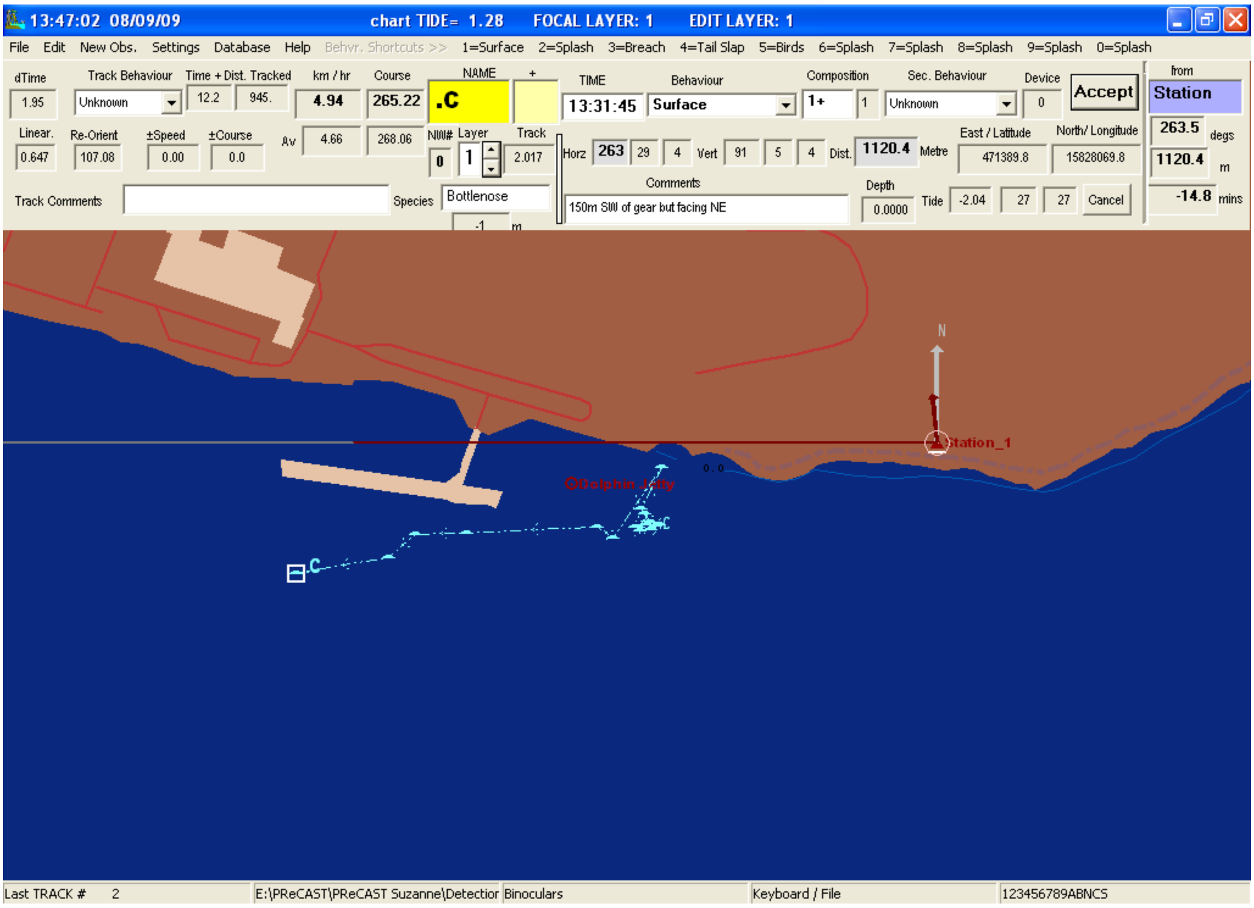
Cyclops tracker (freely available from http://civilweb.newcastle.edu.au/cyclops/) is a marine mammal positioning system designed to accurately record and locate marine mammals from a known location. It was designed by Dr Eric Kniest from the University of Newcastle, New South Wales. This software has as simple graphical user interface (GUI) designed to run on a Windows operating system. It has been specifically designed for efficient use in the field, accepting data directly from electronic theodolites, compass binoculars, electronic compass, GPS and digital cameras. Data can be manually entered using the keyboard and can also be entered as a .csv file (Figure 1.12). Cyclops tracker requires the horizontal and vertical angles for theodolite tracking. The horizontal angle indicates the direction of the observed animal in relation to magnetic north, while the vertical angle is used to calculate the distance from a known location. The system can be used from a land station, vessel or aircraft. The instrument station must have a high observation point overlooking the ocean. Accurate measurements of station height and location are required prior to data entry. The instrument station needs to be coordinated and the direction to a suitable reference object may need to be determined. Corrections for earth curvature, refraction and tides are applied. Additional tidal information can be input to Cyclops tracker to increase accuracy and precision.



Time	Layer	Name	Behaviour	Sec. Behav.	Track Behav.	Composition	Horz.	Vert.	Comments
11:58:00	1	.A	Surface	Unknown	Milling	1+	277.4728	94.275	1 hp S of Lhouse 100m 250/p West orientation
12:00:32	1	.A	Surface	Unknown	Milling	1+	269.4808	95.004	CPOD 2hp E of Lhouse West orientation 350/p
12:01:06	1	.A	Surface	Unknown	Milling	1+	262.1808	94.2045	W
12:02:02	1	.A	Surface	Unknown	Milling	1+	255.0013	93.472	W
12:02:36	1	.A	Surface	Unknown	Milling	1+	252.0623	93.1715	W end of track
12:09:19	1	.B	Surface	Unknown	Unknown	1+	259.5823	93.4605	200m/p W
12:09:54	1	.B	Surface	Unknown	Unknown	1+	258.4923	94.131	E 500+m/p
12:14:21	1	.B	Surface	Unknown	Unknown	1+	248.0058	93.341	W orientation same animals x2 500m/p
12:15:40	1	.B	Birds	Unknown	Unknown	1+	243.4703	93.341	S Bird close by
12:17:27	1	.B	Surface	Unknown	Unknown	1+	247.5233	93.2955	CPOD
12:21:04	1	.B	Surface	Unknown	Unknown	1+	240.4013	93.3035	
12:46:29	1	.C	Surface	Unknown	Unknown	1+	234.0713	92.512	NE 500+m/p NEW
12:49:16	1	.C	Surface	Unknown	Unknown	1+	256.0748	92.5125	E 500+? p
12:51:44	1	.C	Surface	Unknown	Unknown	1+	246.3238	93.2435	W
12:52:23	1	.C	Surface	Unknown	Unknown	1+	246.3853	93.172	
12:56:28	1	.C	Surface	Unknown	Unknown	1+	245.2443	92.2245	W
12:57:51	1	.C	Surface	Unknown	Unknown	1+	249.1328	93.102	W
13:00:25	1	.C	Surface	Unknown	Unknown	1+	268.1938	94.5725	W
13:00:55	1	.C	Surface	Unknown	Unknown	1+	302.4103	95.33	?300m/p E facing it
13:01:19	1	.C	Surface	Unknown	Unknown	1+	307.4413	95.27	
13:01:49	1	.C	Surface	Unknown	Unknown	1+	314.3443	95.3555	S ?200m/p
13:05:30	1	.C	Surface	Unknown	Unknown	1+	304.2638	94.404	W
13:05:52	1	.C	Surface	Unknown	Unknown	1+	308.0803	94.0145	
13:06:14	1	.C	Surface	Unknown	Unknown	1+	310.1108	94.3555	E 250m/p

Figure 1.12 Example Excel.csv file formatted for input into Cyclops Tracker

Data is processed in real time and the cetacean's position is calculated and plotted on the screen. The pod's (e.g. porpoise or dolphin group) identification label is automatically determined, with different pods shown in different colours. Track lines are fitted between cetacean group location fixes (Figure 1.13). Predictions of a group can be made at any time to help locate its next position. The predicted location is displayed on the screen as well as the likely horizontal and vertical angles to the group for that time. The position of the coastline is displayed, with the instrument's location highlighted. Additional instruments such as SAM devices can also be displayed. An observation can then be highlighted to show the point's identification, time of observation, bearing and distance from any instrument. Observation information can be edited at any time and additional information such as visibility and swell can be inputted.



13:47:02 08/09/09 chart TIDE= 1.28 FOCAL LAYER: 1 EDIT LAYER: 1

dTime 1.95
Track Behaviour Unknown
Time + Dist. Tracked 12.2 945.
km / hr 4.94
Course 265.22
NAME .C
TIME 13:31:45
Behaviour Surface
Composition 1+ 1
Sec. Behaviour Unknown
Device 0
from Station
Linear. 0.647
Re-Orient 107.08
±Speed 0.00
±Course 0.0
Av 4.66 268.06
NW# 0
Layer 1
Track 2.017
Horz 263 29 4
Vert 91 5 4
Dist. 1120.4 Metre
East / Latitude 471389.8
North/ Longitude 15828069.8
263.5 degs
1120.4 m
-14.8 mins
Track Comments
Species Bottlenose
-1 m
Comments 150m SW of gear but facing NE
Depth 0.0000
Tide -2.04 27 27

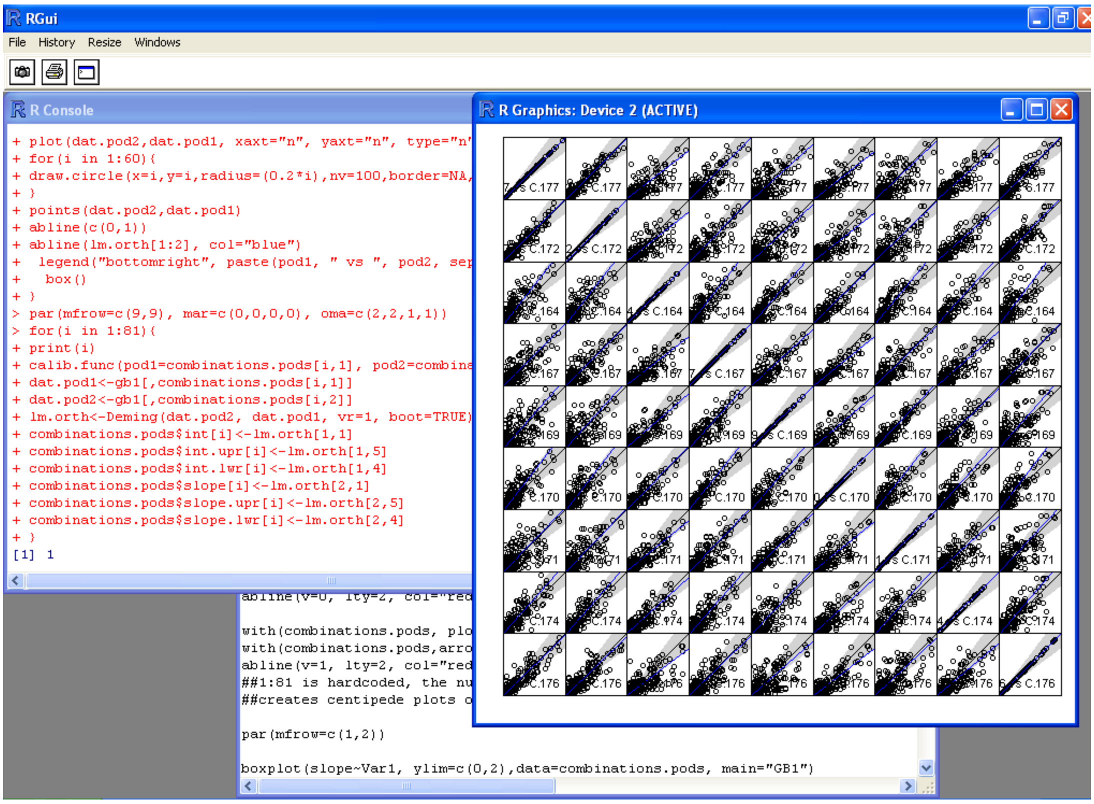
Last TRACK # 2
E:\PReCAST\PReCAST Suzanne\Detection
Binoculars
Keyboard / File
123456789ABNCS

Figure 1.13: Screen grab of Cyclops Tracker PReCAST project in the Shannon estuary cSAC

A complete re-write of Cyclops tracker was conducted and VADAR (Visual Detection and Ranging at sea) was released in late 2011 (http://cyclops-tracker.com/). VADAR has a completely different data file structure to those of previous versions of Cyclops tracker. Raw data and calculated positions can be exported in a text format for input into a Geographic Information System (GIS). The ability to use Cyclops tracker and VADAR in the field has several benefits. Downloading observations directly into a computer speeds up the data input process and reduces data logging errors. Having a group's position calculated in real time helps to check for any observational errors at the beginning of the data collection stage. Displaying group positions also helps keep track of current positions, direction and speed for more successful tracking.

1.3.6. *Statistical Package – R*

R is a language and environment for statistical computing and graphics. It is free software, available at http://www.r-project.org/index.html. The software compiles and runs on a wide range of UNIX platforms, Windows and MacOS. R provides a wide variety of linear and nonlinear modelling, classical statistical tests, time-series analysis, classification, clustering and graphical techniques (R Development Core Team, 2011). R is designed around a true computer language, similar to the S language (see Appendix for full R scripts used). The effective programming language includes conditionals, loops, user-defined recursive functions and input and output facilities (Figure 1.14).



```
+ plot(dat.pod2,dat.pod1, xaxt="n", yaxt="n", type="n'
+ for(i in 1:60){
+ draw.circle(x=i,y=i,radius=(0.2*i),nv=100,border=NA,
+ }
+ points(dat.pod2,dat.pod1)
+ abline(c(0,1))
+ abline(lm.orth[1:2], col="blue")
+  legend("bottomright", paste(pod1, " vs ", pod2, sep
+   box()
+ }
> par(mfrow=c(9,9), mar=c(0,0,0,0), oma=c(2,2,1,1))
> for(i in 1:81){
+ print(i)
+ calib.func(pod1=combinations.pods[i,1], pod2=combina
+ dat.pod1<-gb1[,combinations.pods[i,1]]
+ dat.pod2<-gb1[,combinations.pods[i,2]]
+ lm.orth<-Deming(dat.pod2, dat.pod1, vr=1, boot=TRUE)
+ combinations.pods$int[i]<-lm.orth[1,1]
+ combinations.pods$int.upr[i]<-lm.orth[1,5]
+ combinations.pods$int.lwr[i]<-lm.orth[1,4]
+ combinations.pods$slope[i]<-lm.orth[2,1]
+ combinations.pods$slope.upr[i]<-lm.orth[2,5]
+ combinations.pods$slope.lwr[i]<-lm.orth[2,4]
+ }
[1] 1
```

```
abline(v=0, lty=2, col="red

with(combinations.pods, plo
with(combinations.pods,arro
abline(v=1, lty=2, col="red
##1:81 is hardcoded, the nu
##creates centipede plots o

par(mfrow=c(1,2))

boxplot(slope~Var1, ylim=c(0,2),data=combinations.pods, main="GB1")
```

Figure 1.14 Screen grab of R GUI

R can be extended via *packages*. Packages are available through the CRAN family of Internet sites. This project employed the use of the following packages for specialist statistical analysis and graphical representation:

gtools 2.6.2

This package includes various R programming tools. The function '*combinations*' was used during calibration analysis. The function enumerates the possible combinations of a specified size from the elements of a vector, required to generate all the possible C-POD pairs for comparison on inter unit variability.

MethComp 1.3

MethComp is a package designed for functions for analysis of method comparison studies. This package includes the function '*Deming*', a form of regression of y on x, and assumes that both x and y are measured with error. The function was used to conduct the orthogonal regression comparing C-POD pairs during calibration analysis.

plotrix 3.2-3

The plotrix package contains various plot, labelling, axis and colour-scaling functions for graphical representation. The function '*draw.circle*' draws a circle or multiple circles on an existing plot. This was used to create the 20% error margin along the orthogonal regression comparing C-POD pairs during calibration analysis.

lme4 0.999375-41

lme4 is designed to fit linear and generalised linear mixed-effect models. Analysis on the long-term SAM dataset included a generalised linear mixed-effect model which required POD.ID to be entered as a random variable. The function '*glmer*' was employed to run these models.

aod 1.2

The aod package provides a set of functions to analyse over dispersed counts or proportions. The functions should be considered as complements to more sophisticated methods, such as generalized estimating equations (GEE) or generalized linear mixed effect models (GLMM). The function '*predict*' was used to obtain predicted proportions of detection-positive hours/minutes for the long-term SAM GLMM and the species and habitat assessment GLMM. The function '*wald.test*' was used to obtain chi-squared wald statistics for each of the variables within the GLMM models.

HH 2.1-30

HH is a package for statistical analysis and graphical display. This project used the '*antilogit*' function to back-transform predicted proportions of detection positive hours/minutes in the long-term SAM GLMM and the species and habitat assessment GLMM for graphical display.

2. EVALUATION OF SAM DEVICES USED

Inshore Static Acoustic Monitoring (SAM) was carried out over the duration of the project using three acoustic devices, C-PODs, T-PODs and AQUAclicks. PODs are produced and manufactured by Chelonia Ltd, and AQUAclicks are produced and manufactured by Aquatec in the UK. Both companies commercially supplied these loggers as well as software and support. All three devices were deployed over the duration, and performances were evaluated according to ease of physical handling of equipment, deployment, retrieval and downloading of data on retrieval. Additionally, mooring type and construction were evaluated according to longevity, cost and ease of use.

2.1. Handling

The use of SAM devices encompasses a range of issues such as physical handling of equipment, deployment, retrieval, downloading, mooring type and construction, and of these, deployment method can be the most problematic. Over the duration of the project, more C-POD units were available than any other unit type. T-PODs are no longer manufactured and therefore were used during the present project in order to assess transition between the two devices. AQUAclicks are only commercially available since 2006, and since they are the only other SAM device on the market, it was necessary to assess their performance. However, the AQUAclick units used over the duration were only equipped with re-chargeable batteries, which lead to a short deployment life in comparison with PODs. An upgrade is now available for AQUAclick units in order to extend battery life and to increase the sensitivity to allow for detection of dolphin clicks. Devices were not upgraded over the duration of the project due to the financial cost of this latest development.

A number of deployment methods were undertaken over the course of this project, including the utilisation of navigation marker buoys, jetties, acoustic releases and construction of both light weight (40kg) and heavy weight independent moorings (1,000kg). A number of problems were encountered over the duration of the project, resulting in equipment loss or malfunction, including interference, acoustic release malfunction, mooring malfunction and adverse weather conditions. As the cost of mooring construction is often critical to a project, it is advised to budget for such and a suitable means chosen to fit the project.

As recommended by Chelonia Ltd, preliminary tests should be carried out at deployment locations in order to assess, for example, the level of background noise at a site as this can have a profound impact on battery and memory consumption. In this study, the maximum working duration recorded for a C-POD was 159 days (Table 2.1 and 2.2), 14 days for an AQUAclick and 93 days for a T-POD. Each deployment duration varied due to a number of factors such as weather, ease of access to site and a boat, and availability of people to retrieve the devices. Deployment duration of C-PODs can also be influenced by the capacity of the SD card, but this was not found to be an issue at any of the sites monitored, while neither was the memory capacity of the T-POD. The manufacturers recommend avoiding long deployments where possible in order to avoid data loss of large timescales.

C-PODs have a depth limit of 100m but a deep-water version is available and has been used in the offshore environment (Chelonia Ltd), with a depth limit of 2,000+m. A Deep C-POD was deployed in this study at a depth of 500m. A C-POD containing ten alkaline cells has a positive buoyancy of approximately 0.7 kg. It was aimed to deploy all equipment at mid water, as both dolphins and porpoises were the target species, but also to avoid excess noise detection from surface or bottom biological and environmental processes.

Table 2.1: Deployment details from the Shannon Estuary, average file size per day/deployment

Shannon Estuary			
Deployment number	**No. of days**	**File size (cp.1) (Mb)**	**File size (cp.3) (Mb)**
1	41	40.9	4.2
2	31	47	4.7
3	30	62.4	4.38
4	79	127	7.29
5	80	171	8.3
7	30	43.8	3.0
8	91	312.8	19.8
9	76	68.5	11.4
10	26	84.0	8.6
11	159	137	32.5
	643 (total)	109.44 (mean)	10.4 (mean)

Table 2.2: Deployment details from Spiddal in Galway Bay, average file size per day/deployment (Mean file size is equal to the total file size divided by the number of deployment days).

Spiddal, Galway Bay			
Deployment number	**No. of days**	**File size (cp.1) (Mb)**	**File size (cp.3) (Mb)**
1	115	111	20.9
2	80	149	22
3	131	118	62
4	125	93	25
5	153	84	31
	604 (Total)	0.92 (mean per day)	0.2 (mean per day)

All C-PODs have an address (www.phonehome.org) embossed on the cap of the screw-top lid (Figure 2.1). This has proved to be most successful in locating lost units. Additionally, contact information was written onto units with indelible marker, with the name and phone number provided to further ensure the safe return of lost or dislodged equipment.

Figure 2.1: Address embossed on the lid of a C-POD

C-PODs have a number of advantages over their predecessor, the T-POD, including:

- A large reduction in the false positive rate, i.e. detecting clicks that were not of cetacean origin
- C-POD can log the broadband clicks of dolphins without flooding the POD memory
- C-POD can log odontocete clicks continuously at a frequency range of 20-160 kHz
- A removable Secure Digital (SD) memory card allows large volumes of data to be collected and eliminates the need for connection with a PC in order to set and download units after deployment. This makes handling and downloading easier and safer.

2.2. Battery Duration

Due to their low power requirements, C-PODs can run for between four to five months on eight to ten alkaline D-cells batteries (depending on version 0 or 1 units). The longest deployment recorded during the project was 159 days. The battery brand "Duracell" was used during all deployments. T-PODs have a shorter running time, on average three months, while AQUAclicks only last 14 days and, therefore, have a very poor data return in comparison with PODs.

2.3. Deployment Methods

Five mooring types have used during the study: i) light weight moorings (LWM), ii) heavy weight moorings (HWM), iii) bottom-mounted acoustic release (AR) arrays, and iv) existing structures such as jetties (ES-J), a wave platform device (ES-WP) and navigational buoys (ES-NB).

2.3.1. *Light weight moorings*

Light weight moorings were constructed using polypropylene rope and mooring blocks weighting 20kg each. A maximum of 60kg was used per mooring depending on the site. A single line ran from the mooring blocks to two surface buoys. A single loop was made on the main line three quarters of the way down and all monitoring units were shackled into that loop (Figure 2.2). The loop was lined with a metal thimble to prevent abrasions and wearing of the rope. A second safety line was threaded through the lid of the C-POD and also shackled onto the main line. The main aim of this was to serve as a safety line for the C-POD unit. This light weight mooring worked successfully at all sites but on occasion, in rough weather conditions, the surface buoys did come loose and a diver was required to retrieve the main line and the units from the bottom. The main problem with this method has been disturbance and interference, even though deployment location was outside trawling lines. This method served its purpose successfully and with regular maintenance and replacement of weakened lines, should last year round in sheltered inshore environments, where fishing intensity is low or non-existent.

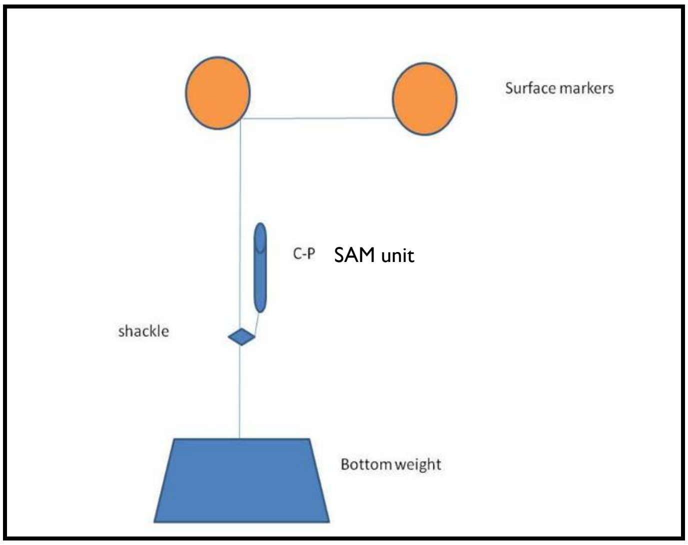


Figure 2.2: Light weight moorings as erected in Galway Bay

2.3.2. *Heavy weight moorings*

Heavy weight moorings were established at two locations in the Blasket Islands cSAC. Mooring type was intensified at this location due to fishing activity and the exposure of the site, which is susceptible to strong gales and heavy seas. Moorings consisted of one tonne of clumped chain acting as a mooring block (Figure 2.3). An additional 20m of chain lead off from this mooring block onto at least 20m of 30mm polypropylene rope, depending on depth. Surface moorings buoys were specified to requirements by the Commissioner of Irish Lights under statutory sanction. Surface markers were 1.2m in focal height with a 2nm light (Figure 2.4). These moorings were deployed in February, and equipment was due to be serviced in May. But when attempted, the pulley system design had snagged. Divers were brought on site to retrieve gear, but all equipment was missing from both moorings. A single empty shackle was left on each mooring at the point where equipment was attached but other smaller shackles were missing. The sum total of equipment missing from mooring was valued in excess of €10,000. All equipment was insured and a successful claim was filed on this occasion.

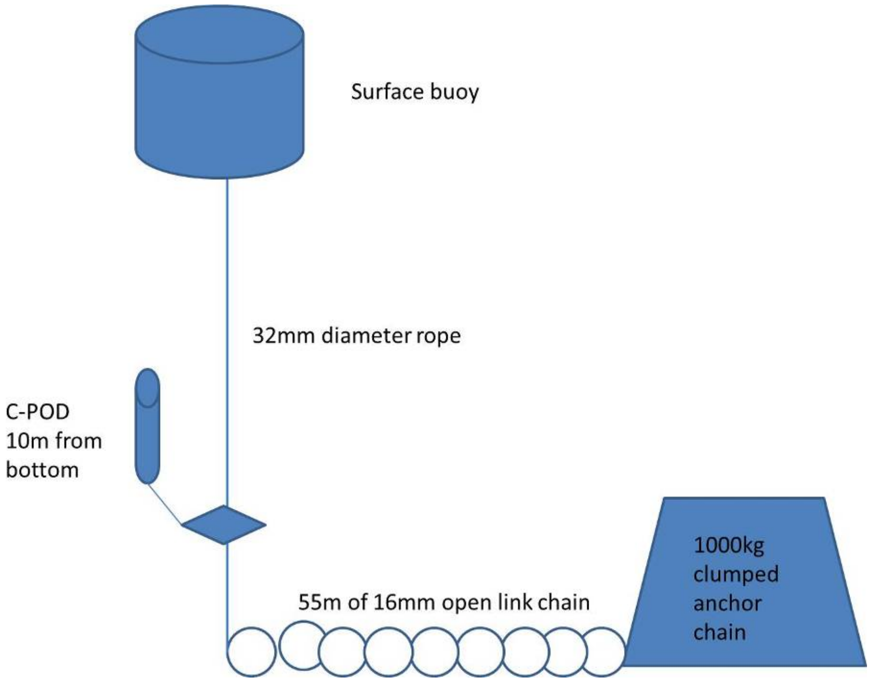


Figure 2.3: Heavy duty mooring erected in the Blasket Island cSAC

Figure 2.4: Heavy duty mooring erected in the Blasket Island cSAC

2.3.3. *Bottom Mounted Acoustic Release Arrays (AR arrays)*

After the failed attempt of the heavy weight mooring in the Blaskets, an alternative method was trialled. This consisted of a bottom-mounted Acoustic Release array. Therefore, it lacked surface markers. This served to reduce drag on the array and not highlight the array's position (Figure 2.5 and 2.6). C-PODs were shackled to an AR device and the release was, in turn, shackled to a sacrificial mooring block (40kg). A number of benthos buoys (pressure tested at depth) were used to give buoyancy and take the array to the surface once the acoustic release was triggered. A command box was used to send signals to the release upon retrieval and units were on the surface within 20 seconds. On one occasion the AR came loose and floated away from the deployment site into Galway Bay. A member of the public walking on a local beach found and reported the equipment as contact details were clearly visible along the side of the unit. Both the release and C-POD were still attached and data was successfully retrieved from the POD. It was most likely that the equipment came loose in heavy sea conditions, rather than due to interference. The success of this method depends on the type of release unit used and battery life. Where battery life is short, pressure is imposed to service gear more regularly, which can be a problem during winter months, especially at exposed sites. If gear is not retrieved on time, it can result in loss of equipment. Two types of release systems have been used over the project's duration. These included an AR transponder model from Marine Electronics Ltd, based in Guernsey in the Channel Islands, and an LRT 7896 release model with roped canister from Sonardyne in the UK.

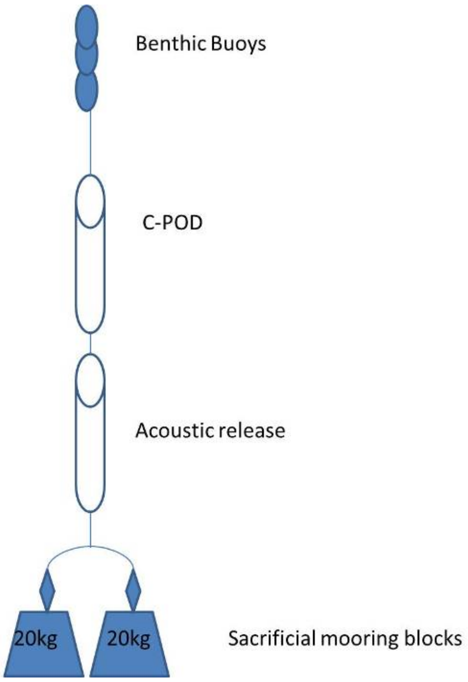


Figure 2.5: Acoustic release equipment as supplied by Sonardyne

Figure 2.6: Acoustic release equipment as supplied by Sonardyne©

2.3.4. *Existing structures, e.g. jetties, wave platform and navigational buoys*

The use of a wave platform as a deployment structure proved most successful as well as the use of more permanent structures such as jetties (Figure 2.7). Deployment from these structures was simple, requiring just a robust rope or a single metal line. Equipment was hung freely from these structures, with a 20kg weight used to anchor the line. Permission was granted from the Marine Institute to deploy PODs from the Mid-Bay buoy as part of the Smartbay system. This provided another method of deployment but was the least successful, as these buoys are smaller and subject to spinning in running tides and heavy seas. The mooring method consisted of a chain hanging from the side of the buoy where the POD and salmon floats served as buoyancy to pull away from the main line (Figure 2.8).

Figure 2.7: Existing structures used as moorings during long-term SAM deployments

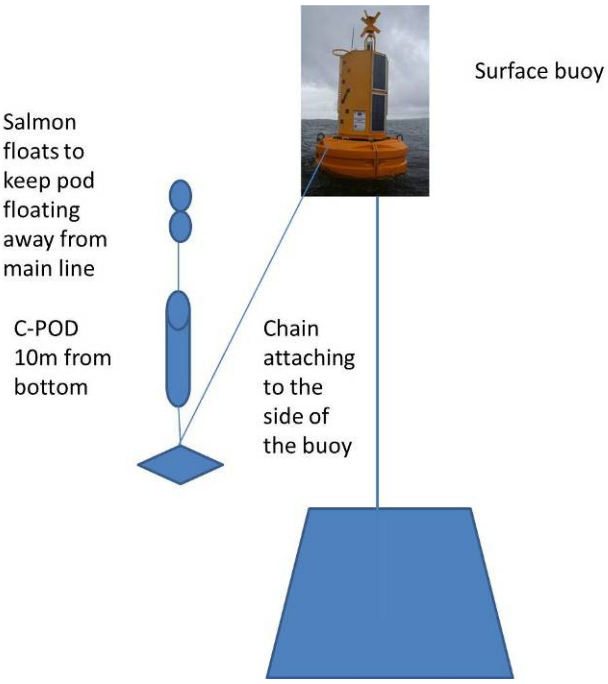


Figure 2.8: Mooring design used for deployment of units from the Smart Bay Buoy network

2.3.5. *An assessment of potential effect of mooring type on cetacean detections*

As harbour porpoises were detected frequently at the wave energy platform off Spiddal, it afforded an opportunity to test the potential effect of mooring type on the presence of cetaceans. SAM was carried out on a continuous basis at the wave platform, so it was decided to assess if there was a difference in detection at two additional sites, 1,000m east of the device and 500m west of the device. Light weight moorings were established at each of these additional sites and a single C-POD was deployed. The presence of the wave platform, which is of substantial size (28 tonne), may have a positive or negative effect on the occurrence of harbour porpoises in the area:

- The presence of such a structure may deter animals. They may not be able to sufficiently forage for food as the structure may impact on their echolocation ability. This event is highly unlikely at Spiddal given the high percentage of days with detections.

- Or the platform itself may act as a cover for many fish species and, therefore, attract fish to the area and, in turn, feeding porpoises. International studies have found that wave buoys can serve as artificial reefs and attract fish and other marine life. In fact, in some parts of the world, conventional buoys are deployed to serve as "Fish Attracting Devices" (FADs) (Nelson, 2003).

Results from this short deployment failed to show a significant difference in detections between sites (P=0.001), suggesting the structure does not influence harbour porpoise presence (Figure 2.9). The effect of depth was not determined as units were deployed at mid-water across sites.

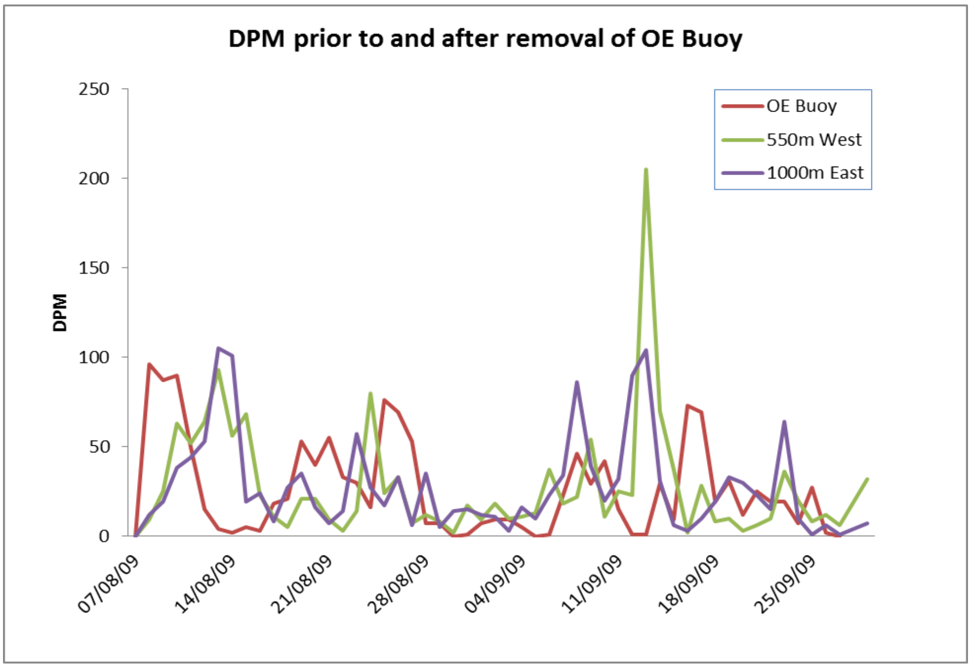


Figure 2.9: Results from C-POD deployments from LWMs and ES-WP

2.4. Retrieval of SAM devices

Mooring type chosen will influence the mode of retrieval for SAM equipment. Where AR systems, existing structures and light weight mooring are used, a rigid inflatable boat (RIB) can be used to retrieve equipment easily and successfully. However, where a heavy duty system is used, it might be envisaged that a RIB can be used for intermittent retrievals but the entire mooring will have to be lifted at least once a year to remove fouling and to ensure no aspect of the system is damaged. The heavy duty mooring in the Blasket Islands was originally designed with a pulley system for ease of retrieval. However, after a period of heavy weather conditions, the system failed due to entanglement of the main line and, therefore, required the assistance of a diver. The most successful mooring types used during the present project were existing structures and, in their absence, the use of AR systems.

2.5. Downloading of SAM devices

Where servicing of equipment had to take place at sea, C-PODs proved to be most successful as only an SD card and battery re-fit had to take place. With T-PODs, a PC was required, which added to the time spent in the field. In addition, communication problems (between T-POD and PC) were occasionally encountered (comms port) when trying to download the data. Servicing is restricted by weather conditions, especially if doing so from a RIB as the internal components of the units are exposed when changing batteries or SD cards, or connecting to a PC. This problem does not arise if the servicing is done from a larger vessel with a sheltered deck. Where servicing involves the exchange of already set units, the time in the field was greatly reduced and vessel type was not an issue.

2.6. Inventory of Units

If multiple units are involved in a monitoring programme, it is good practice to keep an accurate record of their deployment history. This should include information on location, deployment duration, depth, accompanying units if deployed, average file size from deployment. It is also necessary to keep good records from field calibrations. Such records will serve to highlight problematic units but will also be required as a factor to take into account when statistically analysing data at the end of a project.

3. CALIBRATION OF STATIC ACOUSTIC MONITORING DEVICES

3.1. Introduction

Variation in sensitivity between units is known to exist and can have significant effects on a dataset, especially if the variation is large. Therefore the calibration of units is recommended prior to their employment in long-term monitoring programmes, both in the field and in a controlled environment (Kyhn *et al,* 2008; Dähne *et al,* 2006; Berrow *et al*, 2009a). The manufacturers of the C-POD, Chelonia Ltd, calibrate all units to a standard prior to dispatch and, therefore, do not endorse the need for further tank tests when using units to collect presence-absence data (Tregenza *pers comms.*). However, they do recommend field trials to assess the performance of the units prior to their deployment in monitoring programmes. Failures or inconsistencies in C-POD detection is mainly due to transducer failure or faults on the circuit board. Small shifts in performance are much less likely for C-PODs than T-PODs (Tregenza *pers comms*). Incidents such as ship strikes have failed to destroy the transducers of C-POD, highlighting the robustness of these devices. International researchers are commercially operating tank calibrations testing of equipment and make recommendations in the literature for the absolute necessity to carry out such tests (e.g. MEER Germany). However, this method is not feasible for all research groups and, furthermore, is only required if using the data for density estimates. The purpose of tank calibration is to derive a precise detection function for each individual unit by calculating absolute threshold levels (Dähne *et al,* 2006). This is required when attempting to estimate density using SAM data, but also in areas where detection rates are low. In Ireland, the detection rate at study sites is relatively high, with animals being detected on a daily basis, and we do not attempt to estimate density from SAM data.

We carried out a number of field calibration trials over the project duration in order to assess differences in POD sensitivity prior to their deployment in a long-term monitoring programme. This was done to ensure that all units were performing similarly and, therefore, allow for comparison of data from different sites. In all, a total of nine trials were completed using a total of 27 C-POD units. Trials were carried out in Galway Bay and the Shannon Estuary, where densities of harbour porpoises and bottlenose dolphins are known to be high. Some units were purchased as part of the present project and some were auxiliary to this, but all results are presented as they are relevant to the end result and the process of generating a protocol of best practice for SAM. Additionally, an inventory of each unit's history was constantly recorded and updated over the project duration.

3.2. Materials and Methods

3.2.1. *Controlled calibration*

Controlled field calibrations were carried out under licence from the NPWS, with two C-POD units being deployed from Moneypoint jetty (C-950, C-169) in the Shannon Estuary, Co Clare. A synthetic clicker, Teledyne Benthos APL-365 model, was used. SAM equipment to be tested was deployed from a jetty off Moneypoint when no dolphins were recorded visually in the vicinity. It was necessary that these trials were carried out in the absence of dolphins so their echolocation clicks did not interfere with the detection of the synthetic clicker. A RIB equipped with GPS and VHF radio was used to deploy the clicker at varying distances from the jetty to a depth of 2m below the surface. The boat engine was switched off when the clicker was deployed. Time between the GPS and SAM equipment was synchronised and, therefore, accurate comparisons could be made between the distances from the equipment and matched detections when SAM equipment was retrieved. The clicker device had an acoustic output of 162dB re μPa @ 1m and was set to pulse at twice per second at 40 kHz. This was the highest repetition rate the device could be set to and, hence, limited the amount of data analyses when analysing POD results. Only C-POD CP.1 files could be analysed as click train characteristics extracted during train processing and the generation of a CP.3 file by C-POD.exe would result in the loss of data. These trials proved inconclusive due to background noise and the difficulty in finding the slow repetition clicks in the clutter. These trials would prove useful in the field as source level is known but a clicker with a faster click repetition is required and should be carried out in a quiet location.

Figure 3.1: Teledyne Benthos clicker APL-365 model used during controlled field trials ©Teledyne Benthos

3.2.2. *Field calibration*

Two sites were used to carry out the field calibration of C-PODs, the Wave Energy Test Site off Spiddal, Co Galway, and Moneypoint jetty in the Shannon Estuary, Co Clare. The need to establish a mooring system at both sites was avoided as existing structures were used. In Galway Bay, permission was sought and granted from Ocean Energy (a Cork based company) who own and operate the wave energy device, The Seilean, located to the east of Spiddal. This wave energy prototype offered a large platform from which to hang units. Depth at the site was approximately 22m. Hence, a length of 20mm diameter wire with an eye spliced at either end, was used to deploy gear at mid-water. The top end of the wire was shackled to a bracket on the side of the wave platform while the bottom end was attached to a 20kg weight, and the units were shackled securely. Additional buoyancy was applied to the units in the form of salmon floats to ensure they stayed upright in strong currents.

In the Shannon Estuary, a fixed mooring point was established from a small causeway between a main jetty and small landing point at Moneypoint Power Station. This causeway is located approximately 8m above MHWL. A primary roped line, secured in place by two secondary bridle lines, was used to deploy units to a depth of 15m (mid-water). The line was kept at depth through the use of a chain and a weight on the main line. The mooring design was intended to facilitate ease of retrieval from land or by boat. Again, a number of salmon floats were attached to the PODs to ensure they remained in an upright position as currents are quite strong at this site (e.g. 7 knots in mid ebb tide). A small number of T-POD and AQUAclick units were also tested to compare the three types of SAM devices. T-PODs were configured to detect clicks from dolphins and porpoises on alternate channels, 1-6, while C-PODs were set to log tonal clicks within bands of frequencies ranging between 20 and 160 kHz. Dolphin acoustic detections registered on T-PODs consist of clicks within the 50 to 70 kHz channels, and for porpoises, between 92 and 130 kHz channels, following the manufacturer's guidelines. C-PODs will register click trains into two categories of cetaceans: 1) NBHF (Narrow Band High Frequency) and 2) Other (dolphin species, which include all other odontocetes except sperm whales). C-PODs and T-PODs cannot distinguish between dolphin species but as the trials were carried out within the Shannon Estuary, no other dolphin species were recorded. Only acoustic detections under the class "Cet All", which included both high and moderate probability cetacean detections, were used in the analysis.

A summary table of all calibration trials is presented below (Table 5.0). Some units were calibrated more often than others and this was due to some units already being in the field when trials were carried out and only available units could be incorporated into trials. The most detailed trials were carried out at the start and end of the study (November 2008 and March 2011). The end of study calibration trial was composed of a number of sub-trials because of the large number of units (16 units).

Table 3.1: Information on individual calibration trials conducted throughout the PReCAST project

Calibration Trials							
Trial	Sub-trial	Study Site	Start date	End date	**Duration (Days)**	Depth	PODs tested
GB_Cal_001	1	Spiddal	04/11/2008	18/11/2008	14	15m	C-164, C-167, C-169, C-170, C-171, C-172, C-174, C-176, C-177, T-651
GB_Cal_002	2	Spiddal	19/05/2009	19/06/2009	30	15m	C-169, C-173, T-651
MP_Cal_003	3	Moneypoint	22/06/2009	16/07/2009	24	12m	C-164, C-167, C-546, C-547, C-548, C-549
MP_Cal_004	4	Moneypoint	02/10/2009	14/10/2009	12	12m	C-173, C-547, C-549
MP_Cal_005	5	Moneypoint	14/10/2009	04/12/2009	51	12m	C-173, C-794, C-795
MP_Cal_006	6	Moneypoint	11/03/2010	07/04/2010	27	12m	C-172, C-384, C-953
MP_Cal_006	7	Moneypoint	11/03/2010	07/04/2010	28	12m	C-949, C-951, C-952
MP_Cal_006	8	Moneypoint	11/03/2010	07/04/2010	27	12m	C-947, C-950
MP_Cal_007	9	Moneypoint	23/07/2010	19/08/2010	27	12m	C-171, C-1095, C-1147
MP_Cal_008	10	Moneypoint	08/03/2011	31/03/2011	23	12m	C-173, C-547, C-548, C-1147
MP_Cal_008	11	Moneypoint	08/03/2011	31/03/2011	23	12m	C-171, C-795, C-950, C-952
MP_Cal_008	12	Moneypoint	08/03/2011	31/03/2011	23	12m	C-796, C-487, C-1524, C-1525
MP_Cal_008	13	Moneypoint	08/03/2011	31/03/2011	23	12m	C-947, C-951
MP_Cal_008	14	Moneypoint	08/03/2011	31/03/2011	23	12m	C-169, C-488

3.2.3. *Data analysis*

Over the duration of the project, a total of nine field calibration trials were carried out to determine if intra-variability between C-PODs was evident (between 04/11/08 and 31/03/11; Table 3.1) between the two sites in the Shannon Estuary and Galway Bay (Figure 3.2).

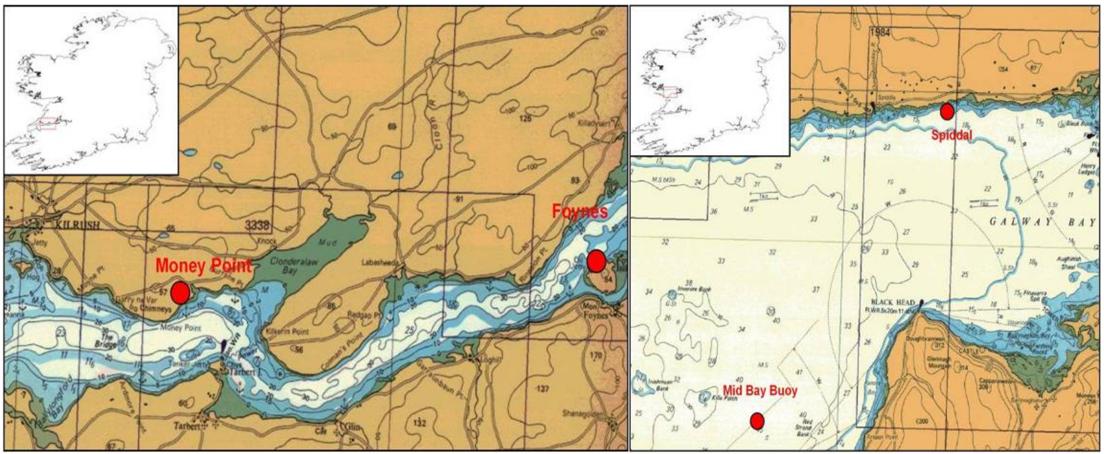


Figure 3.2: Maps of locations where calibrations trials took place: Moneypoint in the Shannon Estuary and Spiddal in Galway Bay

Prior to the project commencement of long-term SAM, all units available (n=12) were deployed in Galway Bay at the Wave Energy Site off Spiddal for a total of 50 days and were also used to compare the three types of SAM devices: C-PODs, T-PODs and AQUAquicks. All unit types were set using the manufacturers' generic settings. Further trials investigated variability between C-POD units only. The mean trial duration across all trials was 26 days. All data were extracted under two categories: 1) Narrow Band High Frequency (NBHF) (porpoise band), and 2) "Other" i.e. the dolphin band using the C-POD.exe software (Version 2.013, June 2011). These data were extracted to Excel.xlsx files using C.POD.exe software and analysed as detection positive minutes across hours (DPM). Where a trial involved the grouping of multiple units in bundles during deployment, these bundles were analysed separately, allowing for analysis of 14 sub-trials.

All statistical analyses were carried out using the program R (R Development Core Team, 2011). Packages gtools, MethComp and plotrix developed for use in R were used to carry out the analyses. A null model, assuming there was no variation in C-POD performance, a = 0 and b = 1, was compared for each combination of C-POD pairs against an orthogonal regression model to assess C-POD performance. Orthogonal regression was chosen as this takes into account the error on both axes. An error margin of ±20% was plotted along the null model to distinguish between the acceptable variation in C-POD performance and problematic variation due to faulty or highly sensitive units (Tregenza *pers comm*.). These graphs were then used to determine successful (regression line within the 20% error margin) or unsuccessful (regression line outside of the 20% error margin) POD combinations. The mean intercept and gradient values of the orthogonal model for each C-POD pair were extracted and used to create centipede plots where deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot indicate how POD comparisons deviate from the null model. This can be clearly identified if only one or two POD combinations were unsuccessful and also whether the difference between the null model and the regression could be mainly attributed to difference in the intercept or the gradient. This was necessary for the next step in data interpretation. Box-plots of mean gradient values from the orthogonal regression (±std) were created to identify poor performing units or very sensitive units, if they existed. Deviation from the red line, 1 on the horizontal axis, indicates any outlying units. Gradient values were chosen for this analysis based on results from the centipede plots, which indicated that for most comparisons the gradient had the greatest deviance from the null model.

3.3. **Results**

Results from the first calibration in Galway Bay showed all C-PODs performed very similar, while there was some deviation in the T-POD data. The AQUAclick data had no reflection of either the C-POD or T-POD data (Figure 5.2). Additionally, AQUAclick data extraction had to be done by eye so extraction parameters could not be generated to facilitate a comparison with C-PODs. Furthermore, they performed poorly throughout the project duration, and only have a battery life of approximately 14 days, whereas a C-POD can last for 150 days and more. Therfore, it was impossible to carry out an accurate comparison between PODs and AQUAclicks, and for this reason, AQUAclicks were not included in the dataset (Figure 3.3).

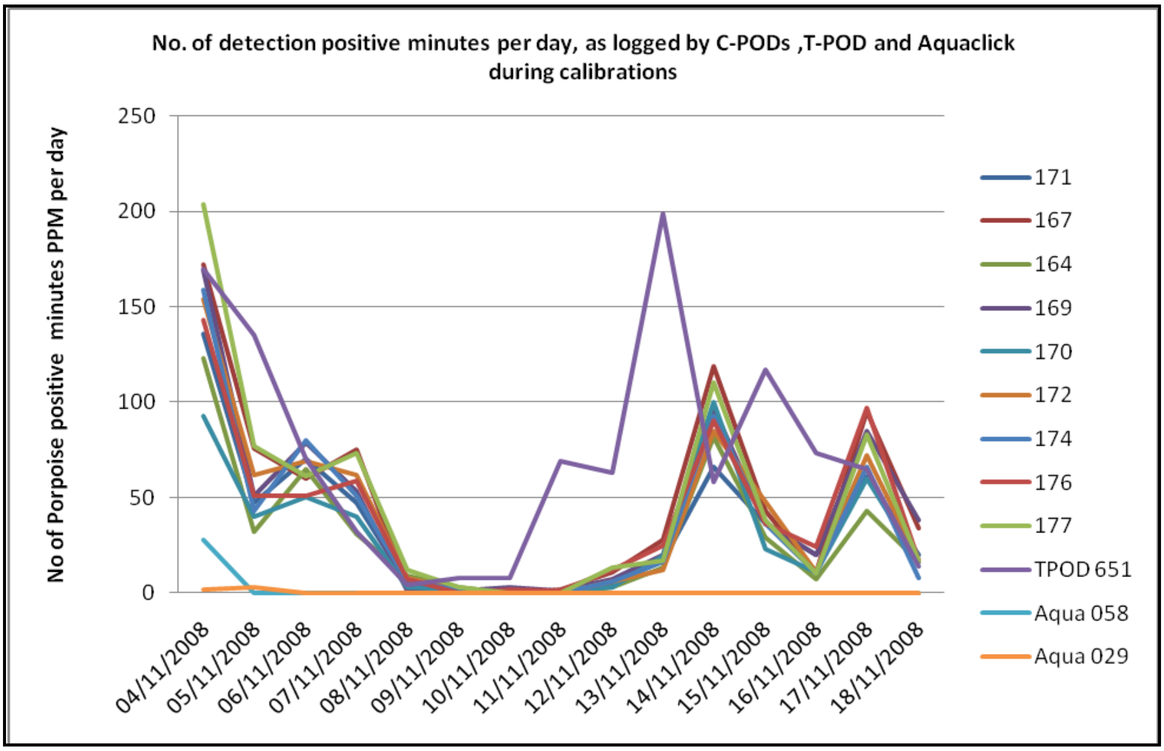


Figure 3.3: Results from GB Cal 001 (sub trial 1) in Galway Bay, including all C-POD, AQUAclicks and T-PODs

Further investigation into C-POD variability (sub trial 1) comfirmed that all nine C-POD units performed within the 20% error margin (Figure 3.4). No units were deemed outliers and although it was uneccessary, centipede plots of intercept and gradient values of the orthogonal regression were created (Figure 3.5). It was accepted that the error between units was mostly evident on the gradient plot. A box plot of the mean gradient values for each unit was created and clearly illustrates the similariity between unit performance (Figure 3.6).

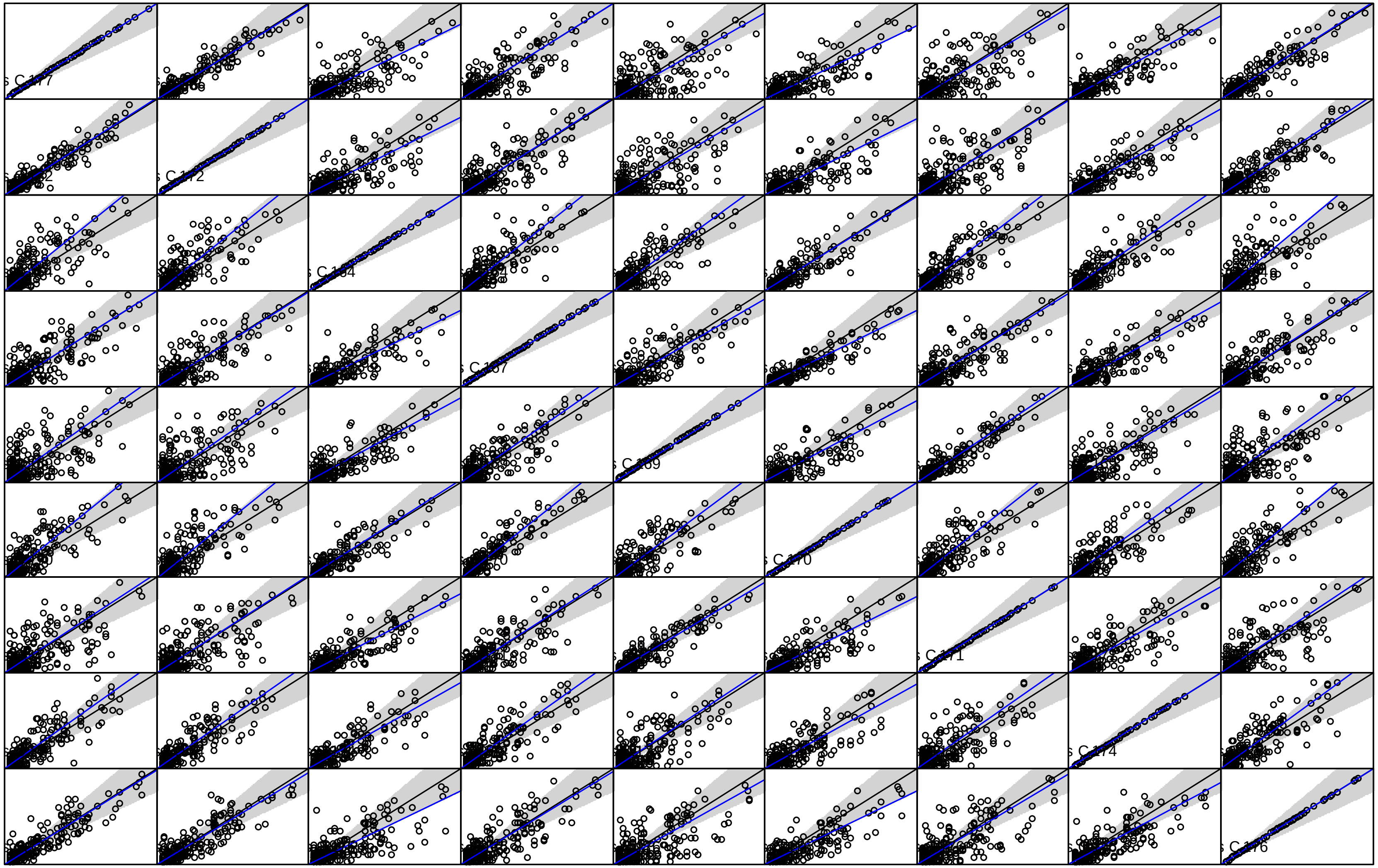


Figure 3.4: Orthogonal regression plot of C-POD comparisons in calibration trial G Cal B001 (sub trial 1), in blue, with a null model where each unit performs exactly the same in black ,and an acceptable error margin of ±20% in grey

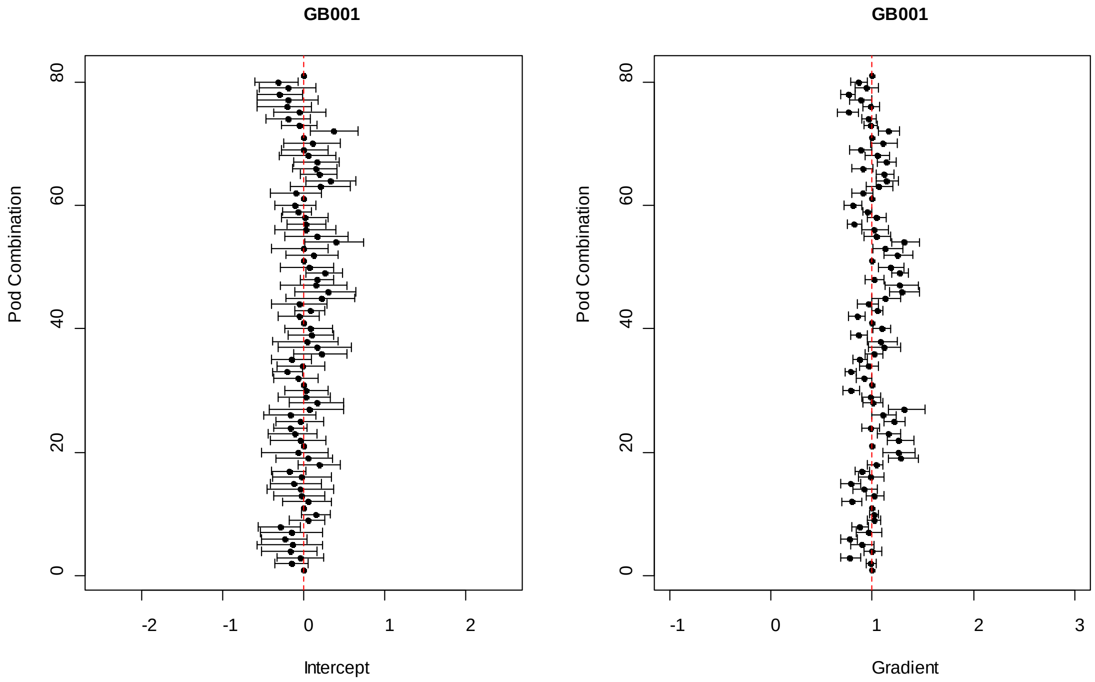


Figure 3.5: Centipede plot of the intercept and slope values (±std) of the orthogonal regression plots for each pod performance comparison in calibration trial GB Cal 001 (Sub trial 1). Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model that both pods are performing the same

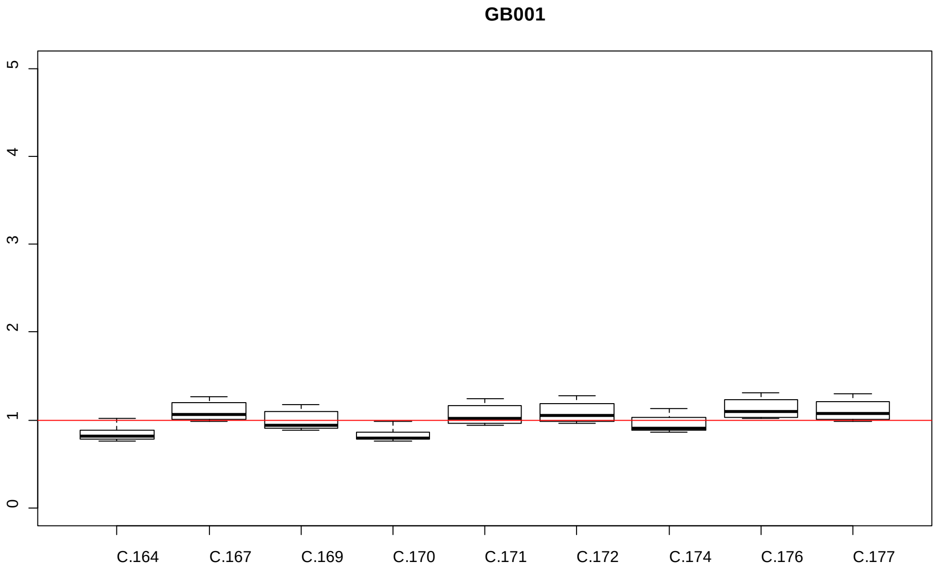


Figure 3.6: Box plot of the mean slope values (±std), of the orthogonal regression plots, for each pod in calibration trial GB Cal 001 (Sub trial 1). Outliers indicate poor performers and pods with high sensitivity

Table 3.2: Results of all calibration sub-trials to determine successful (regression line within the 20% error margin) or unsuccessful (regression line outside of the 20% error margin) POD combinations

Calibration Trials		
Sub trial	**Successful combination**	**Unsuccessful combination**
1	177&172, 177&164, 177&167, 177&169, 177&170, 177&171, 177&174, 177&176, 172&164, 172&167, 172&169, 172&170, 172&171, 172&174, 172&176, 164&167, 164&169, 164&170, 164&171, 164&174, 164&176, 167&169, 167&170, 167&171, 167&174, 167&176, 169&170, 169&171, 169&174, 169&176, 170&171, 170&174, 170&176, 171&174, 171&176, 174&176	
2		169&173
3	548&547, 549&546, 167&546, 546&164	546&547, 549&547, 167&547, 164&547, 548&546, 549&548, 548&167, 548&164
4		549&547, 173&547, 173&549
5	795&794	173&794, 173&795
6		384&172, 953&172, 953&384
7	951&949, 952&949, 952&951	
8		950&947
9	1147&171, 1095&171, 1095&1147	
10	547&173, 548&173, 1147&173, 548&547, 1147&547, 1147&548	
11	950&795	795&171, 950&171, 952&171, 952&795, 952&950
12	1524&796, 1525&1524, 1525&796	487&796, 1524&487, 1525&487
13	951&947	
14		488&169

Investigations into all calibration trials (Table 3.2) revealed differences in C-POD performance but throughout the study period, the majority of units performed within an acceptable error margin of 20%. All C-POD units tested in sub-trials 1, 7, 9 and 10, and 13 performed within the acceptable error margin (See Appendix for all sub-trial regression plots). Of the 27 C-PODs tested over all trials, 10 units were found to be inconsistent during one or more sub trials and were further investigated (Figures 3.7 to 3.45). For sub-trials containing only two units, it was impossible to identify which unit was different or the outlier. In these cases, both units were considered for further investigation where previous calibration results and personal knowledge of the units was also used for interpretation of results. Loss of sensitivity over time was found for units C-169, C-171 and C 952. C-POD 171 performed within the acceptable 20% error margin in the first sub trial (4/11/08-18/11/08) and again over 20 months later in the ninth sub trial (23/07/10-19/08/10) but nearly seven months later (08/03/11-31/03/11), this unit was highlighted as inconsistent with results from other units. Additionally, units C-384, C-487, C-488 and C-953 were considered outliers after one trial. But as they were only tested once, it is unclear whether this was due to an anomaly during the trial, degradation over time or a fault within the unit. For example, C-488 was highlighted during the analysis but was only compared against one other unit, C-169, which was found to be inconsistent with units in previous trials. It is possible that C-488 was functioning correctly but was highlighted because of inconsistencies with C-169. C-548 was highlighted with a variation of more than 20% but in a later trial was found to perform within this error limit. This pattern was also seen for C-173 and C-547.

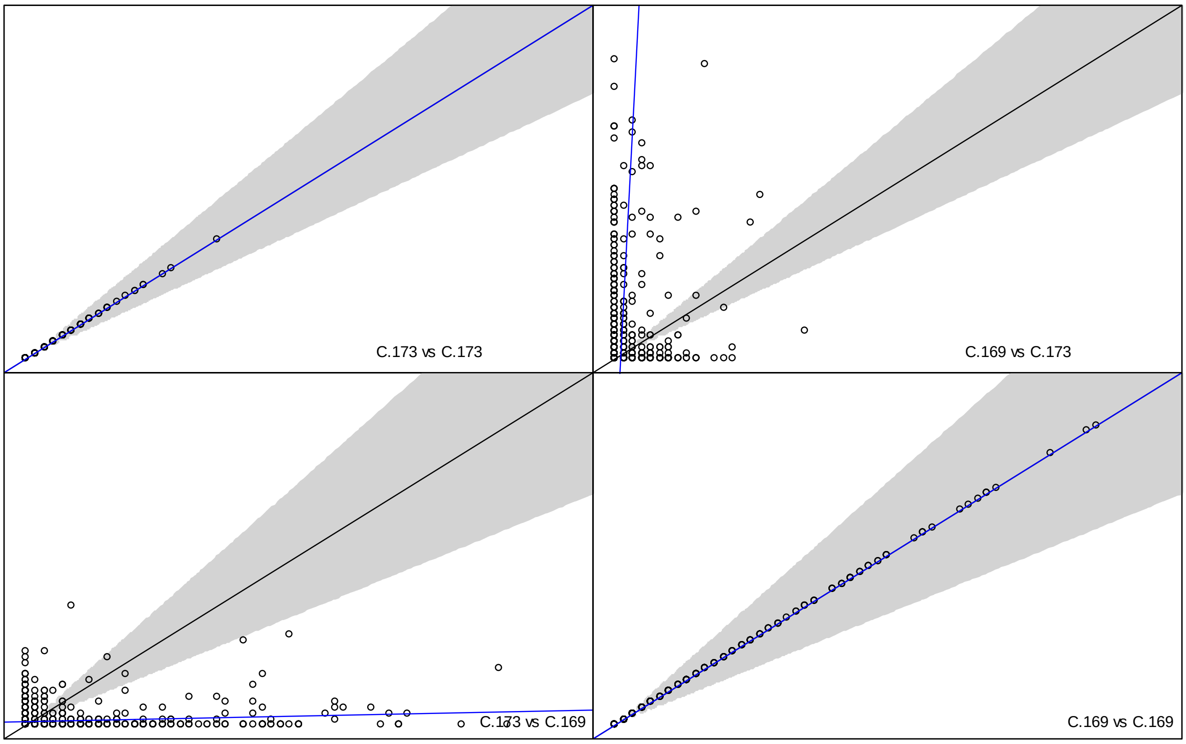


Figure 3.7: Orthogonal regression plot of C-POD comparisons in calibration GB Cal 002 (sub trial 2), in blue, with a null model where each unit performs exactly the same, in black, and an acceptable error margin of ±20%, in grey

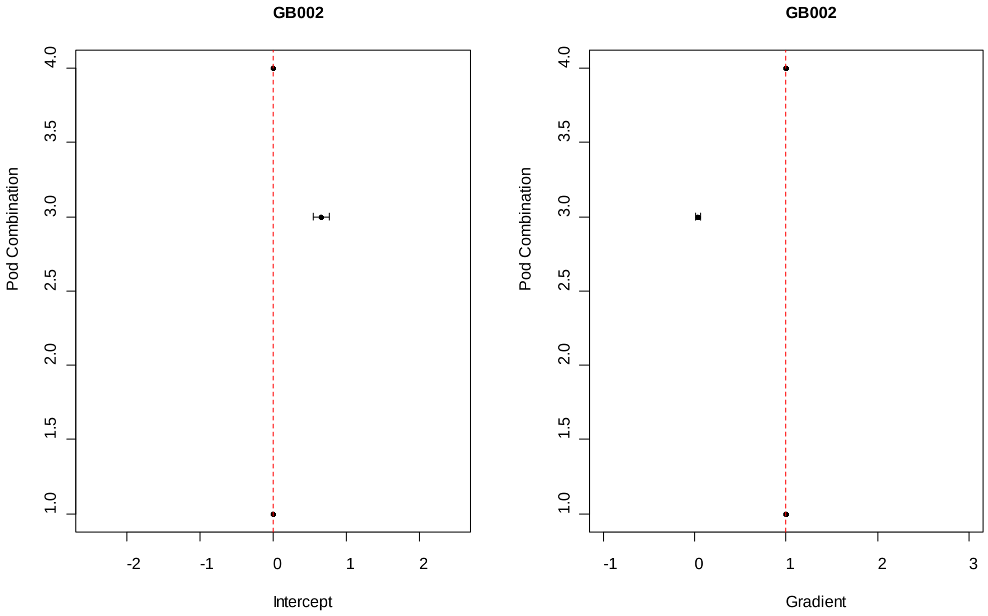


Figure 3.8: Centipede plot of the intercept and slope values (±std) of the orthogonal regression plots for each pod performance comparison in calibration trial GB Cal 002 (Sub trial 2). Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model that both pods are performing the same

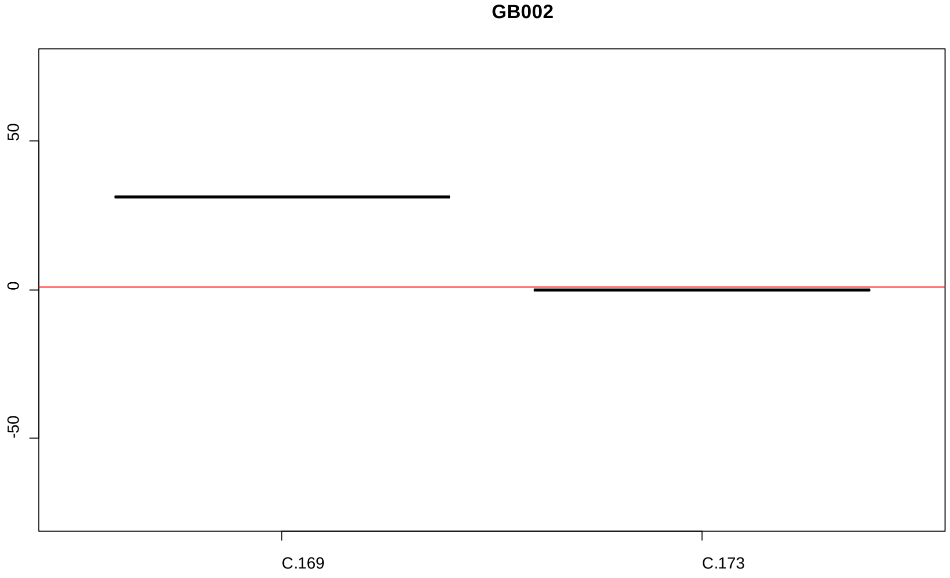


Figure 3.9: Box plot of the mean slope values (±std), of the orthogonal regression plots, for each pod in calibration trial GB Cal 002 (Sub trial 2). Outliers indicate poor performers and pods with high sensitivity

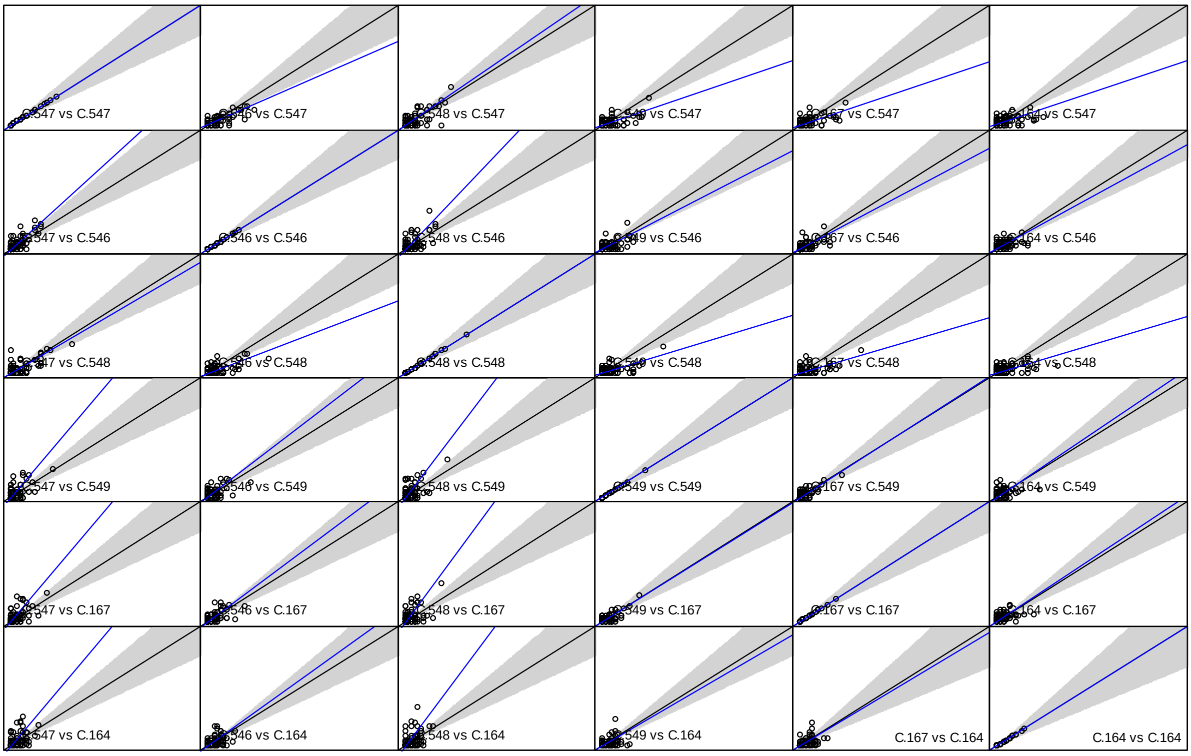


Figure 3.10: Orthogonal regression plot of C-POD comparisons in calibration MP Cal 003 (sub trial 3), in blue, with a null model where each unit performs exactly the same, in black, and an acceptable error margin of ±20%, in grey

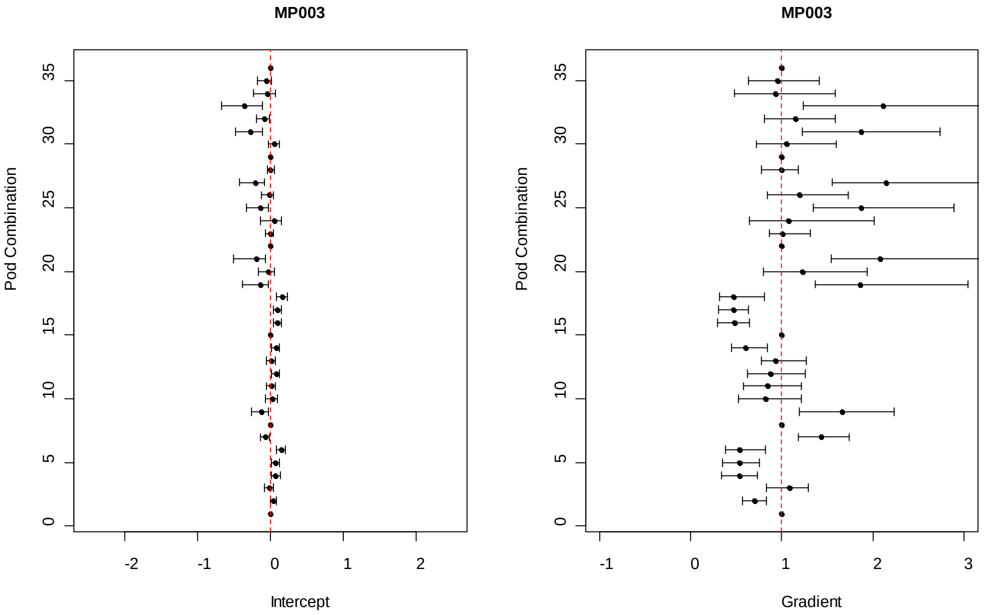


Figure 3.11: Centipede plot of the intercept and slope values (±std) of the orthogonal regression plots for each pod performance comparison in calibration trial MP Cal 003 (Sub trial 3). Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model that both pods are performing the same

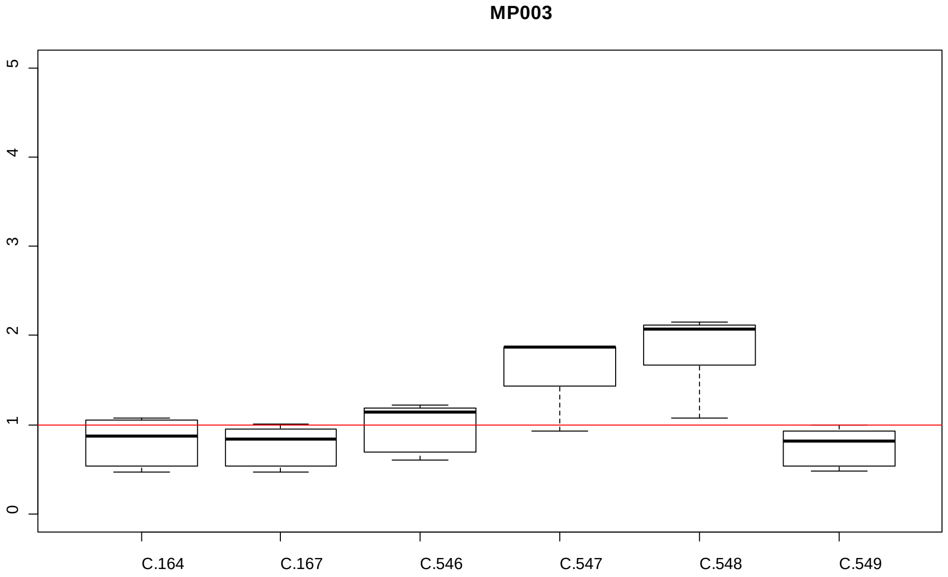


Figure 3.12: Box plot of the mean slope values (±std) of the orthogonal regression plots for each pod in calibration trial MP Cal 003 (Sub trial 3). Outliers indicate poor performers and pods with high sensitivity

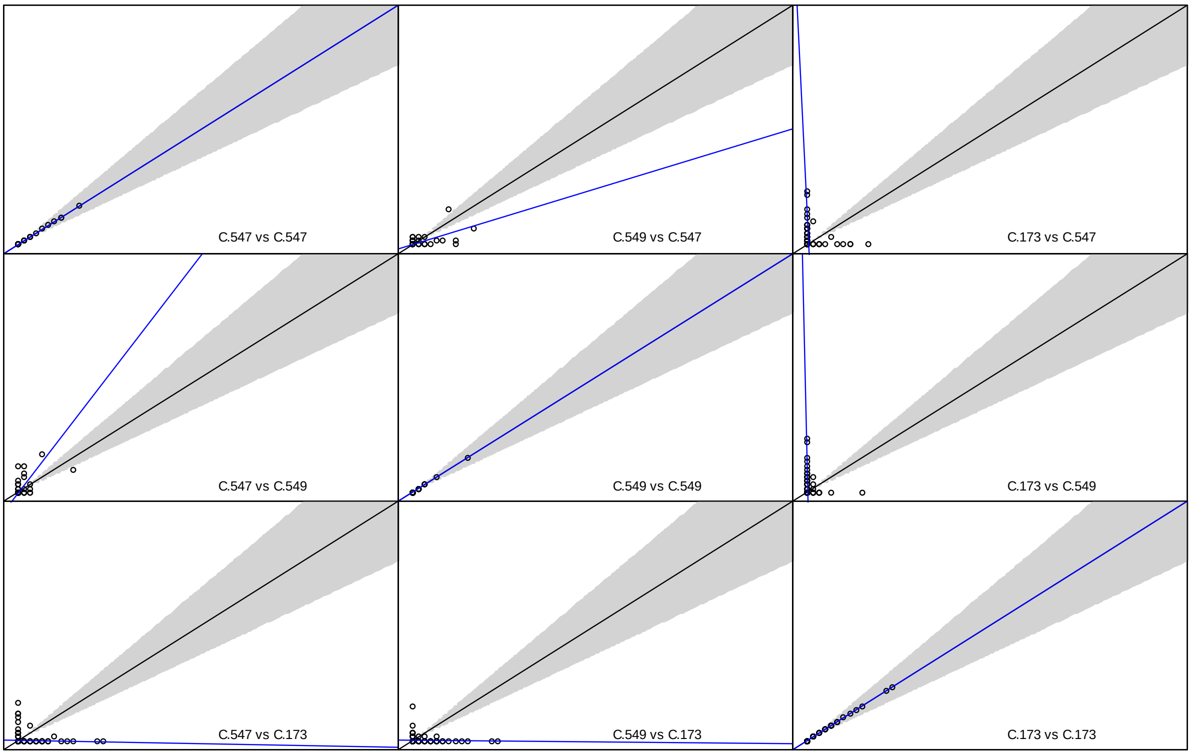


Figure 3.13: Orthogonal regression plot of C-POD comparisons in calibration MP Cal 004 (sub trial 4), in blue, with a null model where each unit performs exactly the same, in black, and an acceptable error margin of ±20%, in grey

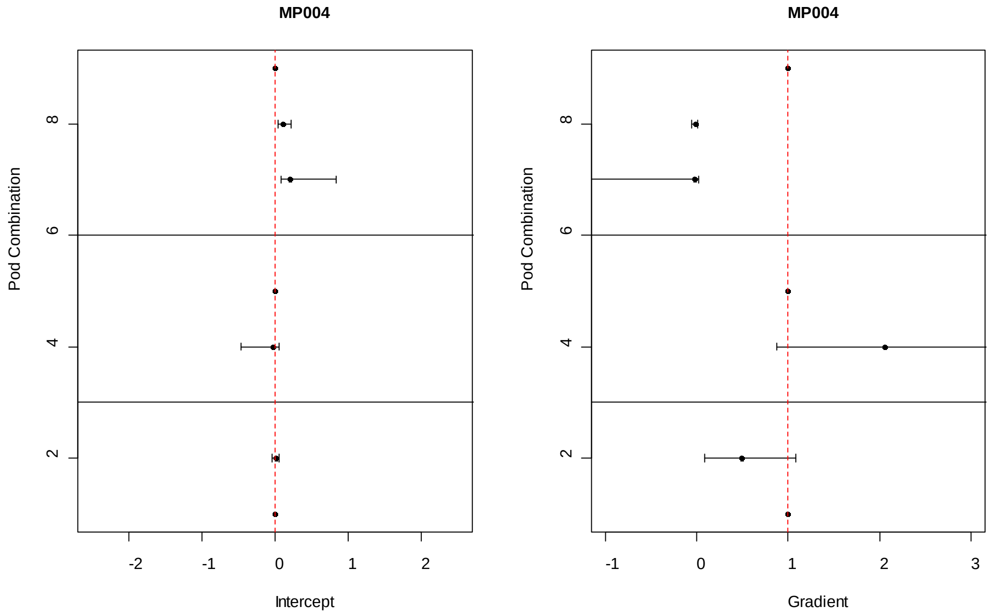


Figure 3.14: Centipede plot of the intercept and slope values (±std), of the orthogonal regression plots, for each pod performance comparison in calibration trial MP Cal 004 (Sub trial 4). Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model that both pods are performing the same

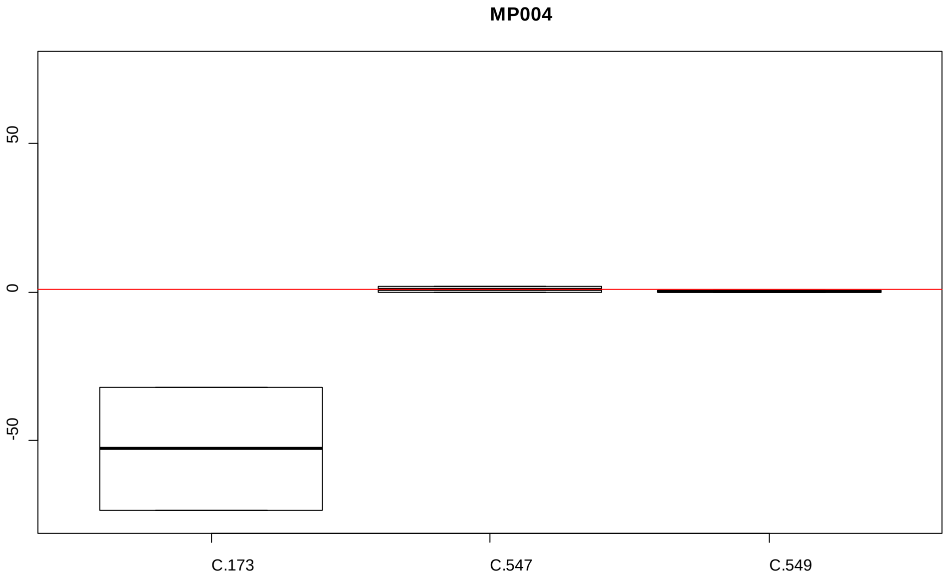


Figure 3.15: Box plot of the mean slope values (±std) of the orthogonal regression plots for each pod in calibration trial MP Cal 004 (Sub trial 4). Outliers indicate poor performers and pods with high sensitivity

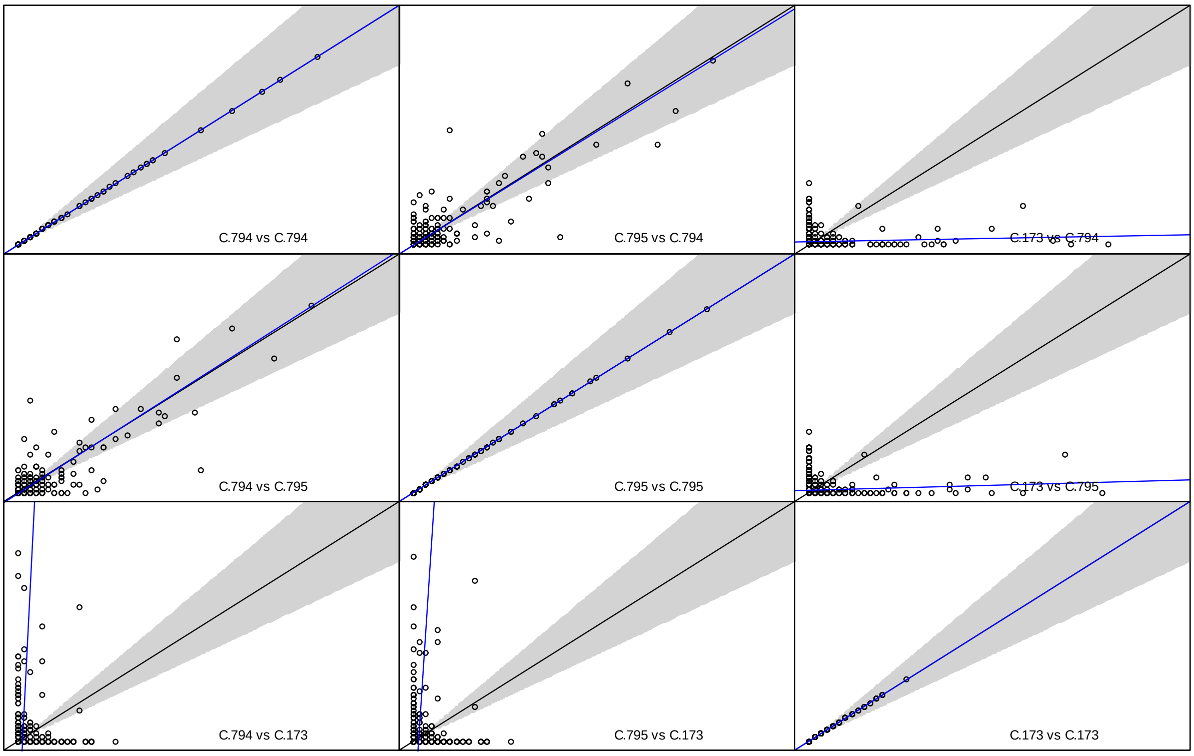


Figure 3.16: Orthogonal regression plot of C-POD comparisons in calibration MP Cal 005 (sub trial 5), in blue, with a null model where each unit performs exactly the same, in black, and an acceptable error margin of ±20%, in grey

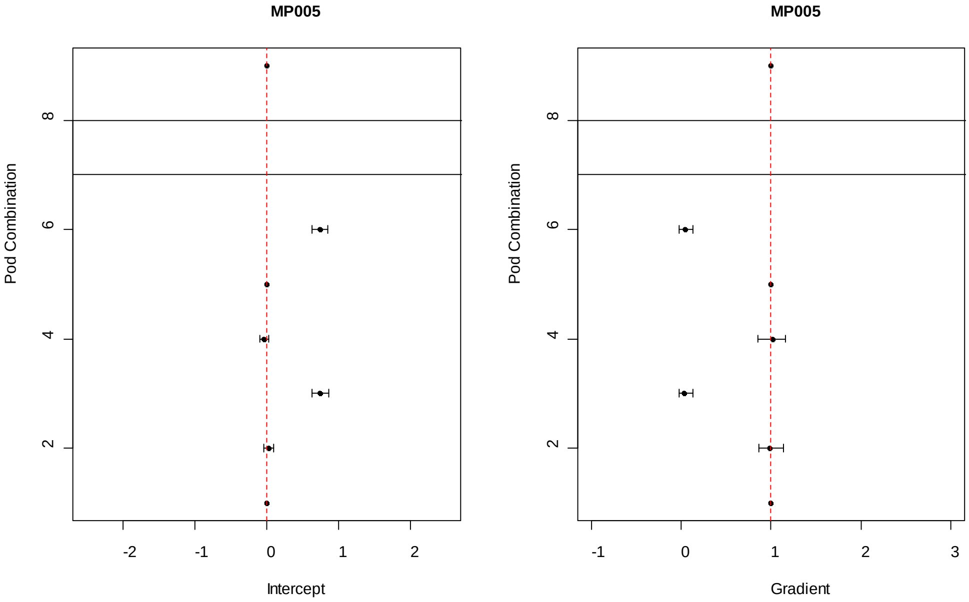


Figure 3.17: Centipede plot of the intercept and slope values (±std), of the orthogonal regression plots, for each pod performance comparison in calibration trial MP Cal 005 (Sub trial 5). Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model that both pods are performing the same

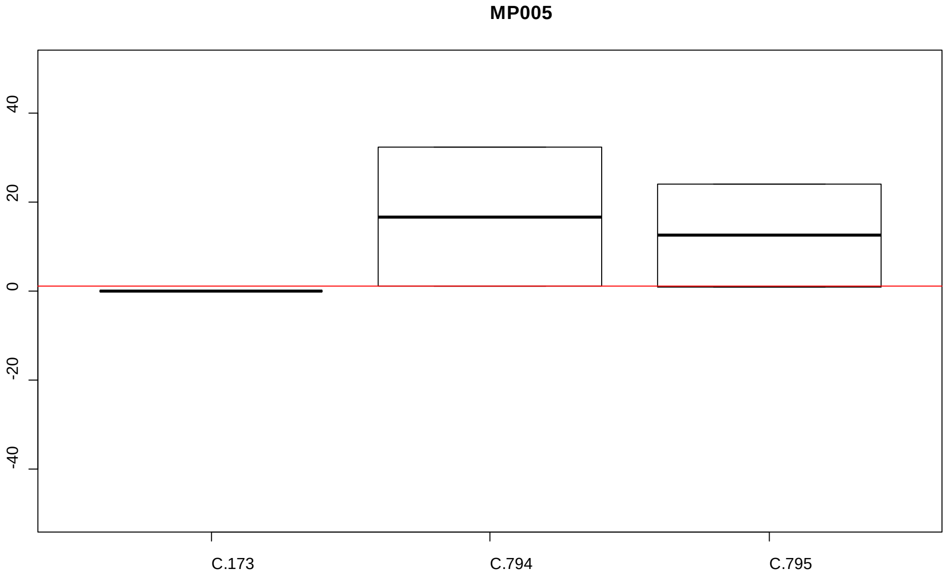


Figure 3.18: Box plot of the mean slope values (±std), of the orthogonal regression plots, for each pod in calibration trial MP Cal 005 (Sub trial 5). Outliers indicate poor performers and pods with high sensitivity

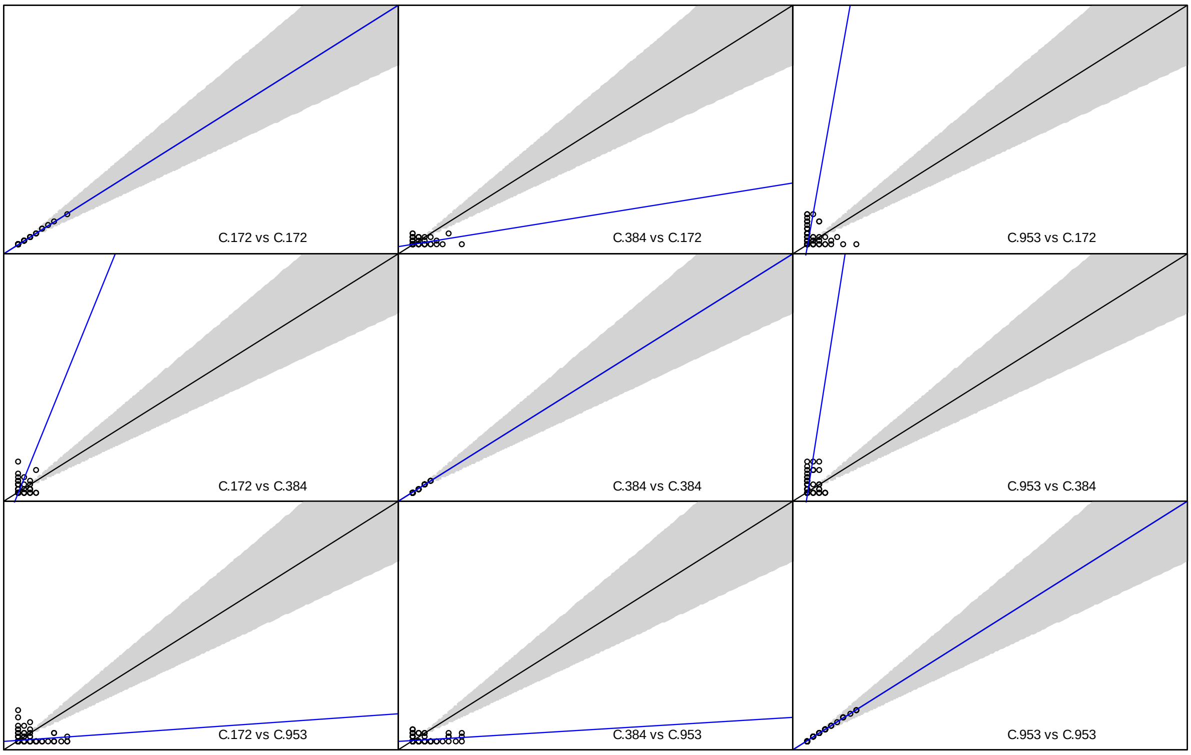


Figure 3.19: Orthogonal regression plot of C-POD comparisons in calibration MP Cal 006 (sub trial 6), in blue, with a null model where each unit performs exactly the same, in black, and an acceptable error margin of ±20%, in grey

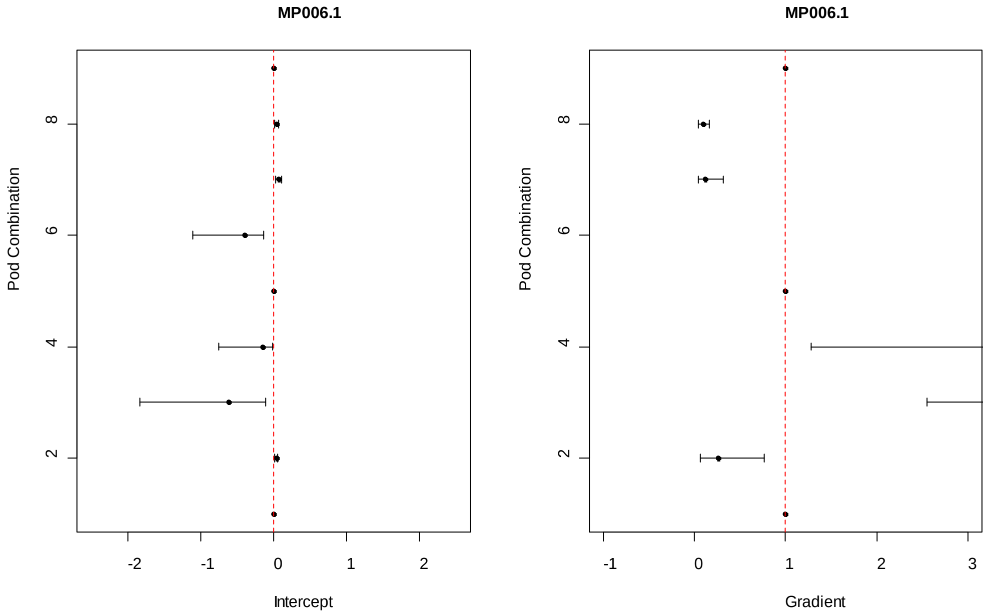


Figure 3.20: Centipede plot of the intercept and slope values (±std), of the orthogonal regression plots, for each pod performance comparison in calibration trial MP Cal 006 (Sub trial 6). Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model that both pods are performing the same

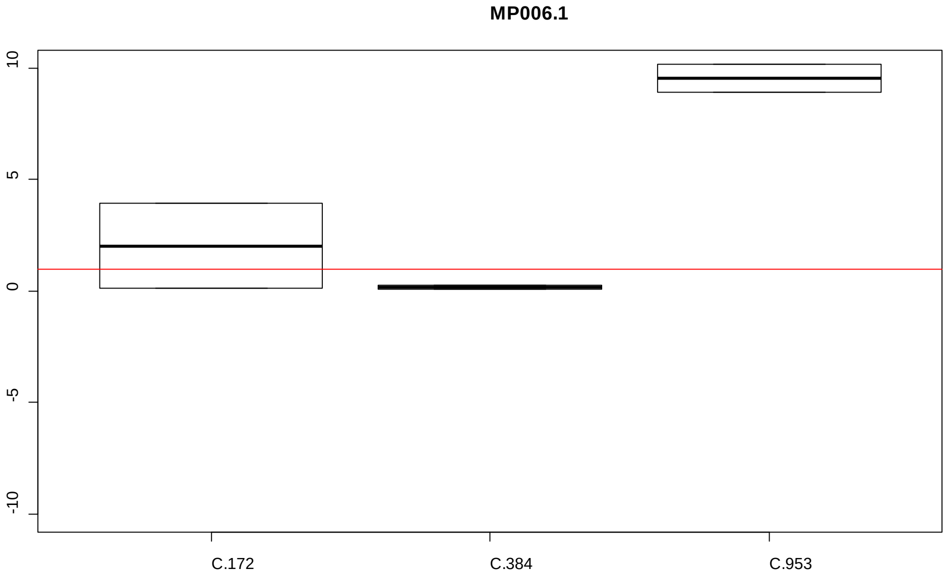


Figure 3.21: Box plot of the mean slope values (±std), of the orthogonal regression plots, for each pod in calibration trial MP Cal 006 (Sub trial 6). Outliers indicate poor performers and pods with high sensitivity

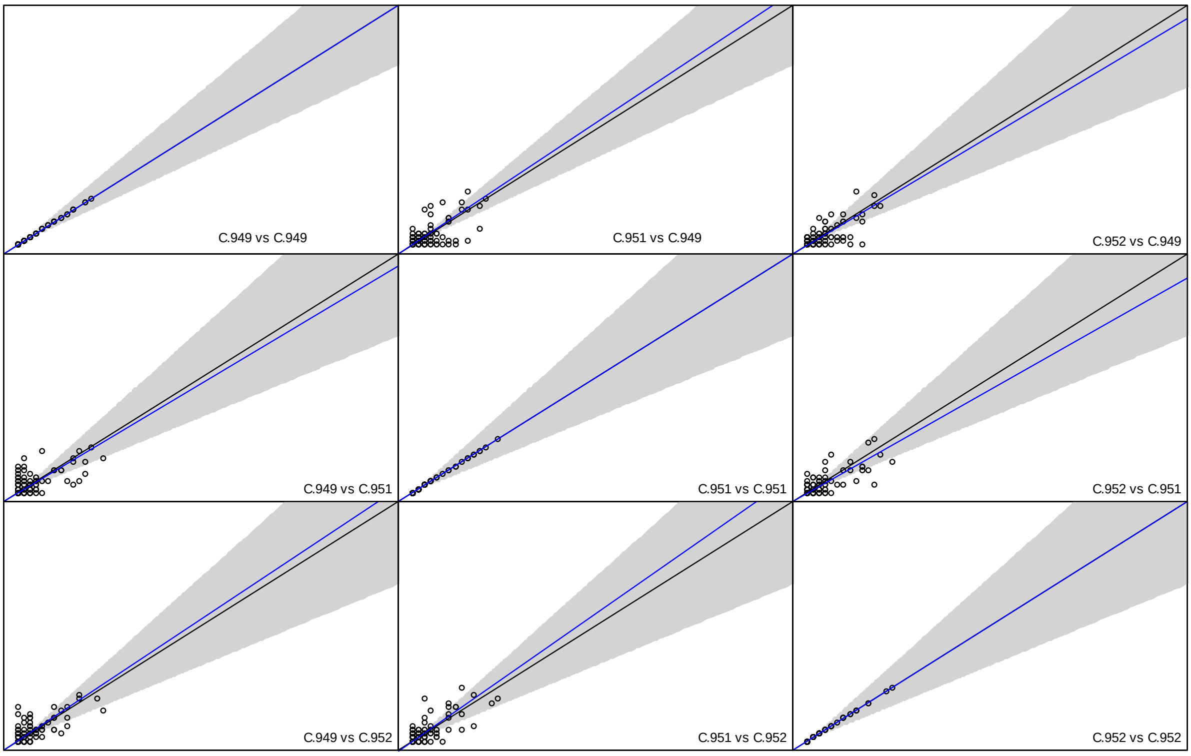


Figure 3.22: Orthogonal regression plot of C-POD comparisons in calibration MP Cal 006 (sub trial 7), in blue, with a null model where each unit performs exactly the same, in black, and an acceptable error margin of ±20%, in grey

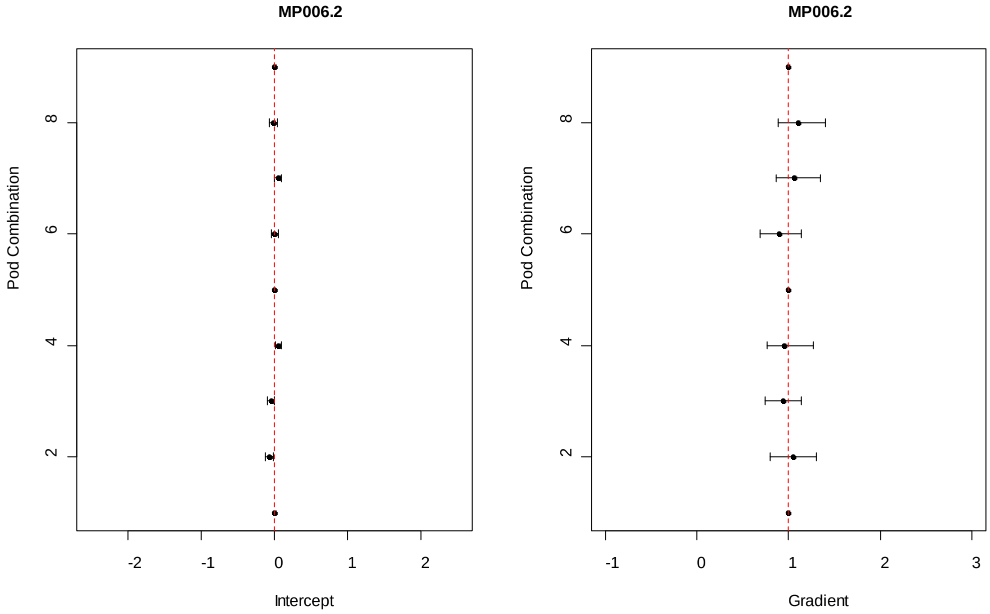


Figure 3.23: Centipede plot of the intercept and slope values (±std) of the orthogonal regression plots for each pod performance comparison in calibration trial MP Cal 006 (Sub trial 7). Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model that both pods are performing the same

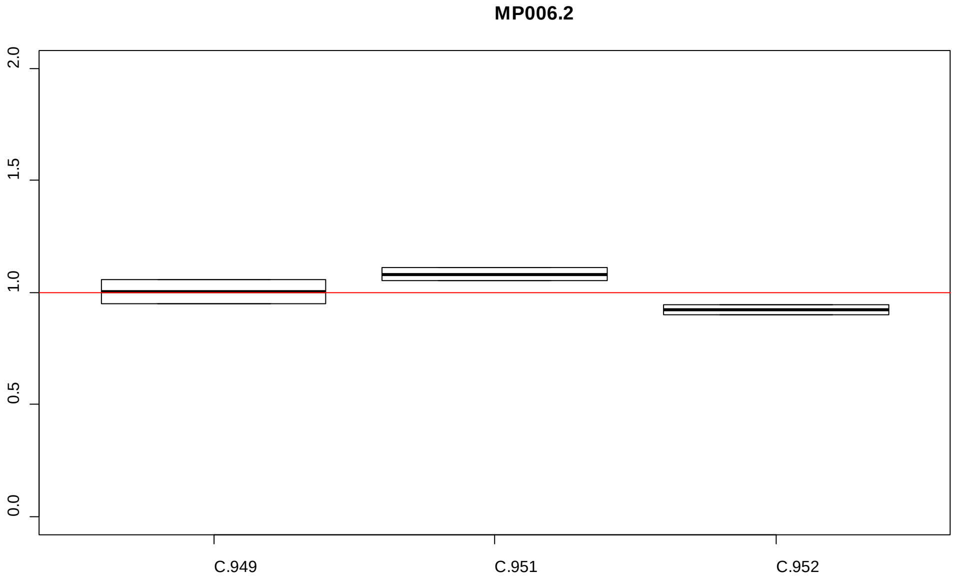


Figure 3.24: Box plot of the mean slope values (±std) of the orthogonal regression plots for each pod in calibration trial MP Cal 006 (Sub trial 7). Outliers indicate poor performers and pods with high sensitivity

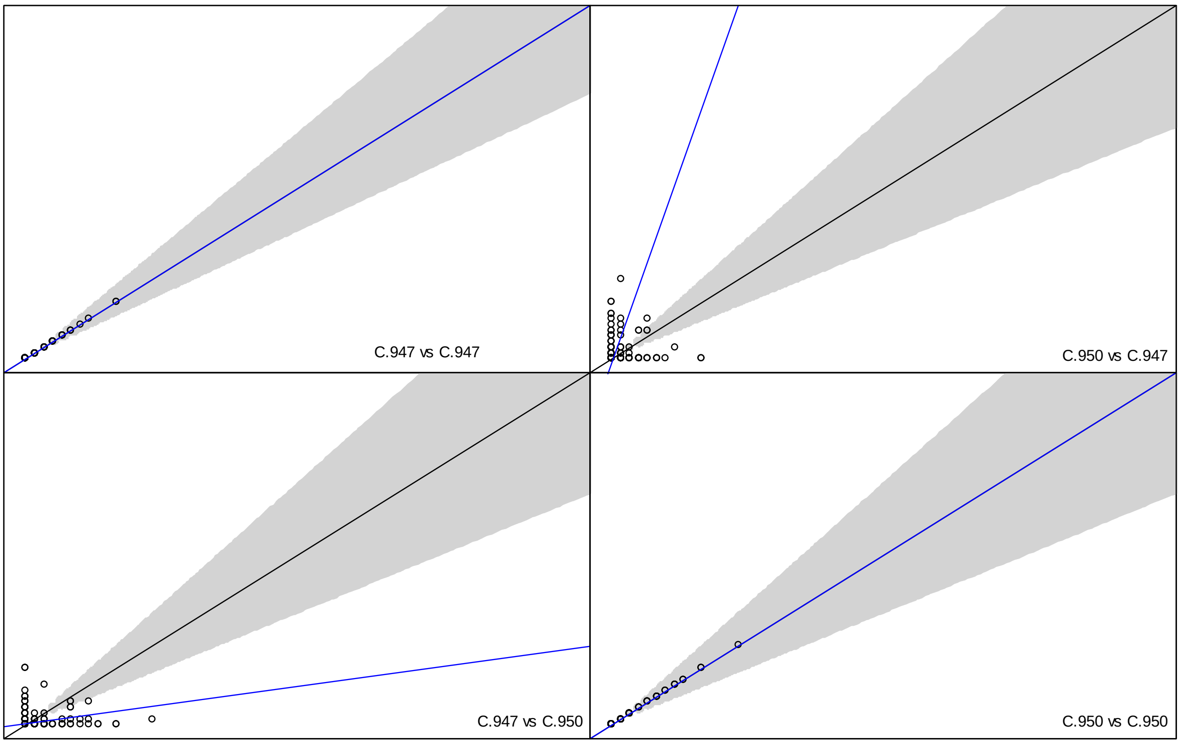


Figure 3.25: Orthogonal regression plot of C-POD comparisons in calibration MP Cal 006 (sub trial 8), in blue, with a null model where each unit performs exactly the same, in black, and an acceptable error margin of ±20%, in grey

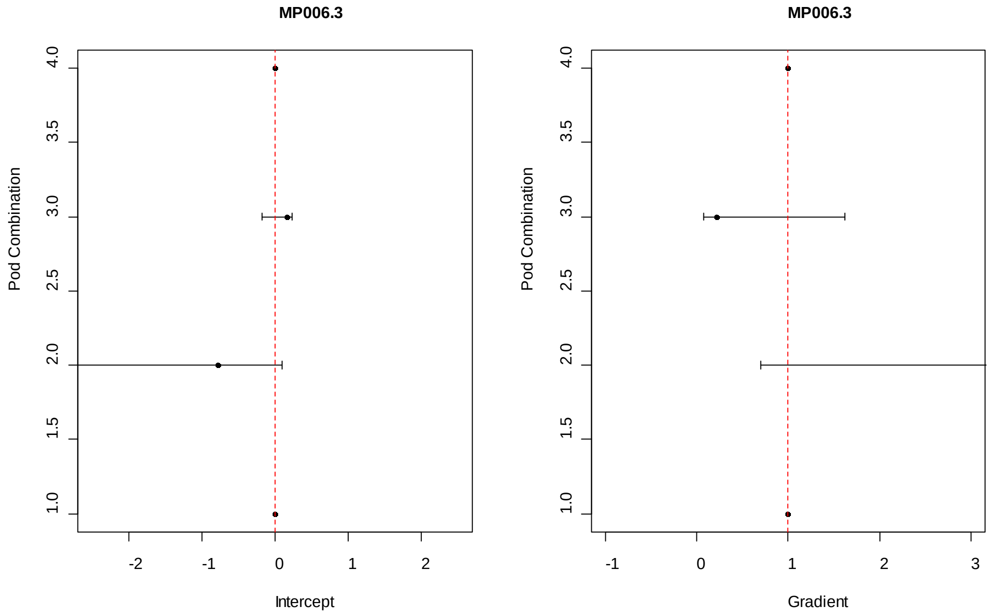


Figure 3.26: Centipede plot of the intercept and slope values (±std) of the orthogonal regression plots for each pod performance comparison in calibration trial MP Cal 006 (Sub trial 8). Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model that both pods are performing the same

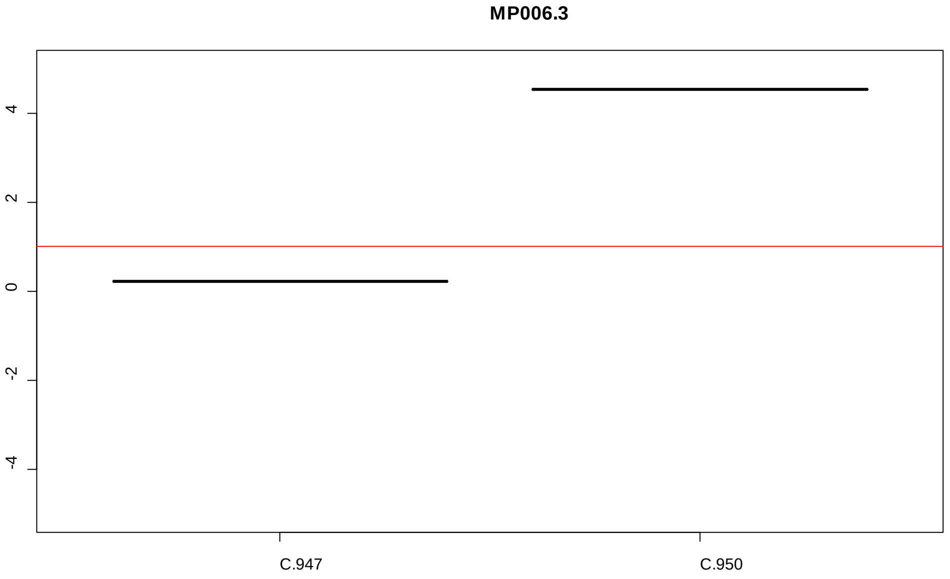


Figure 3.27: Box plot of the mean slope values (±std) of the orthogonal regression plots for each pod in calibration trial MP Cal 006 (Sub trial 8). Outliers indicate poor performers and pods with high sensitivity

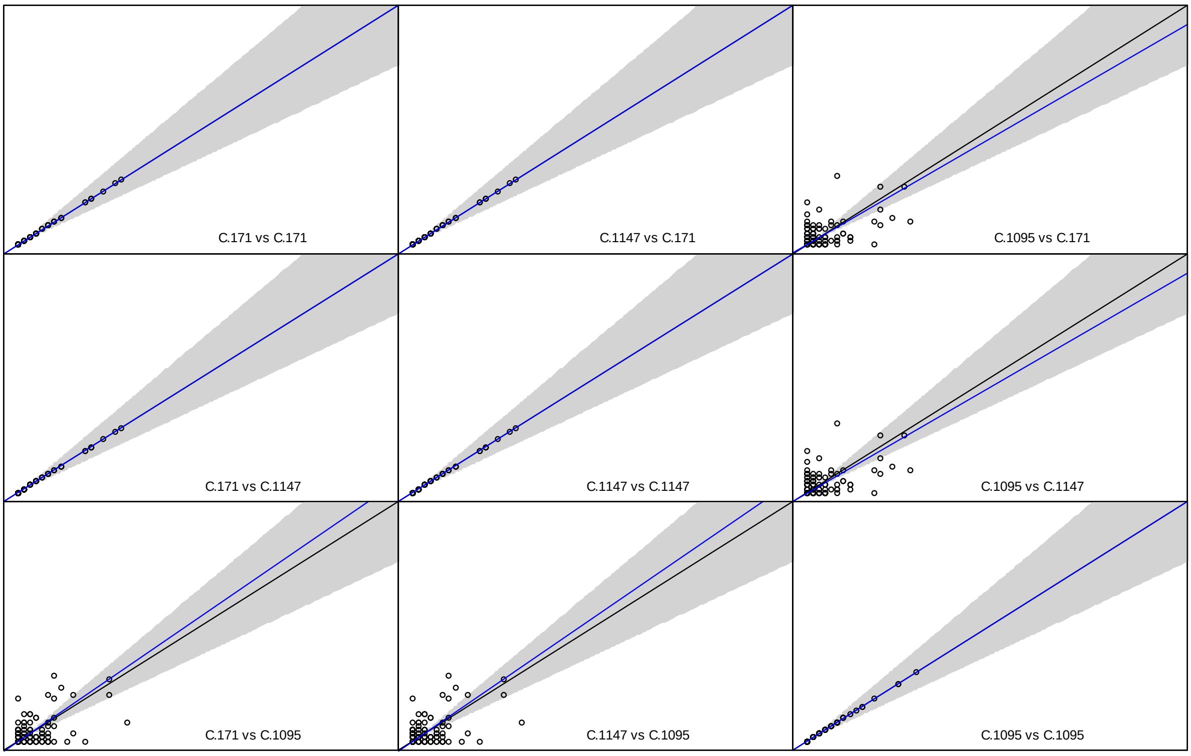


Figure 3.28: Orthogonal regression plot of C-POD comparisons in calibration MP Cal 007 (sub trial 9), in blue, with a null model where each unit performs exactly the same, in black, and an acceptable error margin of ±20%, in grey

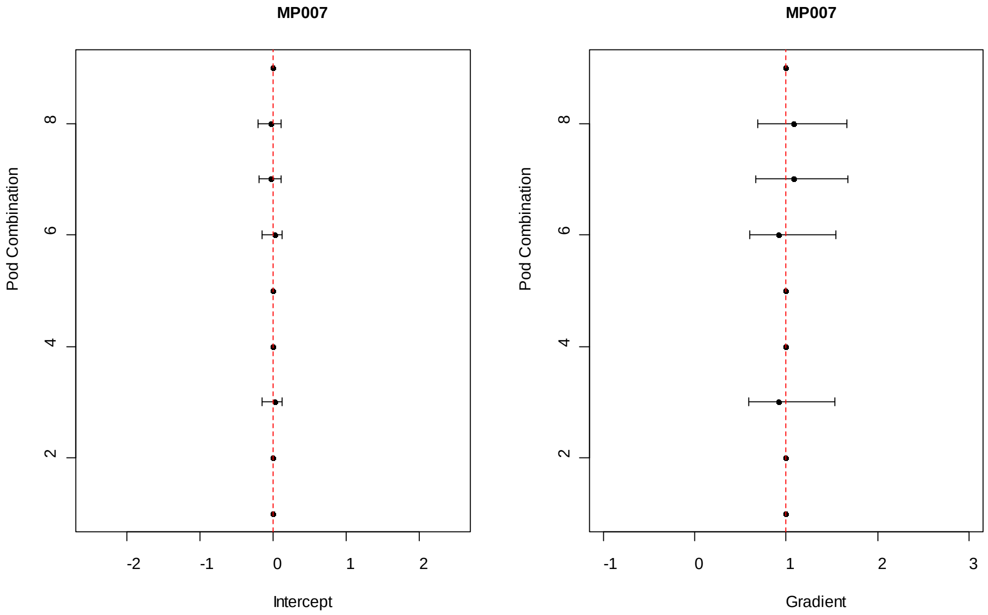


Figure 3.29: Centipede plot of the intercept and slope values (±std) of the orthogonal regression plots for each pod performance comparison in calibration trial MP Cal 007 (Sub trial 9). Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model that both pods are performing the same

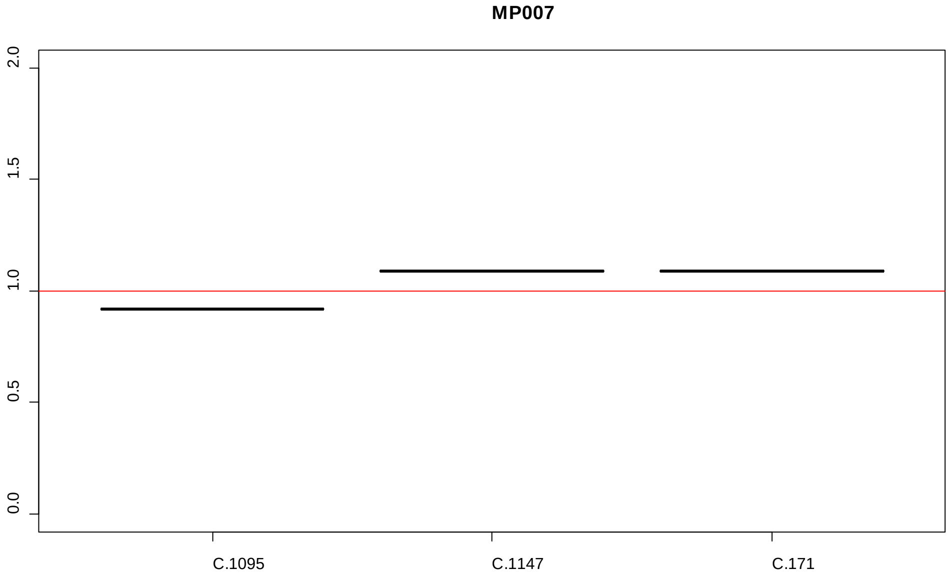


Figure 3.30: Box plot of the mean slope values (±std) of the orthogonal regression plots for each pod in calibration trial MP Cal 007 (Sub trial 9). Outliers indicate poor performers and pods with high sensitivity

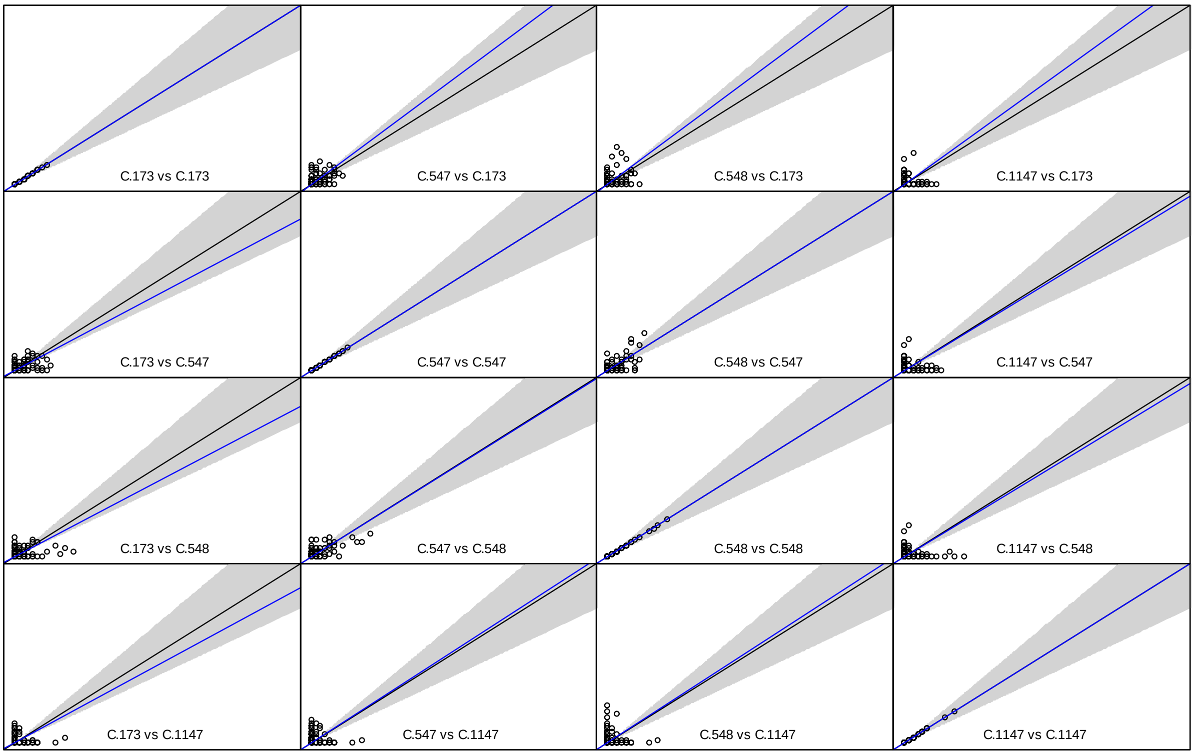


Figure 3.31: Orthogonal regression plot of C-POD comparisons in calibration MP Cal 008 (sub trial 10), in blue, with a null model where each unit performs exactly the same, in black, and an acceptable error margin of ±20%, in grey

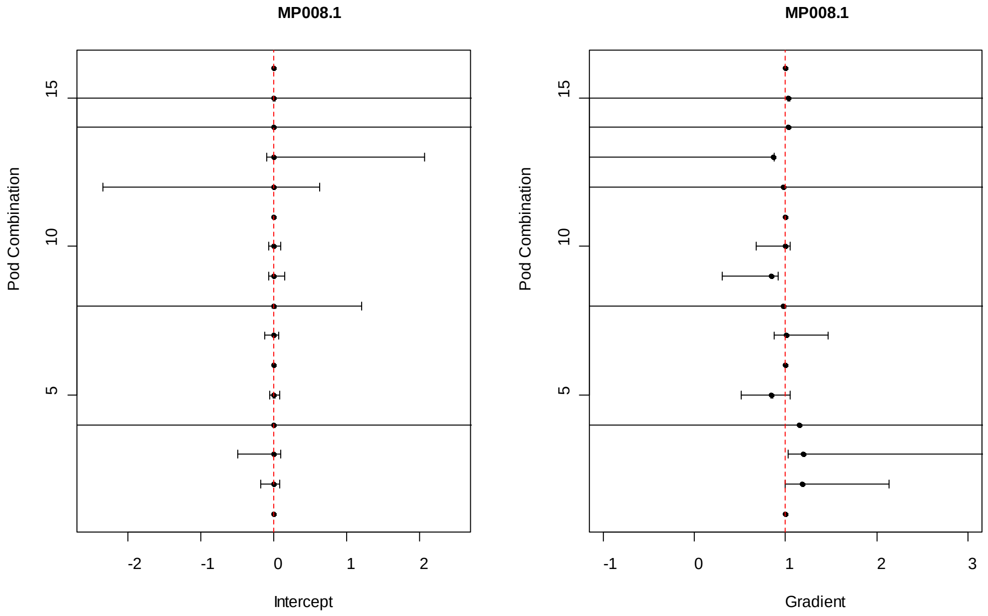


Figure 3.32: Centipede plot of the intercept and slope values (±std) of the orthogonal regression plots for each pod performance comparison in calibration trial MP Cal 008 (Sub trial 10). Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model that both pods are performing the same

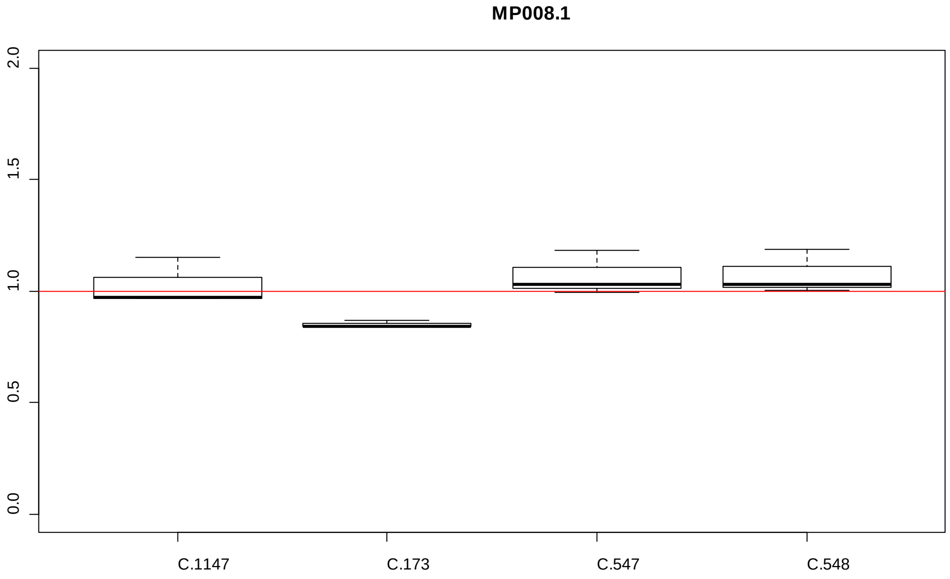


Figure 3.33: Box plot of the mean slope values (±std) of the orthogonal regression plots for each pod in calibration trial MP Cal 008 (Sub trial 10). Outliers indicate poor performers and pods with high sensitivity

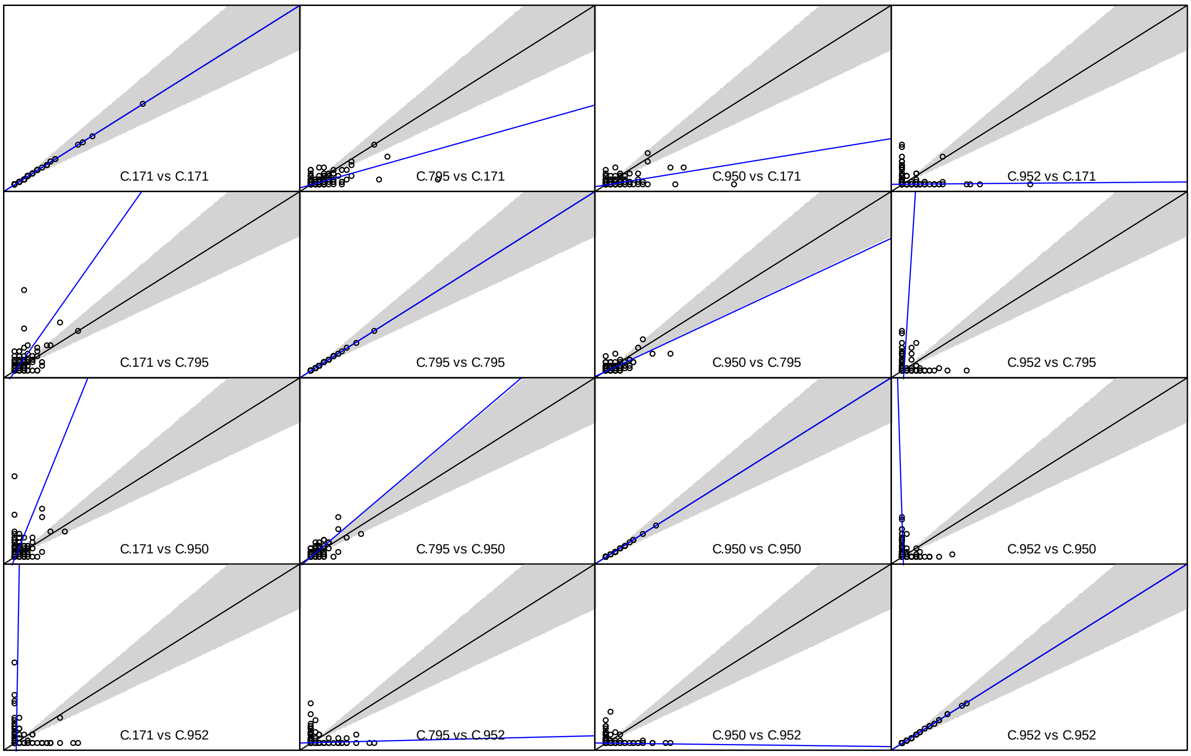


Figure 3.34: Orthogonal regression plot of C-POD comparisons in calibration MP Cal 008 (sub trial 11), in blue, with a null model where each unit performs exactly the same, in black, and an acceptable error margin of ±20%, in grey

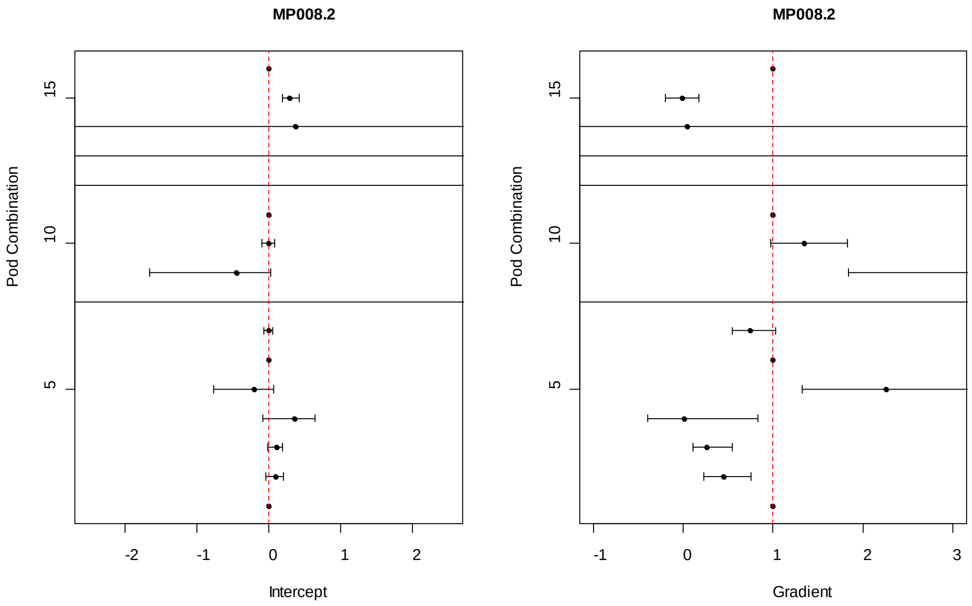


Figure 3.35: Centipede plot of the intercept and slope values (±std) of the orthogonal regression plots for each pod performance comparison in calibration trial MP Cal 008 (Sub trial 11). Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model that both pods are performing the same

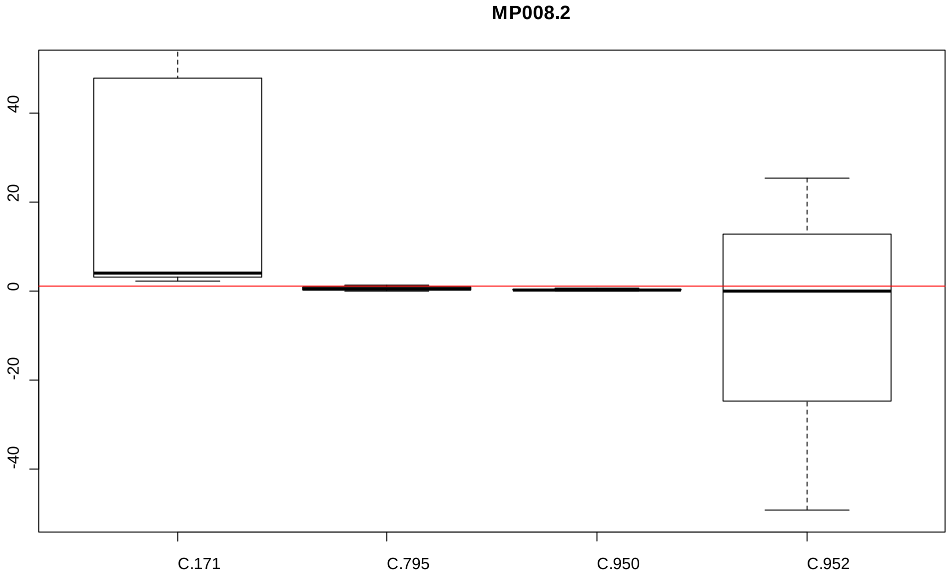


Figure 3.36: Box plot of the mean slope values (±std) of the orthogonal regression plots for each pod in calibration trial MP Cal 008 (Sub trial 11). Outliers indicate poor performers and pods with high sensitivity

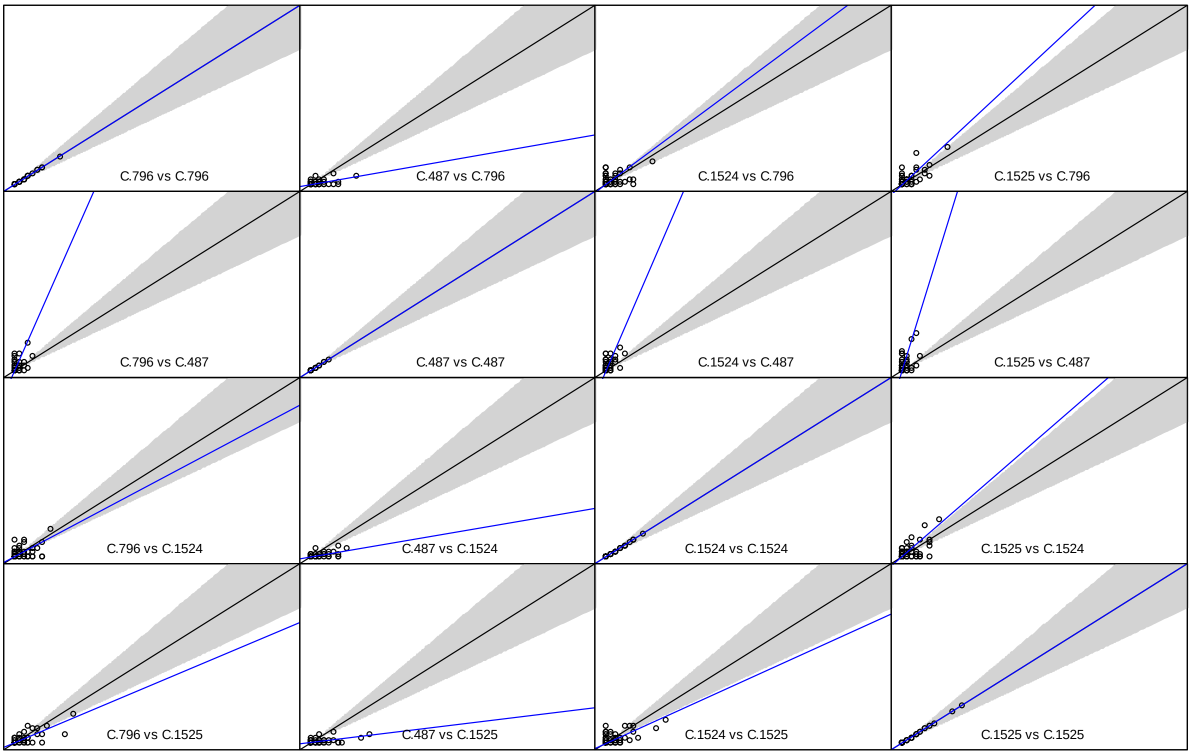


Figure 3.37: Orthogonal regression plot of C-POD comparisons in calibration MP Cal 008 (sub trial 12), in blue, with a null model where each unit performs exactly the same, in black, and an acceptable error margin of ±20%, in grey

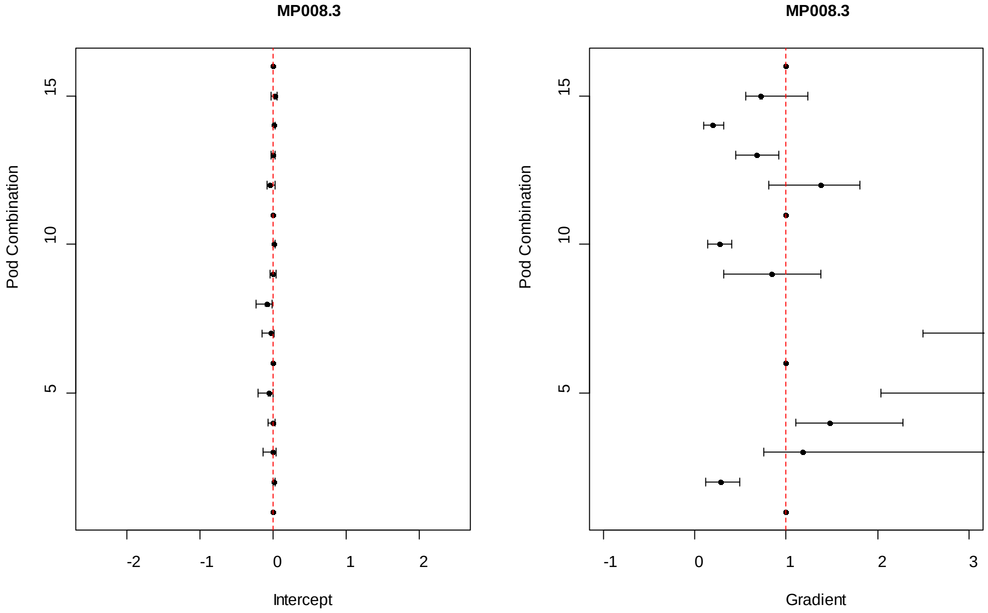


Figure 3.38: Centipede plot of the intercept and slope values (±std) of the orthogonal regression plots for each pod performance comparison in calibration trial MP Cal 008 (Sub trial 12). Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model that both pods are performing the same

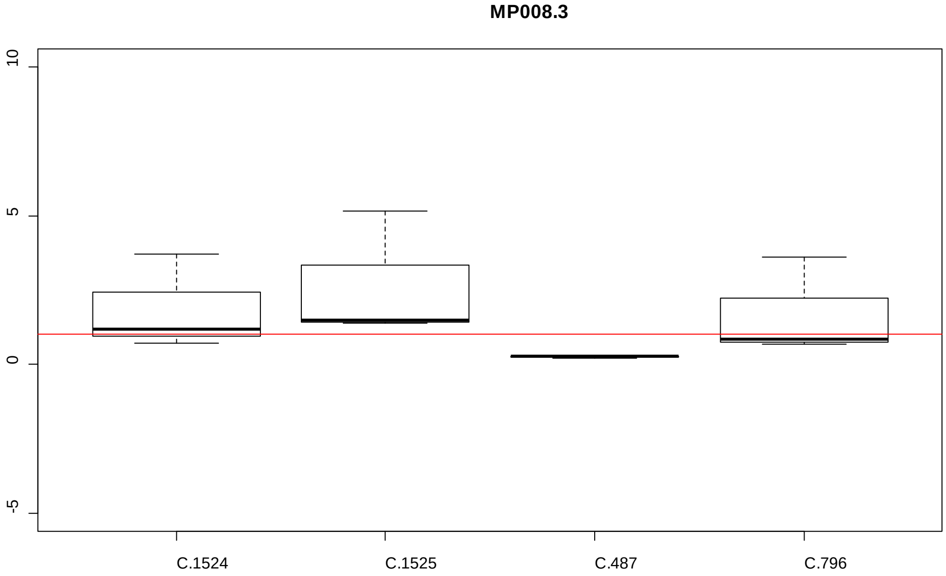


Figure 3.39: Box plot of the mean slope values (±std) of the orthogonal regression plots for each pod in calibration trial MP Cal 008 (Sub trial 12). Outliers indicate poor performers and pods with high sensitivity

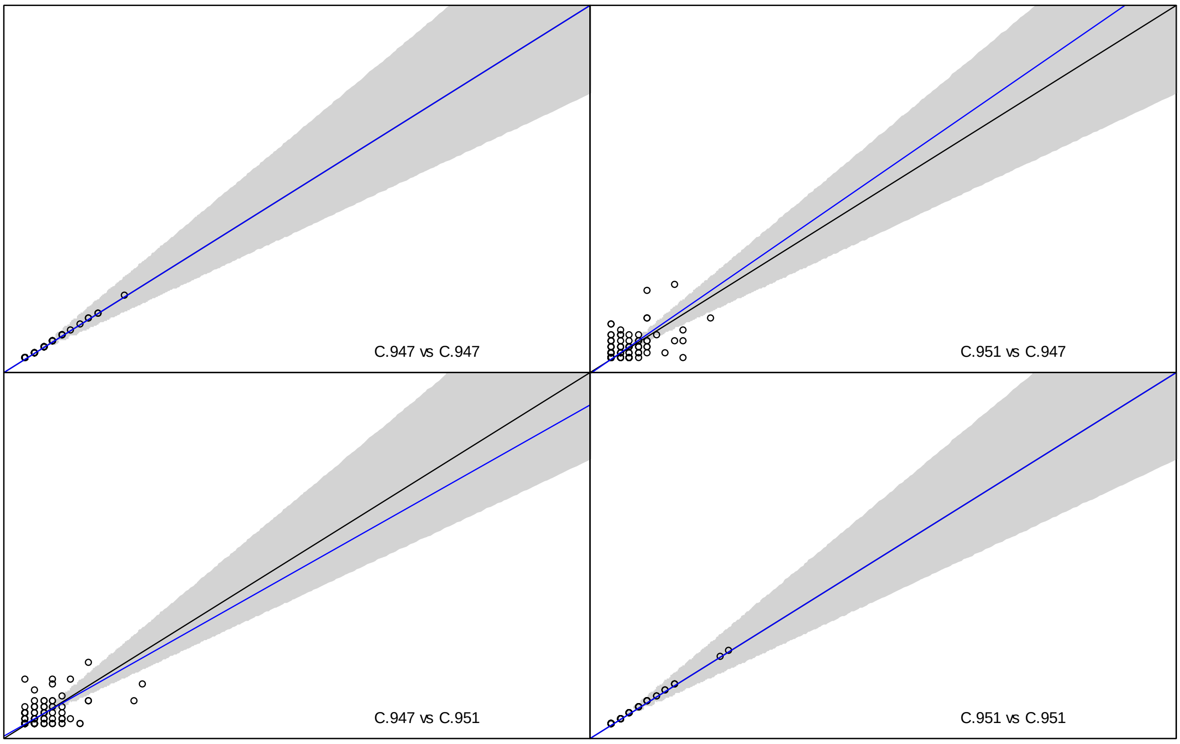


Figure 3.40: Orthogonal regression plot of C-POD comparisons in calibration MP Cal 008 (sub trial 13), in blue, with a null model where each unit performs exactly the same, in black, and an acceptable error margin of ±20%, in grey

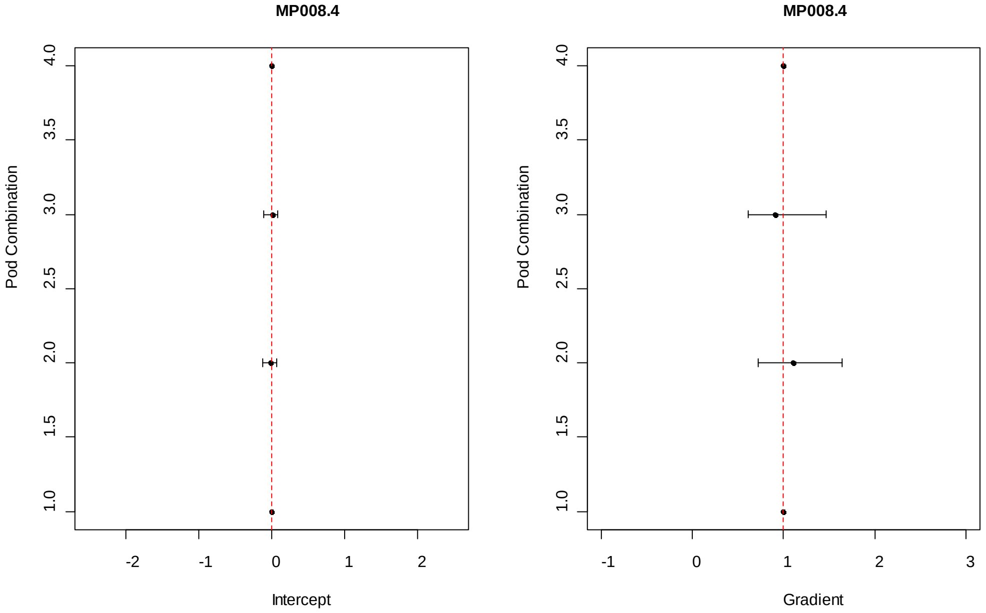


Figure 3.41: Centipede plot of the intercept and slope values (±std) of the orthogonal regression plots for each pod performance comparison in calibration trial MP Cal 008 (Sub trial 13). Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model that both pods are performing the same

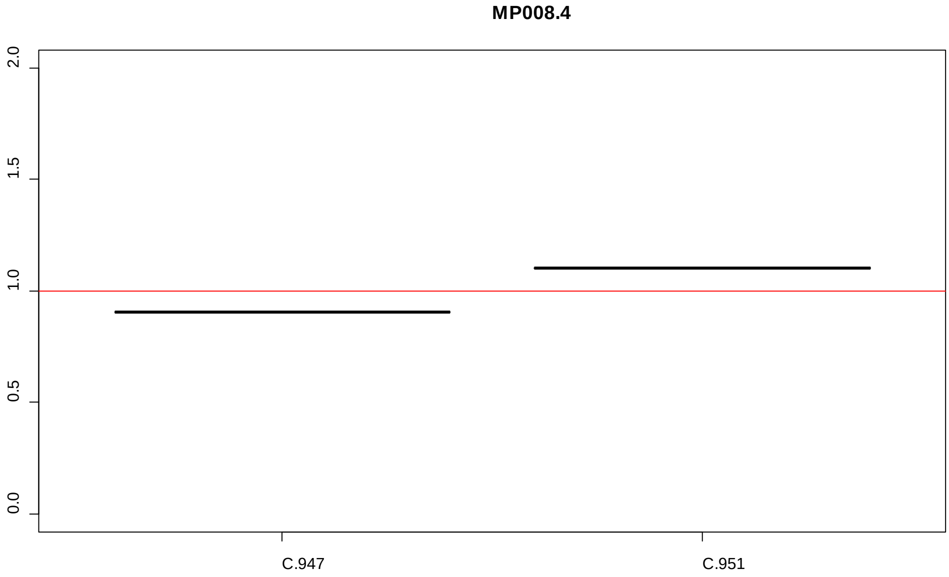


Figure 3.42: Box plot of the mean slope values (±std) of the orthogonal regression plots for each pod in calibration trial MP Cal 008 (Sub trial 13). Outliers indicate poor performers and pods with high sensitivity

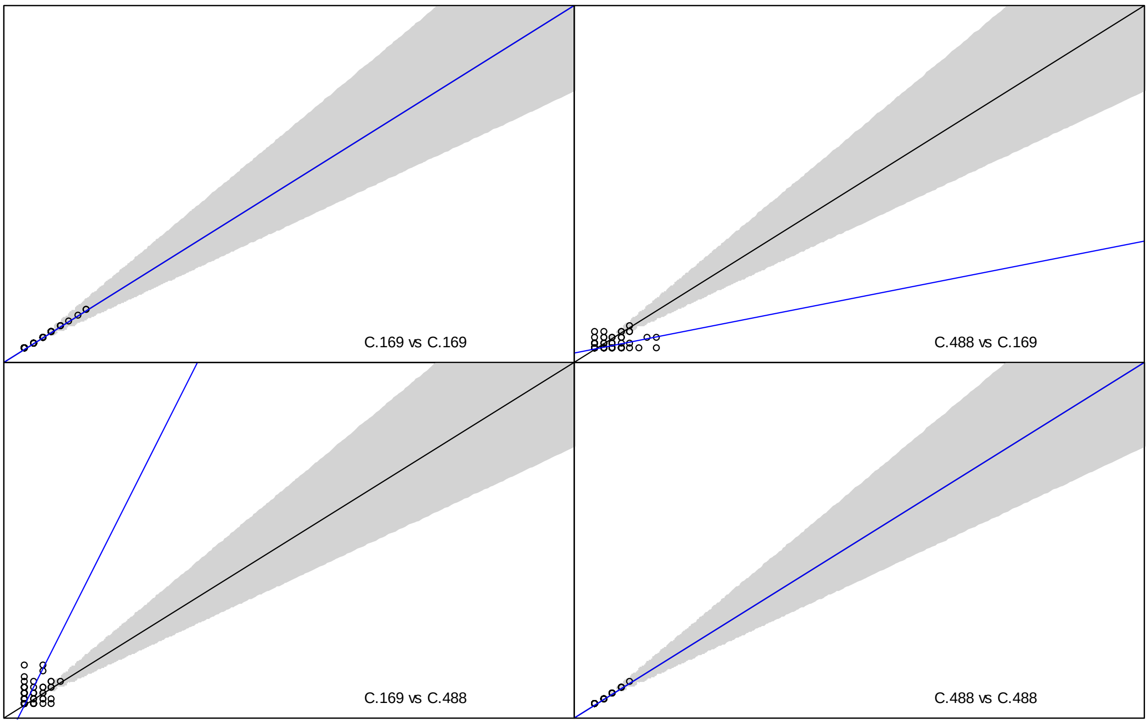


Figure 3.43: Orthogonal regression plot of C-POD comparisons in calibration MP Cal 008 (sub trial 14), in blue, with a null model where each unit performs exactly the same, in black, and an acceptable error margin of ±20%, in grey

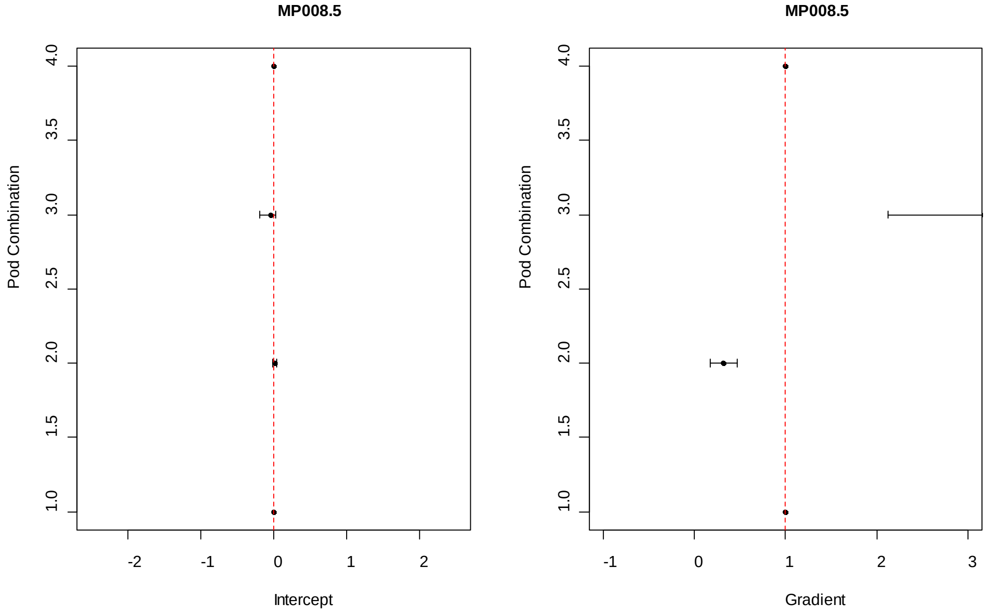


Figure 3.44: Centipede plot of the intercept and slope values (±std) of the orthogonal regression plots for each pod performance comparison in calibration trial MP Cal 008 (Sub trial 14). Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model that both pods are performing the same

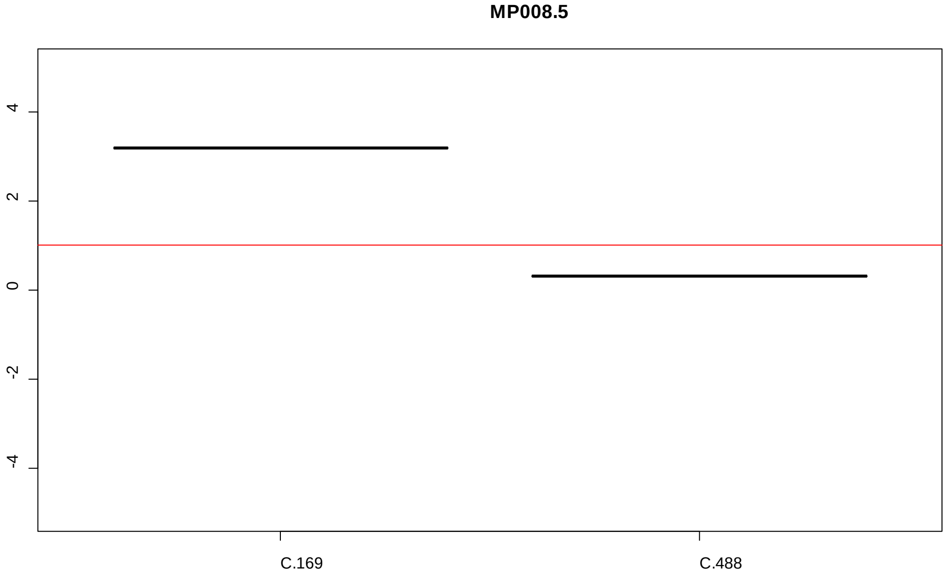


Figure 3.45: Box plot of the mean slope values (±std), of the orthogonal regression plots, for each pod in calibration trial MP Cal 008 (Sub trial 15). Outliers indicate poor performers and pods with high sensitivity

3.4. Discussion

From the dataset, it is recommended that field trials such as those carried out are sufficient to monitor C-POD performance and to identify outliers that need to be re-calibrated by the manufacturer. It is probable that C-PODs over time may lose sensitivity due to various reasons (rough handling, accidental drops, exposure of internal components when servicing) and unit to unit variation will increase. Conducting field calibration is necessary when introducing new units to an existing study and should also be carried out annually to determine any possible degradation over time. This analytical technique of POD performance relies on unit to unit comparisons and three diagnostic tools to identify error and potential outliers. In this analysis 10 units were highlighted for further investigation but four of these were found in later trials to perform within the acceptable 20% error margin. A further two units, C-488 and C-947, may have been functioning correctly. But due to comparisons against only one other unit, it is impossible to determine which unit was responsible for the variation. It is, therefore, recommended that C-PODs should be sent back to the manufacturer for re-calibration only when field calibration trials highlight a unit as problematic after more than one trial. It is also advised that field trials should test three units or more at a time to aid more informed data interpretation.

Units that were thought to have decreased in sensitivity over time gave an average timeline of 17-24 months, based on all possible scenarios. Informed evaluations were made throughout the study to determine whether units were highlighted perhaps due to an anomaly associated with the trial or whether the units required re-calibration. No units were continually highlighted as problematic during the calibration study and therefore all C-POD data were used in the project analysis. This project employed three methods to account for variation in C-POD units: Field calibration tests were used to identify any faulty or degrading units; units were randomly assigned to sites by re-placing PODs with a different unit when they were retrieved and, thirdly, POD ID was inserted as a random factor during statistical analyses. In the event that a unit is continually highlighted as inconsistent, it is also possible to apply a correction factor to the data. Correction factors are generated where a reference unit is kept solely for calibration purposes and is used from which to compare all other units. A reference unit is identified during an initial trial as being the most sensitive unit. A correction factor (CF) can be calculated by using the following equation, where the mean number of Detection Positive Minutes (DPM) per hour recorded by the reference unit (the most sensitive unit) is divided by the mean number of DPM of the least sensitive unit:

$$\mathbf{CF} = \frac{\mathbf{DPM/h\ (reference\ unit)}}{\mathbf{DPM/h\ (pod\ to\ be\ calibrated)}}$$

This is only necessary in cases of substantial variability (>20%) or when the methods to account for variation described above have not been carried out. This method was not employed during the present study.

The use of controlled experiments carried out in tanks is only necessary where measurements are required on absolute thresholds of individual units for the estimation of density from SAM data. When studies only require presence/absence data for the exploration of habitat use and behaviour, field calibrations are sufficient and allow comparison of data between sites (Tregenza *pers comms*.). The method of rotating units between sites and the inclusion of POD ID during statistical analyses incorporates levels of variation between units and has not previously been carried out. Therefore, this study can serve to inform future SAM programmes. The use of clicker devices of known sources and frequency proved useful in the exploration of detection range for PODs and can also be applied to other SAM and PAM devices.

The deployment location of units should also be taken into account as deployments in noisy areas, with a lot of background noise from shipping, break waters, strong tidal currents or other environmental conditions, will use the battery and data storage at a greater rate than in an area where there is little background noise. This may lead to units having to be retrieved and serviced more often than recommended to avoid gaps in the dataset. Additionally, high levels of background noise can interfere with the detection ability of units to record echolocation clicks and, therefore, can bias a dataset. Trials should be carried out to assess the effect of depth on unit performance where units are to be deployed in deep water, i.e. greater than 50m. All deployments during the present study were within 37m; therefore, the effect of depth could not be sufficiently determined. It is recommended that deployments for multiple species be carried out systematically with a standardised depth used across locations. Alternatively, where species specific sites are monitored, units should be deployed at the depth those animals are most active (i.e. PODs deployed close to the bottom in locations where porpoises are solely monitored and mid water for dolphin monitoring). Where dolphins and porpoises occur, deploying units at mid water allow for the successful monitoring of both species.

4. DETECTION RANGE OF SAM

4.1. Introduction

If SAM is to be used to monitor the distribution and habitat use of cetacean species and to inform conservation management, it is essential to determine the detection range of the acoustic equipment (Akamatsu *et al,* 2001, Akamatsu *et al,* 2008). Therefore, it is important to know over what distance the acoustic device effectively detects the target species and to decide on the number of units required to effectively monitor an area. A number of studies using T-PODs have looked at detection distance for various cetaceans, including harbour porpoises (Tougaard *et al,* 2006), bottlenose dolphins (Philpott *et al,* 2007; Bailey *et* al, 2010) and Hector's dolphins (*Cephalorhynchus hectori*), *(*Rayment *et al,* 2009b). Corresponding theodolite and T-POD data resulted in an effective detection radius of 107m for harbour porpoises, with detection probability decreasing rapidly at greater distances (Tougaard *et al,* 2006).

Philpott *et al* (2007) calculated the distance between the closest bottlenose dolphin in a school and a T-POD (*v*3) through land-based theodolite tracking. Simultaneous visual and acoustic detections of dolphin schools were used to measure acoustic detection distance of the T-POD. Echolocation encounters logged during land-based observation periods were used to match up visual and acoustic data. The nearest observed distance for each school was used in order to determine a conservative estimate of T-POD detection range. They reported a range of over 1,200m for a single school. However, the author was unable to exclude the possibility that the detection might have been caused by an unobserved group at closer distance, especially since the author was the only observer during the field trials. Rayment *et al* (2009b) also used the theodolite tracking technique to match acoustic detections of Hector's dolphins with the precise times of theodolite readings, taking measurements from the centre of a dolphin group. They had two observers on site, one for theodolite operation while the other person recorded group position and group size. They defined the maximum detection distance as the maximum distance between a focal dolphin group and the T-POD (*v*3), corresponding to an acoustic detection on a T-POD within 10 seconds of the theodolite reading. They found a maximum detection distance of 431m between a Hector's dolphin group and the T-POD. They also estimated the effective detection radius (EDR), which is the range at which all dolphin groups are expected to be detected. This was estimated at between 198m and 239m depending on the clicks used in determining detection.

4.2. Material and Methods

During the present study, trials were carried out at two locations to determine the detection range of two acoustic devices, C-PODs and T-PODs, for both harbour porpoises and bottlenose dolphins. As bottlenose dolphins are resident in the Shannon Estuary, the site at Moneypoint was chosen for simultaneous deployments with land-based theodolite tracking. Trials were carried out from Black Head in Galway Bay as harbour porpoises are regularly recorded close to shore at this location.

T-PODs were configured to detect clicks from dolphins and porpoises on alternate channels, 1-6, while C-PODs were set to log tonal clicks within frequency bands ranging between 20 and 160 kHz. Dolphin acoustic detections registered on T-PODs consist of clicks within the 50 to 70 kHz channels, and porpoises between 92 and 130 kHz channels, following the manufacturer's guidelines. C-PODs will register click trains into two categories of cetaceans: 1) NBHF (Narrow Band High Frequency) and 2) Other (dolphin species which include all other odontocetes, except sperm whales). C-PODs and T-PODs cannot distinguish between dolphin species but as the trials were carried out within the Shannon Estuary, no other dolphin species were recorded. Only acoustic detections under the class "*Cet All*", which included both high and moderate probability cetacean detections, were used in the analysis.

Land-based theodolite tracking was carried out using a Leica T100 Electronic Theodolite. The theodolite was set up on top of a cliff at a disused quarry (at an elevation of 17.54m) adjacent to Moneypoint power station, whereas acoustic equipment was statically moored from a jetty (Figure 4.1). In Galway Bay, the theodolite was set up adjacent to Black Head Lighthouse, at a height of 13.5m. The acoustic equipment was deployed 183m offshore on a light weight mooring. The method used during observations at both sites consisted of two observers positioned on land, where one person operated the theodolite and the other observed and followed the group of cetaceans (Figure 4.2). The second person ensured that only one group was within the field of view. Once cetaceans entered the observation area, the tracker focused the theodolite on the group, taking horizontal and vertical angle readings at least every 30 seconds if possible. Tracking was focussed on the nearest animal to the SAM gear, giving a minimum distance to the group assuming that the nearest animal was more likely to be detected by the SAM equipment. The surveyor kept scanning, giving information about group composition and behaviour, and also searching for other groups, which might confound the results. For every tracking event, the following information was noted: group formation (tight, loose and dispersed), surface mode (peppy, quiet, surface rush, occasional races), direction, speed (normal, fast, and slow), and behaviour (travelling, socializing, and feeding), (modified from Leeney *et al,* 2007). A group was defined as individuals moving in the same direction within 100m of each other and exhibiting the same behaviour (Shane, 1990). Cetaceans were tracked until they left the area or the tracker lost sight of the group. All observations were made during daylight hours in Beaufort sea state ≤ 2.

Figure 4.1 and 4.2: Theodolite set up with the reference point in the background (jetty at Moneypoint Power Station) and observer-based tracking

4.2.1. *Data Analysis*

Theodolite readings were entered into an Excel.csv file at the lab and were then imported into the marine mammal positioning system Cyclops Tracker (http://cyclops-tracker.com/). This programme has been designed to accurately record and locate marine mammals from a known location. Cyclops tracker requires the horizontal and vertical angles for theodolite tracking: the horizontal angle indicates the direction of the observed animal in relation to magnetic north while the vertical angle is used to calculate the distance from a known location. As tide height can alter the vertical angle reading and, therefore, the distance estimation, tidal parameters spanning the whole time period of the land-based study were input into Cyclops prior to data analyses.

Two methods were employed to determine an accurate detection range. For the first method, an acoustic match was defined as an acoustic detection on the C-POD/T-POD, which corresponded to a visual observation of the focal group within the timeframe of that sighting (Bailey *et al*, 2009; Philpott *et al*, 2007). As this was a coarse match for the precise theodolite fixes, only the minimum distance recorded from each matched focal group to the acoustic equipment was used for analysis. This was used to determine a conservative estimate for the detection range.

A second approach described by Rayment *et al* (2009b) was applied to determine a more accurate detection range of the acoustic equipment. Using this approach, a successful match was defined as an acoustic detection on the C-POD/T-POD which corresponded to a visual detection within the same ten-second period. This method takes into account swimming speeds, which for bottlenose dolphin and harbour porpoise have been recorded at rates of 6.09m/s and 4.2m/s respectively for high speed swimming, giving error values of 61m and 42m (Fish, 1993, Otani *et al*, 2001). Detection distances were calculated for each acoustic match and used as independent observations as there was no evidence to suggest that detection distances from the same group were less variable than those from different groups (Rayment *et al,* 2009b). Where more than one visual detection corresponded to an acoustic detection, the most conservative distance was recorded.

4.3. Results

Detection distance trials were carried out at Black Head for harbour porpoise and in the Shannon Estuary for Bottlenose dolphins (Table 4.1). Mooring types varied as did deployment period.

Table 4.1: Summary of deployment details where land-based theodolite tracking was carried out (ES-J = Existing structure-Jetty, LWM=Light weight mooring)

Summary of trial deployments						
Study site	**Start date**	**End date**	**Depth (m)**	**Mooring**	**Total hrs**	**Units**
Moneypoint	02/07/2009	15/07/2009	12	ES-J	312	9 (8 C-PODs)
Black Head	01/06/2010	04/06/2010	10	LWM	72	3 (2 C-PODs)

4.3.1. *Harbour porpoise trials at Black Head*

During 39 hours of land-based visual monitoring, 36 harbour porpoise groups were visually detected, with distances ranging from 19.9m to 1,951.8m from the SAM equipment (e.g. Figure 4.3). Of these 36 groups, 81% were detected on the C-POD and 50% were detected on the T-POD (Figure 4.4). Using the first approach, the minimum distances calculated from each acoustically matched group to the C-POD ranged from 19.9m to 430.6m, with 97% of groups detected at less than 400m. The T-POD detection distances ranged from 109.4m to 453.5m, with 83% of groups detected at less than 400m (Figure 4.5). No acoustic detections were recorded within the band 0-99m for the T-POD. This is most likely due to a difference in the sensitivity of the hydrophone element as the T-POD was deployed alongside the C-POD.

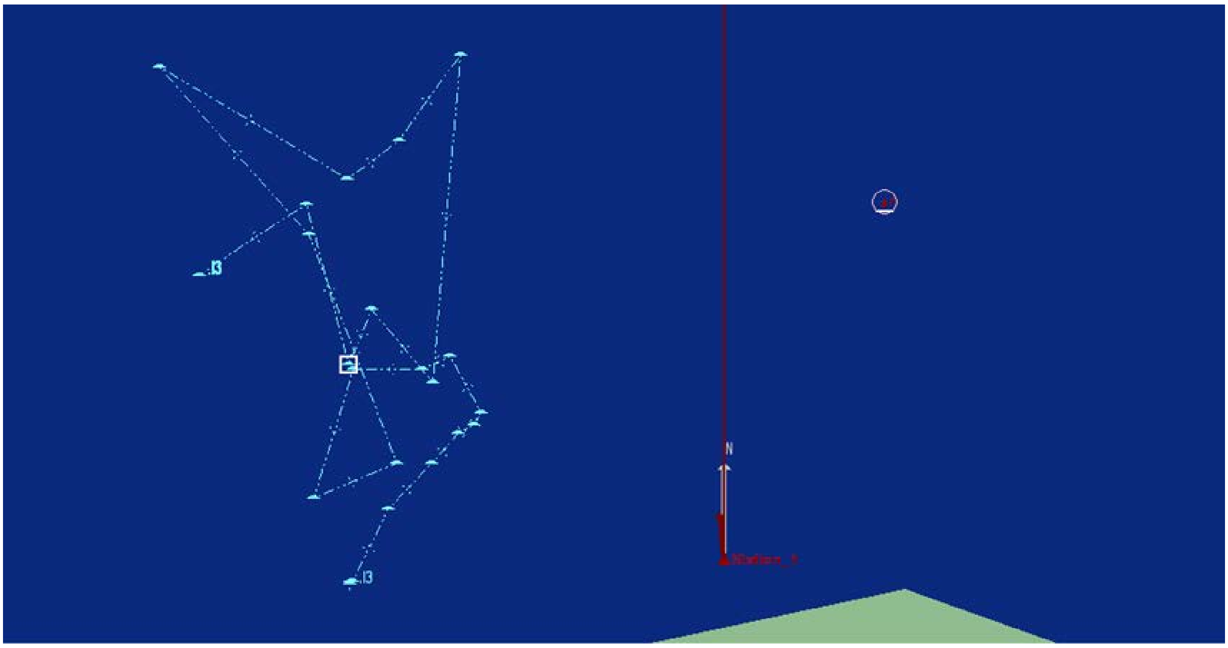


Figure 4.3: Example of a harbour porpoise track from Blackhead, Co Clare, 03/06/2010. The theodolite tracking station is shown in as 'Station 1' and the position of the SAM equipment is indicated by a white circle. The distance range of this track was calculated as 209.3m to 344.2m from the SAM equipment

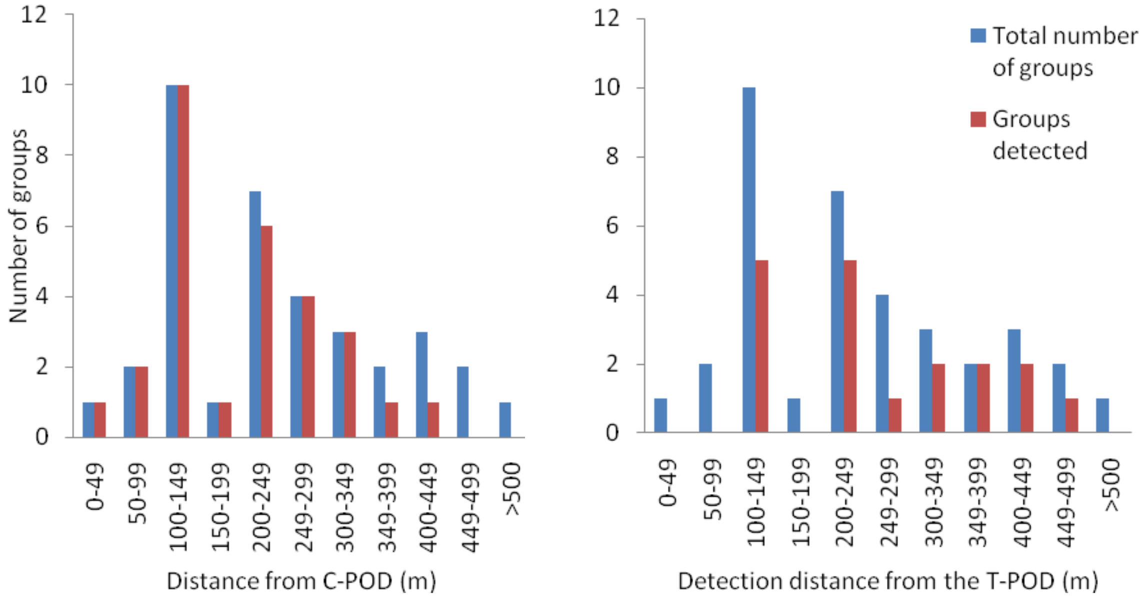


Figure 4.4: Number of harbour porpoise groups detected, both visually and acoustically, and the total number of groups visually detected with distances from the SAM equipment

The second technique to investigate detection range of C-PODs and T-PODs resulted in 50 harbour porpoise acoustic matches with the C-POD and 27 matches with the T-POD. The furthest distance that a visual observation corresponded to an acoustic detection was 441m ±42m (92% <400m) for the C-POD and 534.3m ±42m (59 % < 400m) for the T-POD, allowing for a slightly higher estimate of detection range (e.g. Figure 4.6 and 4.7)

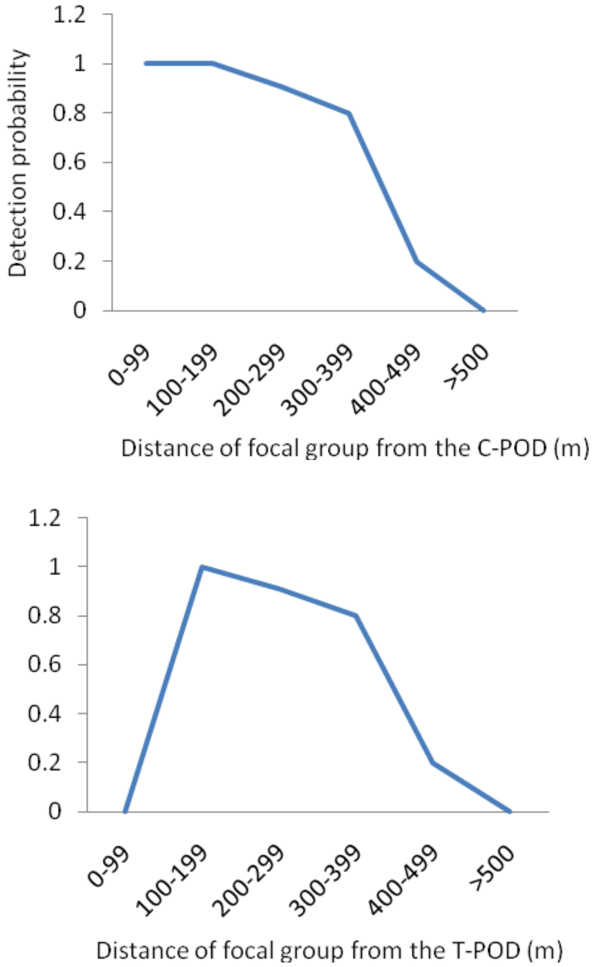


Figure 4.5: C-POD and T-POD detection probability over varying distance categories where probability is the number of acoustically matched groups divided by the total number of groups within each distance category

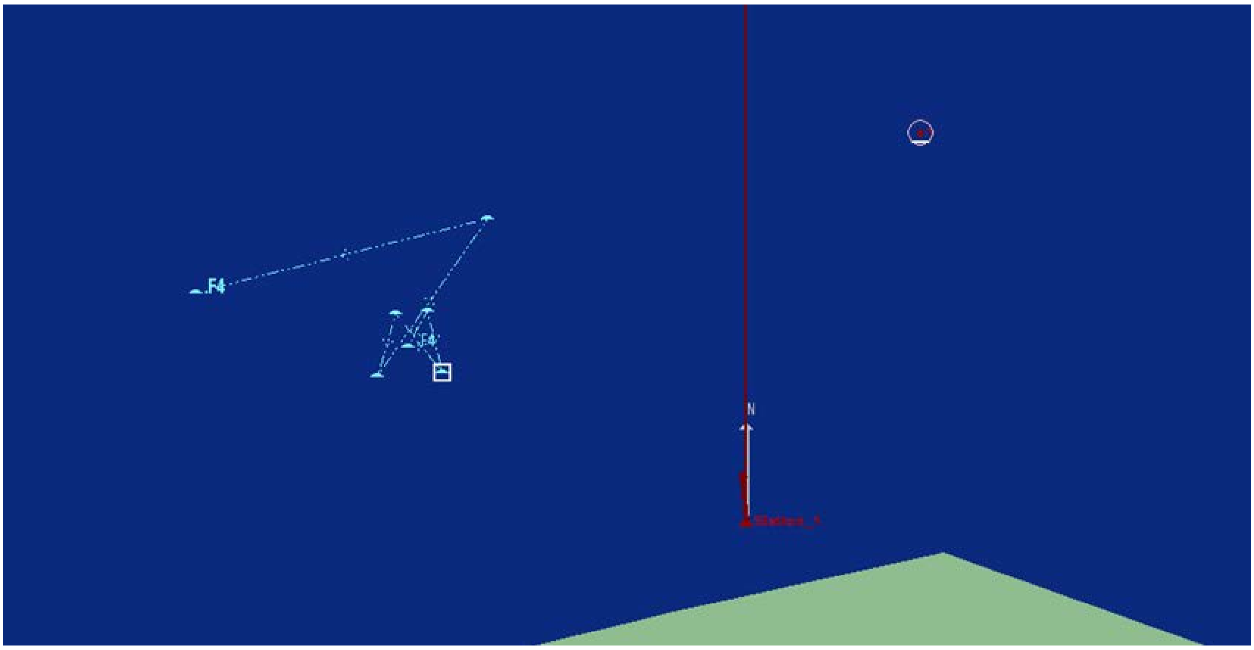


Figure 4.6: Example of a harbour porpoise track from Blackhead, County Clare, 04/06/2010. The theodolite tracking station is shown in as 'Station 1' and the position of the SAM equipment is indicated by a white circle. The distance range of this track was calculated as 190.2m to 319.8m from the SAM equipment

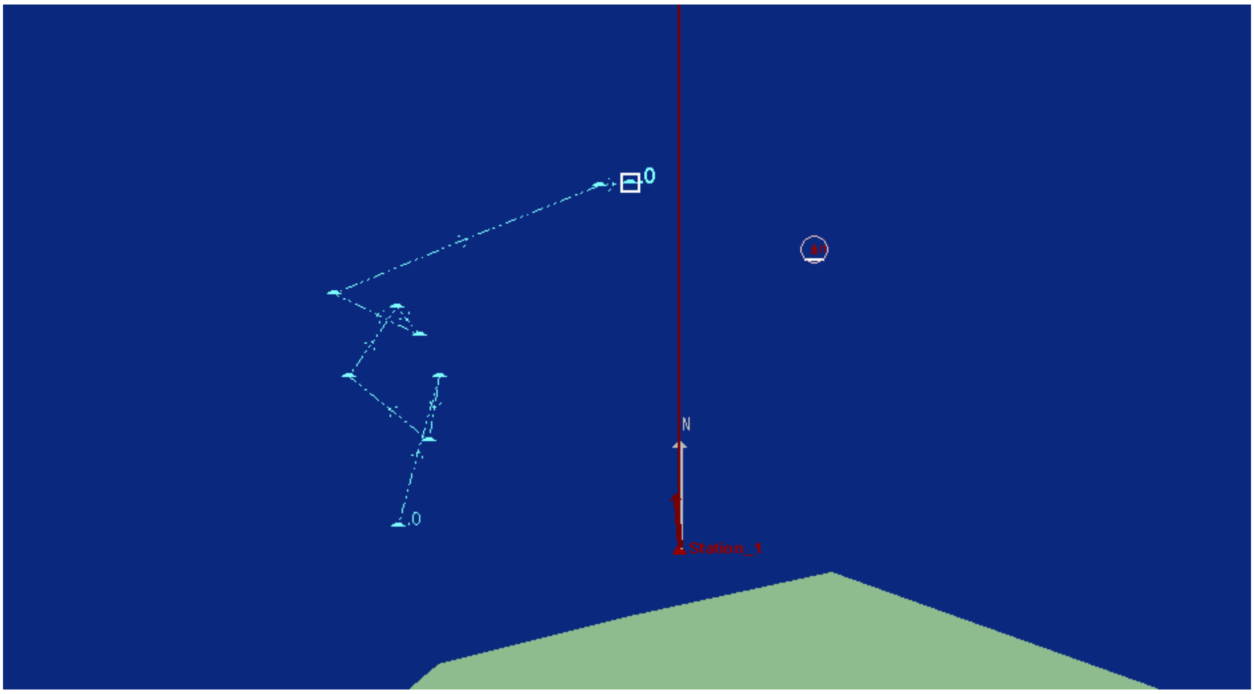


Figure 4.7: Example of a harbour porpoise track from Blackhead, County Clare, 02/06/2010. The theodolite tracking station is shown in as 'Station 1' and the position of the SAM equipment is indicated by a white circle. The distance range of this track was calculated as 109.4m to 279.9m from the SAM equipment

4.3.2. *Bottlenose dolphin trials in the Shannon Estuary*

During 47 hours of land-based visual monitoring, a total of 30 bottlenose dolphin groups were visually detected at distances ranging from 47.3m to 6,731.6m from the SAM equipment (e.g. Figure

4.9 and 4.10). Of these, seven groups (23%) were detected on the C-POD (Figure 4.8). Using the first approach, the minimum distances calculated from each acoustically matched group to the C-POD ranged from 83.1m to 284.0m.

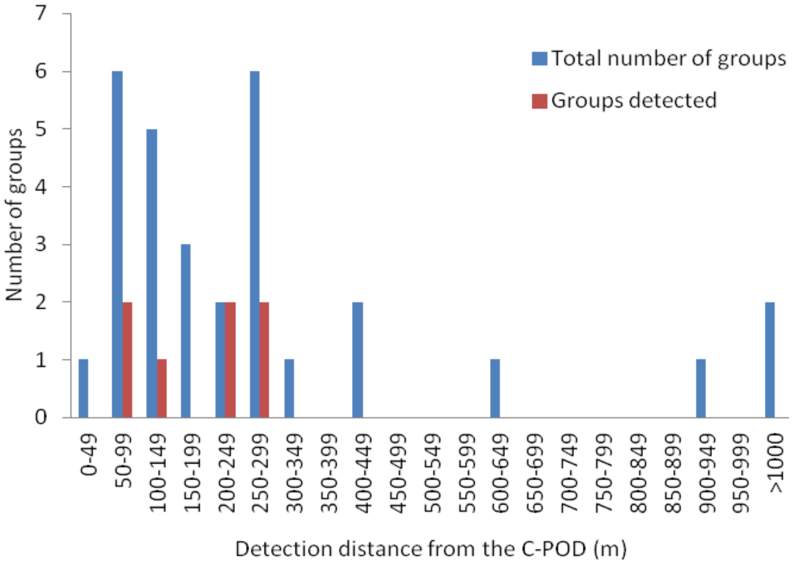


Figure 4.8: Number of bottlenose dolphin groups detected (both visually and acoustically) and the total number of groups visually detected with distances from the SAM equipment

The second technique used to investigate detection range of C-PODs resulted in 12 bottlenose dolphin acoustic matches corresponding with visual data. The furthest distance that a visual observation corresponded to an acoustic detection was 797.6m ±61m (75% of groups recorded<400m) for the C-POD, allowing for an extensively higher estimate of detection range (Table 4.2).

Table 4.2: Acoustically matched bottlenose dolphin tracks with distance of dolphin group from C-POD calculated in meters

Matched Bottlenose dolphin tracks		
Date	**Track ID**	**Distance from CPOD (m)**
02/07/2009, 11:08:03	.A	797.6
02/07/2009, 11:08:31	.A	727.2
02/07/2009, 12:17:00	.C	277.3
08/07/2009, 13:21:32	.C2	125.2
08/07/2009, 13:21:54	.C2	120.3
08/07/2009, 13:23:08	.C2	104.9
09/07/2009, 12:15:13	.B3	401.2
09/07/2009, 12:30:51	.C3	353.2
09/07/2009, 12:31:21	.C3	355.1

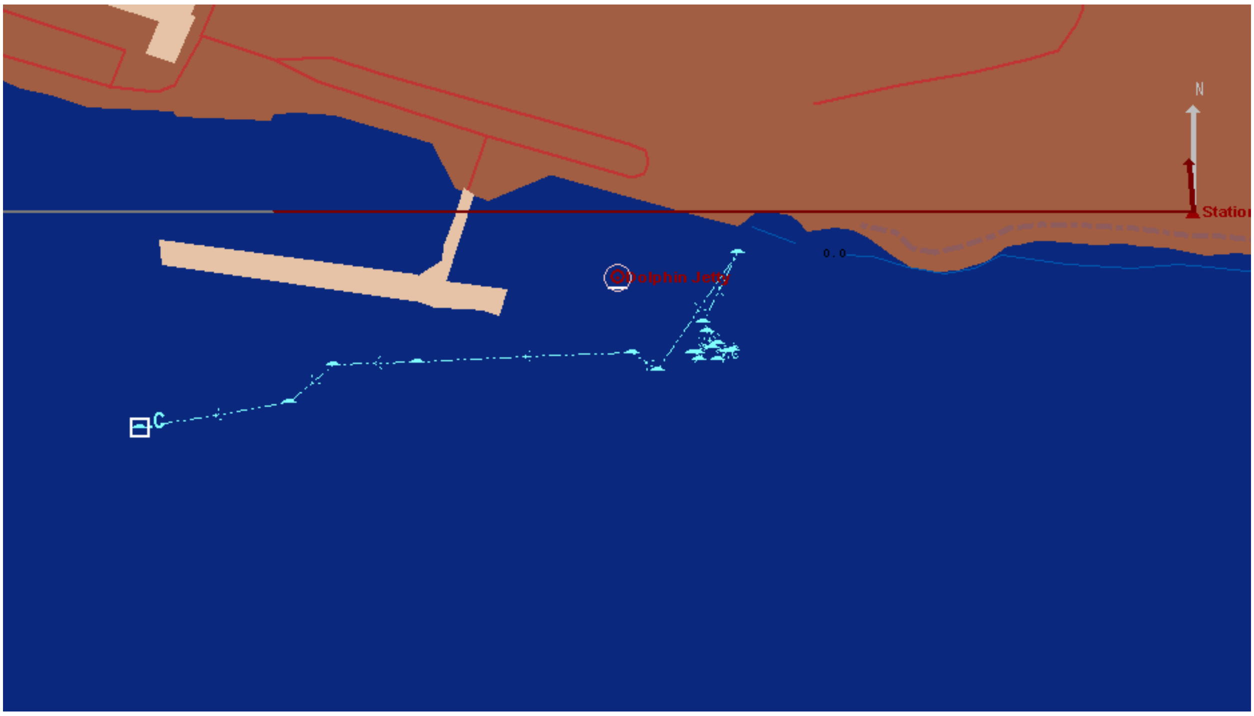


Figure 4.9: Example of a bottlenose dolphin track from Moneypoint, County Clare, 08/07/2009. The theodolite tracking station is shown in as 'Station 1' and the position of the SAM equipment is shown as 'Dolphin Jetty'. The distance range of this track was calculated as 83.1m to 544.5m from the SAM equipment

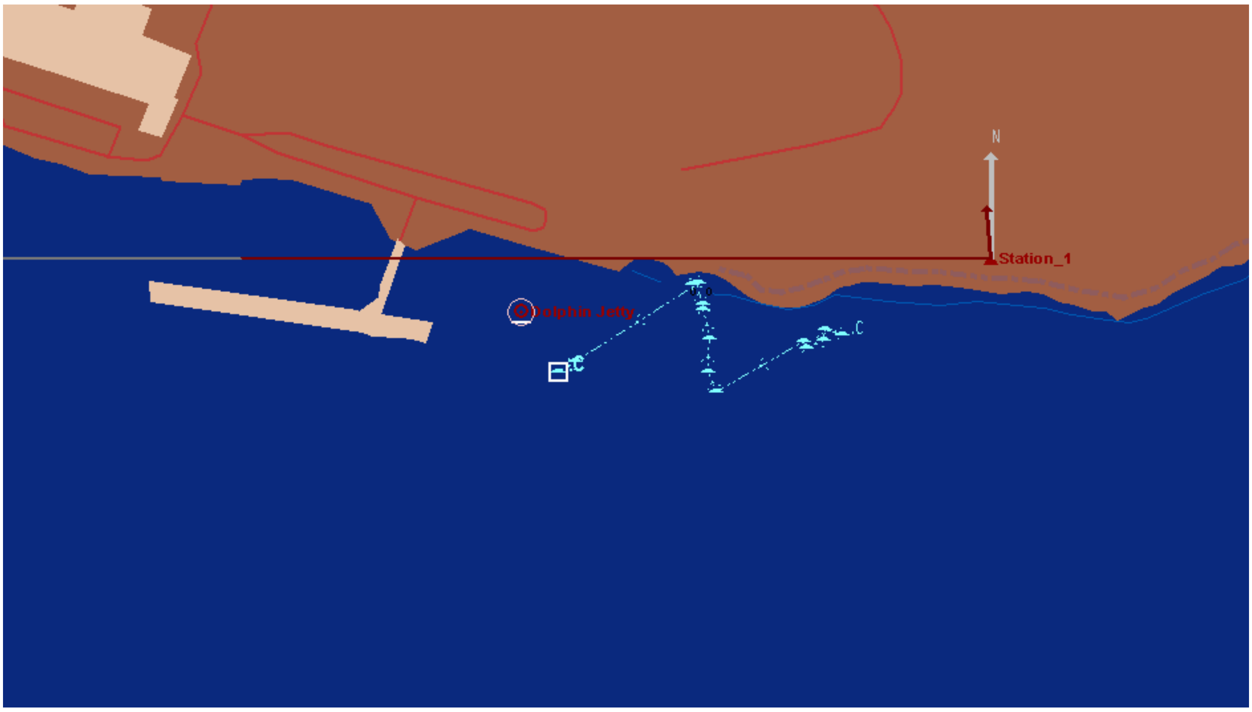


Figure 4.10: Example of a bottlenose dolphin track from Moneypoint, County Clare, 10/07/2009. The theodolite tracking station is shown in as 'Station 1' and the position of the SAM equipment is shown as 'Dolphin Jetty'. The distance range of this track was calculated as 93.7m to 428.9m from the SAM equipment

4.4. Discussion

As a result of the detection distance trials carried out, a detection range for C-PODs was derived for bottlenose dolphins (797.6m) and harbour porpoises (441m). The large difference in detection range between both can be attributed to the acoustic characteristics of their echolocation clicks, where dolphins are broadband at mid frequency and porpoise being narrowband and high frequency. It is these characteristics that affect their click attenuation through the water column and, as a result, influence their detectability by a unit. The detection range generated as part of the current study for bottlenose dolphins is much less than a previous estimate derived in the same study site but further out the estuary by Philpott *et al* (2007), using v3T-PODs. This difference in results is most likely due to difference in the composition of the hydrophone but may also be due to the fact that a single observer was used during land-based observations and, therefore, only tracked animals could be noted. If another group occurred closer to the SAM gear, then it would be difficult to determine. T-POD results recorded during the present study fail to reflect C-POD data, where no detections were recorded within the 0-99m band. This result could not be explained as the unit was set to record dolphins and porpoises and, therefore, may be due to the software extraction and is not as sensitive as the new C-POD.exe. Results from porpoise trials are similar to those reported by Rayment *et al* (2009b) for Hector's dolphins, which have a very similar click structure to harbour porpoise (narrow band, high frequency).

Land-based theodolite tracking can be a coarse method of range estimation for units but as it takes into account free swimming animals in their natural habitat, it gives an accurate reflection of an animal's approach sequence to the equipment. The main sources of error associated with this method include observer variability, accuracy of theodolite positioning and estimation of station height when carrying out analyses.

The SAM equipment located at Moneypoint jetty was surrounded by large metal pylons. It is possible that these structures would affect bottlenose dolphin echolocation, potentially reducing the detection distance of 'dolphin' clicks by the SAM gear, as animals may alter the frequency of their clicks in the vicinity of the equipment to prevent being ensonified by returning echoes. During long-term monitoring at Moneypoint, a total of 235 DPMs were recorded in the NBHF channel using C-PODs. This accounted for 6% of the total C-POD DPMs at Moneypoint. This result was due to bottlenose dolphins increasing their frequency of click production, and this was confirmed from visual observations at the site when only dolphins were present.

Results from this study yielded fewer acoustic matches with bottlenose dolphin data than harbour porpoise. As the C-POD will only provide information on echolocating animals, silent or non-echolocating individuals will remain undetected. Studies in Sarasota Bay found that bottlenose dolphins can often swim for 10 minutes without echolocating and that their use of echolocation varied depending on water clarity (Au, 2000). Therefore, if animals are known to use an area for foraging then they will be more likely detected than if just passing through. If a foraging site is used for detection trials, then results can be generated more efficiently. A study by Akamatsu *et al* (2007) found that harbour porpoises produce a sonar click train every 12.3 seconds,while 90% of the periods with no echolocation lasted only 20 seconds or less. Hence, the authors concluded that harbour porpoises seem to continuously echolocate. For this reason, detection range for harbour porpoise are more easily derived if a good site is established with a high vantage point.

Tracking of both bottlenose dolphins and harbour porpoises during the present study recorded groups of varying sizes and behaviour. During all trials, the animal nearest the SAM equipment was the focus of all visual theodolite tracks. Group size or behaviour type of tracked animals was not correlated against detection ability for either species during the present study. However, a recent study by Nuuttila *et al* (2012) found that single bottlenose dolphins were more likely to be detected using C-PODs in comparison with groups of multiple animals, regardless of behaviour.

In order to reduce the variability and increase the precision of this method, multiple observers should be used to carry out fieldwork. Observers should be tasked with tracking using the theodolite, another observer should be on data recording, and an additional observer is required to watch the area in the vicinity of the SAM equipment to verify that the animals being tracked are in fact the closest in range. Additionally, the theodolite should be continually monitored to ensure it stays in a level position. These trials should be carried out in areas with high densities and where animals are known to occur at varying distances from the deployment location. It is also important that the area has not got a high level of background noise as this will interfere with a unit's ability to detect echolocation clicks and not give a true representation of their detection capability. The field calibration of equipment should be carried out prior to detection distance trials in order to ensure that unit performance has been assessed. Where differing sensitivities are observed between units, multiple PODs should be deployed. This will also mitigate against wasting field time if units fail to operate.

The results derived during the present study will serve to provide baseline information for management, planning long-term monitoring programmes for specific species or areas. In order to determine the minimum number of units required to effectively monitor an area of known distance, then, the detection range of the equipment coupled with the average home range of the target species should be taken into account.

5. LONG-TERM SAM ON THE WEST COAST OF IRELAND

5.1. Introduction

Static Acoustic Monitoring (SAM) involves the detection and recording of cetacean vocalizations or echolocation clicks and is a very valuable tool for the exploration of fine scale habitat use by the various odontocete species. SAM can be carried out with a number of devices including static hydrophones (Berrow *et al* 2006), C-PODs and T-PODs (Carlström, 2005; Verfuß *et al,* 2007; Berrow *et al,* 2009a), A-Tags (Akamatsu *et al,* 2008), porpoise click loggers (PCLs/AQUAclick), (Roos, 2007), Ecological Acoustic Recorders (EARs), (Lammers *et al*, 2008), Pop-Ups (http://www.birds.cornell.edu/) and sonobuoys (Moore *et al,* 1989). In comparison with SAM, visual observation carries with it many constraints and is influenced by variables such as sea state (Evans and Hammond, 2004; Teilmann, 2003; Palka, 1996; Clarke, 1982), observer variability (Young and Peace, 1999; O'Brien *et al*, 2006), optics and height above sea level. Evans and Hammond (2004) state that visual surveys should generally not be carried out in sea states above Beaufort scale 2, as the probability of detecting animals is markedly reduced above this. SAM is especially useful for monitoring small vocal cetaceans since it can be carried out without the interference of the variables mentioned above, and, most importantly, does not negatively impact upon the animals. A SAM device called a Timed Porpoise Detector (T-POD) has been used during a number of studies for various purposes, including environmental impact assessments (EIAs) (Carstensen *et al,* 2006), interactions between cetaceans and fisheries (Cox *et al,* 2001; Leeney *et al,* 2007; Berrow *et al,* 2009b), monitoring population trends (Verfuß *et al,* 2007; Berrow *et al,* 2009a), and behaviour including diel and tidal trends in vocal activity (Carlström, 2005). Initially, the POD or porpoise detector, designed and manufactured by Chelonia Ltd (www.chelonia.co.uk) in the UK, was intended specifically to detect harbour porpoises, while more recent versions (T-PODs and presently C-PODs) were designed to detect both harbour porpoises and dolphins. The echolocation characteristics of porpoises and dolphins differ, but an overlap in frequencies can make the discrimination between species difficult.

As a monitoring tool, the POD essentially provides information on the presence of animals and gives a measure of vocalization activity and behaviour. However, these data are non-quantitative and give no information on absolute abundance of animals in an area. A study by Tougaard *et al* (2006) generated a measure of absolute density by assuming that sampling an area *n* times through SAM is the equivalent to sampling *n* sub-areas, e.g. during an aerial survey, and found that the estimate they generated from acoustic data was similar to that determined as part of an international SCANS project (Small Cetacean Abundance in the North Sea) survey conducted in July 1994. However, this method of analysis is novel and has not been widely adapted.

SAM gives an alternative means to monitor cetacean species and data can be acquired continuously if the target species are vocalising. The main advantage of SAM is that is can provide information on species that can go undetected visually for up to 87.1% of the time (bottlenose dolphins; Mate *et al,* 1995) and 95% (harbour porpoise; Read and Westgate, 1995).

The aim of the present study was to acoustically explore the occurrence of small cetaceans at three sites (two candidate SACs) on the west coast of Ireland. The efficacy of SAM and its potential as a monitoring technique was addressed. Under the EU Habitats Directive (92/43/EC), Ireland is required to maintain the total national population of Annex II species (harbour porpoise and bottlenose dolphin) at *Favourable Conservation Status* (FCS) through ensuring that there is a sufficiently large habitat of suitable quality available to support the long term survival of these species. Criteria necessary to support an area as suitable for SAC designation includes the continuous or regular presence of the species, a high density estimate for the area by comparison with adjacent areas, and a good adult to calf ratio. If an area can be shown to support the above criteria and can be highlighted as an area essential to the life and reproduction of the species, then it should be considered for SAC designation (Johnston *et al,* 2002). An assessment of FCS of a species needs to be underpinned with precise scientific knowledge. Although SAM data will only provide information to fulfil part of this criteria and needs to be supplemented with visual data for the generation of density and absolute abundance, it can record important spatial and temporal trends at and between sites which could not be collected by visual means. As part of long-term SAM, it was also aimed to explore the feasibility of an acoustic monitoring index of activity at a site. This index should serve as a means to monitor an area over time scales of various durations and to highlight increases and decreases in activity. The index could be compared across sites to assess acoustic activity and to highlight the importance of specific sites.

5.2. **Material and Methods**

During long-term SAM, C-PODs were the main tool used for monitoring as they provided the longest battery life and were automated (Table 7.0). C-PODs log tonal clicks within frequency bands between 20 and 160 kHz. C-PODs registered click trains into two categories of cetaceans: 1) NBHF (Narrow Band High Frequency) and 2) Other (dolphin species which include all other odontocetes, except sperm whales). All data were extracted using C.POD.exe and exported to Excel.xlsx files as Detection Positive Minutes (DPMs). C-PODs were deployed at a number of locations on the west coast, including Galway Bay, the Shannon Estuary (bottlenose dolphin cSAC), and the Blasket Islands (harbour porpoise cSAC) (Figure 5.1).

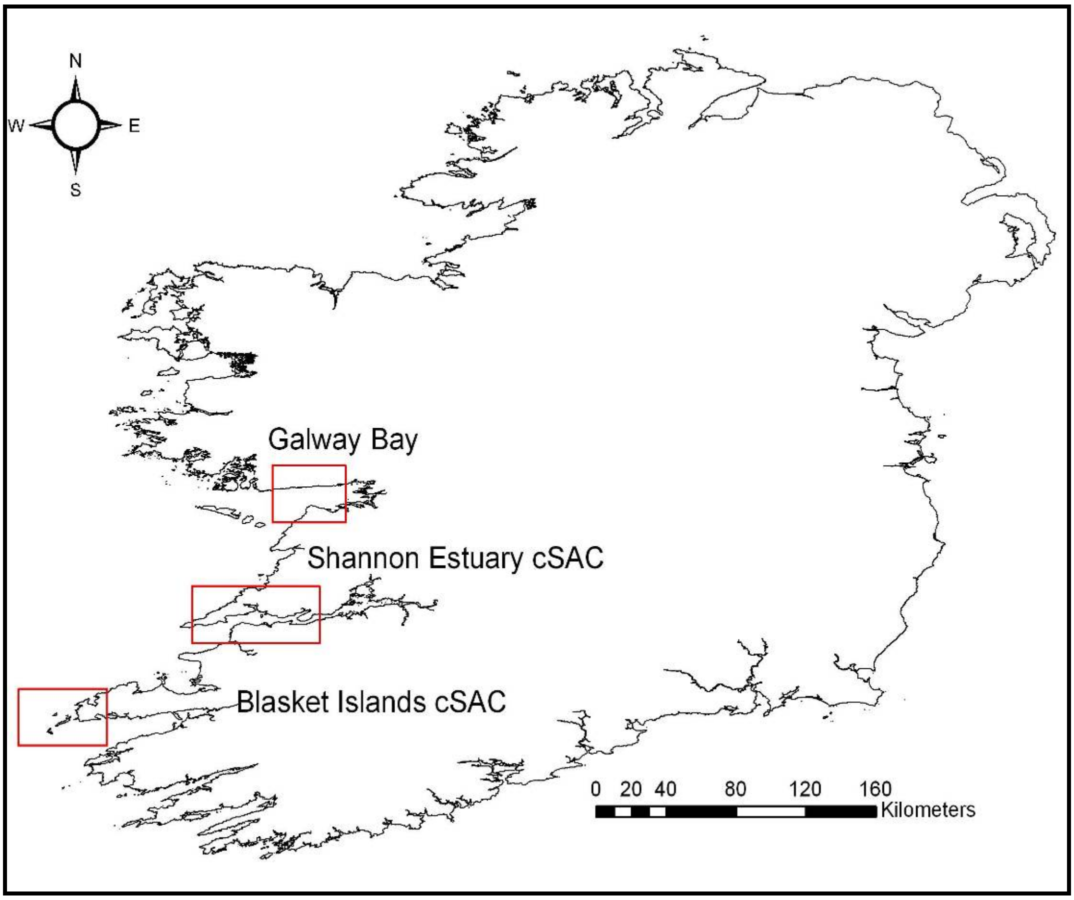


Figure: 5.1 SAM locations on the west coast of Ireland

The first analysis to be carried out was to assess the difference between C-PODs and their predecessor, the T-POD. In order to aid the transition from the use of T-PODs to C-PODs and to allow the comparison of data between the two devices, simultaneous deployment of C-POD/T-POD units was carried out at Moneypoint (bottlenose dolphins) and Galway Bay (harbour porpoise). DPMs were extracted per day for each device over the deployment period and an average ratio was generated to evaluate the performance of the two devices.

Table 5.1: Summary data from all deployments in all locations (mooring type, HWM=Heavy weight mooring, AR=Acoustic release mooring, ES-J=Existing structure-Jetty, ES-WP=Existing structure-Wave platform, ES-NB, Existing structure-navigation buoy)

Summary data from all deployment and moorings used										
Location	Site	Mooring	POD TYPE	POD ID	START DATE	END DATE	DAYS	HRS	DPM NBHF	DPM DOL
Blaskets	The GOB	HWM	C	170	02/02/2009	25/03/2009	52	1213	3015	2
Blaskets	Inishtooskert	AR	C	176, 487, 547	29/07/2009	21/06/2010	264	6294	3930	181
Blaskets	Wild Bank	HWM, AR	C	168, 549, 796	29/07/2009	13/06/2010	289	6874	2097	252
Shannon	Foynes	ES-J	C	169, 176, 547, 548, 1147	19/02/2009	24/10/2010	591	14060	69	1158
Shannon	Moneypoint	ES-J	C	164, 167, 173, 176, 384, 546	10/01/2009	08/02/2011	671	15995	1731	3204
Shannon	Moneypoint	ES-J	T	324	09/01/2009	03/05/2010	245	5670	330	490
Galway	Spiddal	ES-WP	C	164	13/01/2009	09/09/2010	572	13664	28246	125
Galway	Spiddal	ES-WP	T	324	13/01/2009	09/07/2010	189	4439	2207	10
Galway	Mid-bay	ES-NB	C	172	11/05/2009	06/07/2009	56	1344	375	30

5.3. Results

A total of 2,409 days (57,417 hours) were monitored over the duration of this study, using C-PODs across three study sites and including six locations (Table 5.2).

Table 5.2: Results of C-POD deployments from all sites along the west coast between January 2009 and February 2011

C-POD deployments											
				NBHF	NBHF	NBHF	NBHF	Dolphin	Dolphin	Dolphin	Dolphin
Location	Total Days	Total Hours	Total Min	DPD	Total DPM	% DPD	% DPM	DPD	Total DPM	% DPD	% DPM
Spiddal	572	13664	819840	541	27902	94.58	3.40	24	125	4.218	0.02
Inishtooskert	264	6296	377760	236	3930	89.394	1.04	64	181	24.242	0.05
Wild Bank	289	6874	412440	221	2097	76.471	0.51	46	252	15.917	0.06
The GOB	52	1213	72780	49	3015	94.231	4.14	2	2	3.846	0.003
Moneypoint	641	15308	918480	103	235	25.741	0.03	466	4010	72.699	0.44
Foynes	591	14062	843720	46	69	7.797	0.01	244	1158	41.356	0.14

5.3.1. *C-POD T-POD comparison*

A total of 189 days were compared from Spiddal in Galway Bay where, on average, C-PODs detected seven times more DPMs that the T-POD (Figure 5.2). A peak in detection in C-POD data around the 75-day mark was reflected in the T-POD data, but at a lower level due to a difference in sensitivity between units. This trend is evident across the deployment period. The peak reflects an increase in porpoise detection at the site.

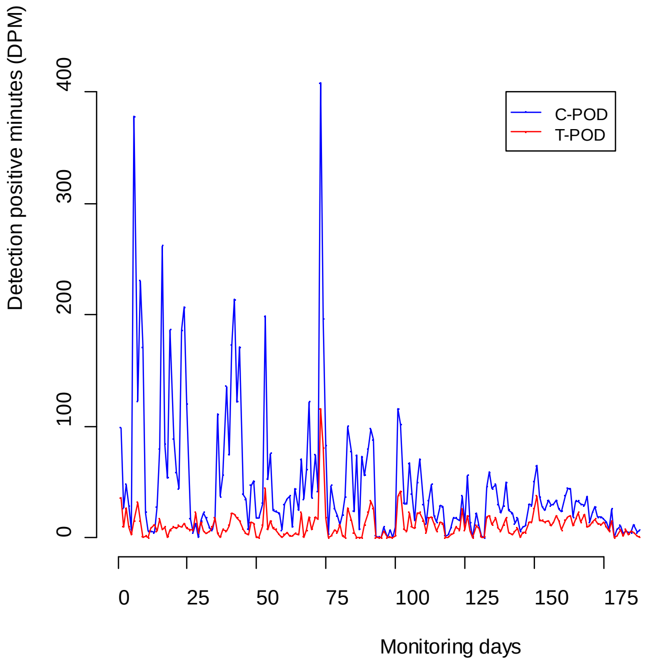


Figure 5.2: Detection positive minutes (DPM) recorded in the narrow band high frequency (NBHF) channel for both T-POD and C-POD units in Galway Bay

A similar comparison was carried out on the Moneypoint data to assess inter device performance for dolphin detections. A total of 154 days were compared at the site, and results showed that on average, C-PODs detected four times more DPMs than T-PODs (Figure 5.3). Therefore, it is recommended that any archived T-POD data from these sites be multiplied up by the ratios generated, especially when comparing monitoring indexes. This method, although rudimentary, will provide a means to compare data previously collected.

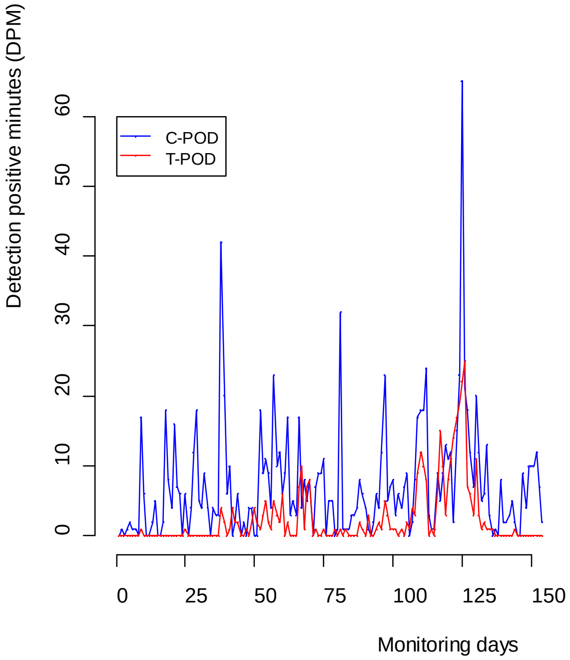


Figure 5.3: Detection positive minutes (DPM) recorded in the Dolphin channel for both T-POD and C-POD units at Moneypoint in the Shannon Estuary

Galway Bay

Long-term SAM commenced in Galway Bay in January 2009 and continued until September 2010 at the Wave Energy Platform off Spiddal (Figure 5.4). It was envisaged that SAM would also be carried out from a second site at the Marine Institute's Mid-Bay Buoy, but due to equipment loss, this second site was abandoned. Black Head was identified as an ideal site for long-term monitoring as porpoises have been recorded at this site consistently over the years (O'Brien, 2009). However, the tidal movements at this site proved too big a risk to deploy equipment over the long term and, hence, the site was only used for short-term deployments for detection trials in favourable weather conditions. At the Wave Energy Platform, a total of 572 days were monitored. A final deployment took place in September 2010, but over the winter months, the mooring buoy was reported washed up on the north shore, and thus the POD could not be retrieved from a boat. Two attempts by dive teams have failed to locate the unit as of July 2011.

Results from the Spiddal deployments show that, on average, harbour porpoises were recorded between 92% (T-POD) and 95% (C-POD) of days monitored, while dolphins were rarely recorded (4% days, C-POD), (Table 5.3). Over the 572 days monitored by the C-POD, a total of 27,902 Detection

Positive Minutes (DPM) were recorded (4,515 Detection Positive Hours; DPH), where, on average, the %DPM over the deployment was 3.4 for harbour porpoises.

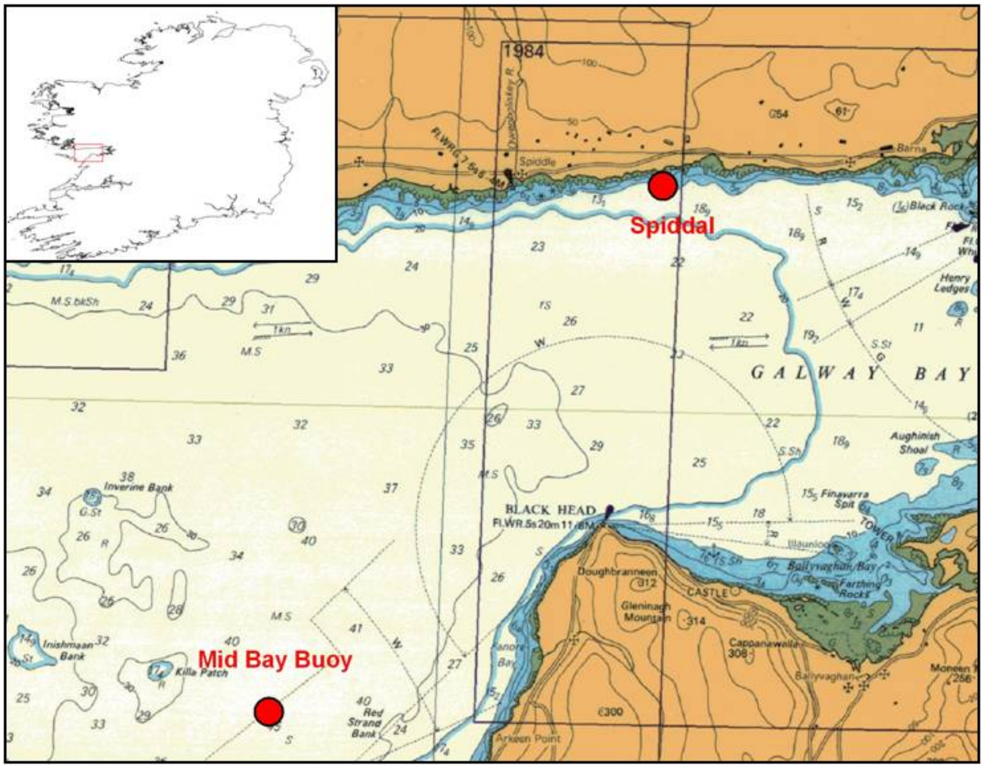


Figure 5.4: SAM locations in Galway Bay

Shannon Estuary cSAC

Long-term SAM was conducted in the Shannon Estuary cSAC at two sites, Moneypoint, County Clare, and Foynes, County Limerick (Figure 5.5). Long-term SAM of bottlenose dolphins commenced at Moneypoint Jetty in January 2009 and continued until February 2011. C-POD units monitored for a total of 641 days and recorded 4,245 DPMs (4,010 in the Dolphin channel and 235 in the NBHF channel) (Table 7.1). Bottlenose dolphins were recorded on 73% of days, with a monitoring index of 0.437 %DPM (0.026 in the NBHF channel) (Table 5.3). This study recorded 235 DPM in the NBHF channel using C-PODs, 6% of the total C-POD DPMs at Moneypoint (Table 5.3). The proportion of NBHF detections was highest during spring - 11% of the total DPMs. C-POD units were deployed at the Foynes study site for a total of 591 days, between February 2009 and October 2010. Results show that, on average, bottlenose dolphins were recorded on 41% (C-POD) of days monitored. During the monitoring period, C-POD units recorded 1,227 DPMs (1,158 in the Dolphin channel and 69 in the NBHF channel). The average %DPM was calculated as 0.137 for bottlenose dolphins (0.008 in the NBHF channel) (Table 5.3).

Of the 69 DPMs recorded within the NBHF, a small percentage of these was associated with a single click train also counted in the dolphin category. This was not problematic during the present project as the numbers of NBHF DPMs were low, and, additionally, the data were transformed to a binomial format.

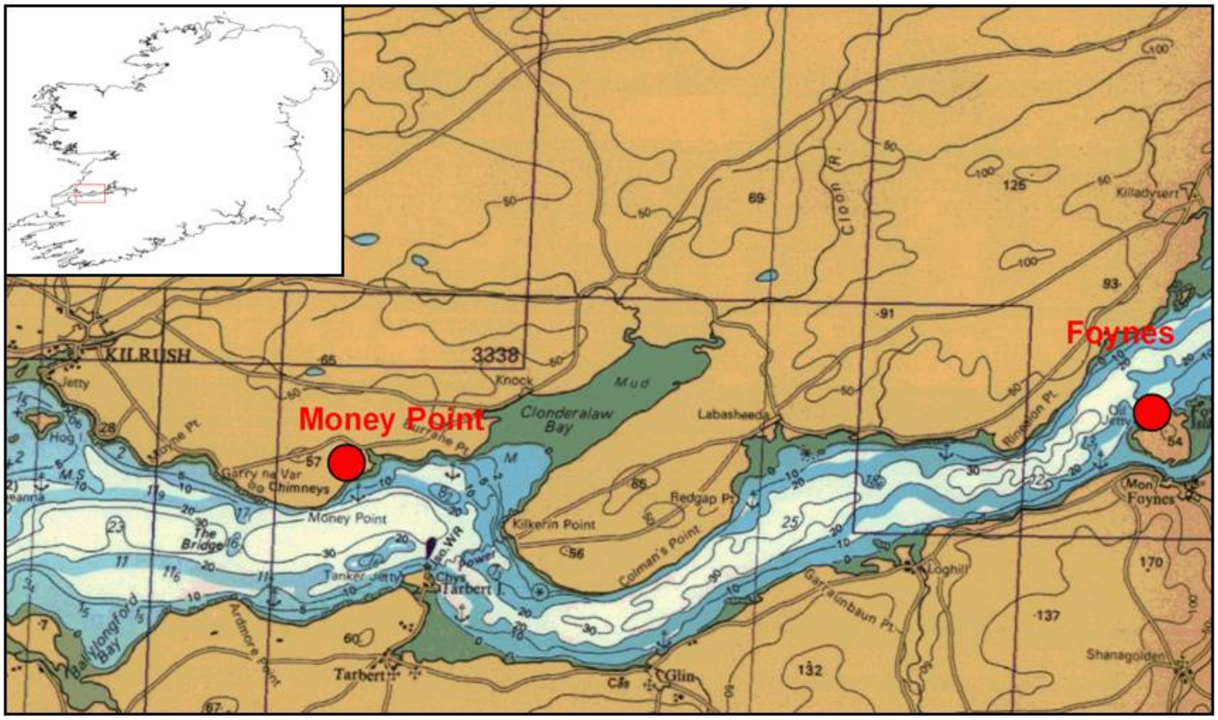


Figure 5.5: SAM locations in the Shannon Estuary cSAC

Table 5.3: Total detection positive minutes (DPM) and percentage recorded by C-POD units in NBHF and Dolphin channels across four variables - season, diel, tidal phase and tidal cycle - at Moneypoint

Summary tables - Moneypoint						
Variable	**Level**	**NBHF DPM**	**Dolphin DPM**	**Total DPM**	**% NBHF DPM**	**% Dolphin DPM**
Season	**Spring**	70	571	641	10.920	89.080
	Summer	39	1141	1180	3.305	96.695
	Autumn	38	618	656	5.793	94.207
	Winter	88	1680	1768	4.977	95.023
Diel	**Morning**	17	258	275	6.182	93.818
	Day	63	1277	1340	4.701	95.299
	Evening	5	141	146	3.425	96.575
	Night	150	2334	2484	6.039	93.961
Tidal phase	**Spring tide**	40	809	849	4.711	95.289
	Neap tide	25	399	424	5.896	94.104
	Transitional	170	2802	2972	5.720	94.280
Tidal cycle	**Slack low**	89	1300	1389	6.407	93.593
	Flood	48	805	853	5.627	94.373
	Slack high	58	688	746	7.775	92.225
	Ebb	40	1217	1257	3.182	96.818

Blasket Islands cSAC

Long-term SAM was conducted at the Blasket Islands cSAC at three sites, Inishtooskert, Wild Bank and the Gob (Figure 5.6). C-POD units monitored the Inishtooskert site for 264 days, between July 2009 and June 2010. During this period, harbour porpoise were recorded on 89% of days. C-POD units recorded 3,930 DPMs in the NBHF channel, with very few dolphin detections (181 DPM). The monitoring index of %DPM for harbour porpoises at Inishtooskert was 1.040, and 0.05 for dolphins. Monitoring at Wild Bank commenced in July 2009 and ran until June 2010. A total of 289 days were recorded, with harbour porpoise detections occurring for 76% of the days. C-PODs recorded 2,097 DPMs of NBHF (252 DPMs in the Dolphin channel), resulting in a monitoring index for harbour porpoise at Wild Bank of 0.508 and 0.06 for dolphins. C-POD units were deployed at the Gob for two months in February and March 2009 for a total of 52 days. 3,015 DPMs of NBHF were recorded with very few dolphin detections (2 DPM). This resulted in a monitoring index of 4.143 for harbour porpoise. For full tables of long-term SAM see the Appendix.

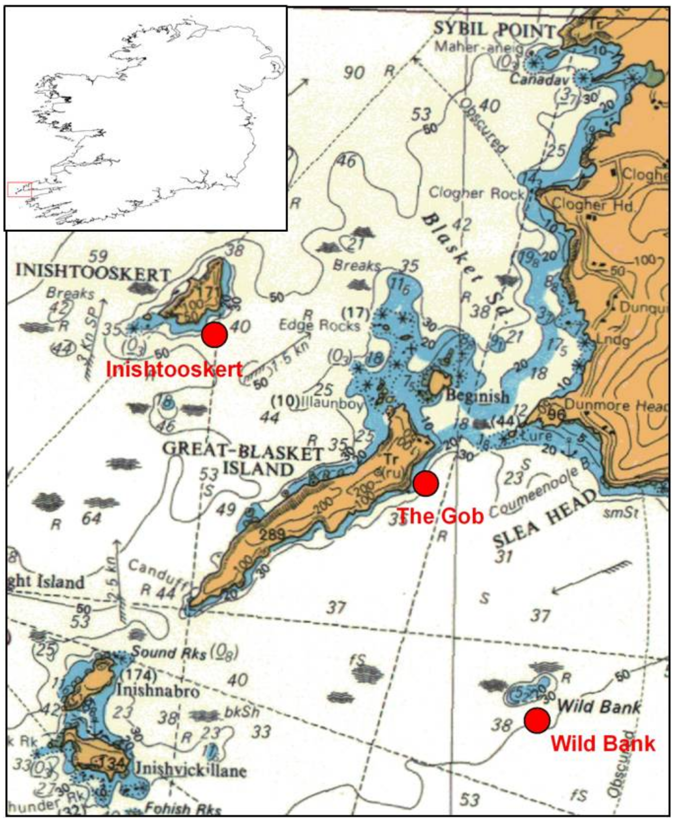


Figure 5.6: SAM locations in the Blasket Island cSAC

5.3.2. *Long-term SAM model*

Patterns of cetacean presence have been described over seasonal scales (Canning *et al*, 2008; Bolt *et al*, 2009; Simon *et al*, 2010; Gilles *et al*, 2011), diel cycle (Cox and Read, 2004; Carlström, 2005; Todd *et al*, 2009; Phillpot *et al*, 2007) and tidal patterns (Philpott *et al*, 2007; Marubini *et al*, 2009). The Shannon Estuary cSAC is a busy shipping area yet remains home to the only known resident group of bottlenose dolphins. The bottlenose dolphin and the harbour porpoise are protected under Annex II of the EU Habitats Directive. Investigating such patterns of cetacean presence is crucial to ensure FCS of harbour porpoises and bottlenose dolphins as required by the directive. Initially, all data were extracted as DPM per hour. However, the number of zeros within the dataset was vast and it is not recommended to analyse data in this form. In order to overcome the zero inflation, the data were transposed into a binomial format of Detection Positive Hours (DPH), where 1=detection(s) recorded and 0=no recorded detections. This was also the rationale behind the use of the generalized linear mixed-effect model (GLMM) analyses described below. Data were categorized into season, diel, tidal phase and tidal cycle. Season was categorized as spring (February, March, and April), summer (May, June, July), autumn (August, September, October) and winter (November, December, January). Diel cycle was split into four phases (morning, day, evening and night), following methods described by Carlström (2005). Morning began at the onset of civil twilight, and the duration was calculated as twice the time between the beginning of civil twilight and sunrise. Evening ended at the end of civil twilight and lasted twice the duration of the time between sunset and end of civil twilight. Information on sunset and sunrise was obtained from the U.S. Naval Observatory (http://aa.usno.navy.mil/data/docs/RS_OneDay.php). As data were extracted from the C-POD units by hour, times between 12:30 and 13:29 were recorded as 13:00, times between13:30 and 14:29 were recorded as 14:00 etc. Tidal phase was classified according to the phases of the moon, using tidal data (WXTide 32). Spring tide was calculated as 24 hours either side of the highest high water and neap tide, lowest low water (O'Brien, 2009). Data were further categorised by tidal cycle. One hour before and after high water was termed 'slack high', while one hour before and after low water was termed 'slack low'. Hours that fell between slack high and slack low were classified as ebbing tide. Similarly hours that fell between slack low and slack high were classified as flood.

All statistical analyses of the SAM data were carried out using the programme R. A GLMM was fitted to the binomial data using the glmer function in the lme4 package developed for R. C-POD ID number was included as a random factor to take into account variability between units. Akaike's information criterion (AIC) and a histogram of fitted residuals were used as diagnostic tools for model selection. Wald chi-squared tests were computed for each variable and predicted proportions of DPH were extracted across all levels and displayed as box plots using the HH package developed for R.

Galway Bay (Spiddal)

Data were analysed using detections in the NBHF channel. Data were analysed by year, and both 2009 and 2010 results are presented here. The model including all four variables was chosen for this analysis. All four variables were found to significantly affect harbour porpoise presence in both years (Figures 5.7 and 5.8).

In the 2009 dataset, season was shown to significantly affect DPH (χ^2=58.8, p<0.0001), where a peak in harbour porpoise occurrence was observed through autumn and winter. Results from the model also highlight diel cycle to contain significant variation (χ^2= 26.7, p<0.0001), indicating that night and morning phases have a higher level of harbour porpoise detection. A significant variation across tidal phase (χ^2= 36.1, p<0.0001), shown in Figure 5.7, exists between neap tide and spring tide with a rise in DPH during neap tide. Results suggest the significance of tidal cycle (χ^2=39.6, p<0.0001), which can be most likely attributed to the predicted drop in detections during slack low tide.

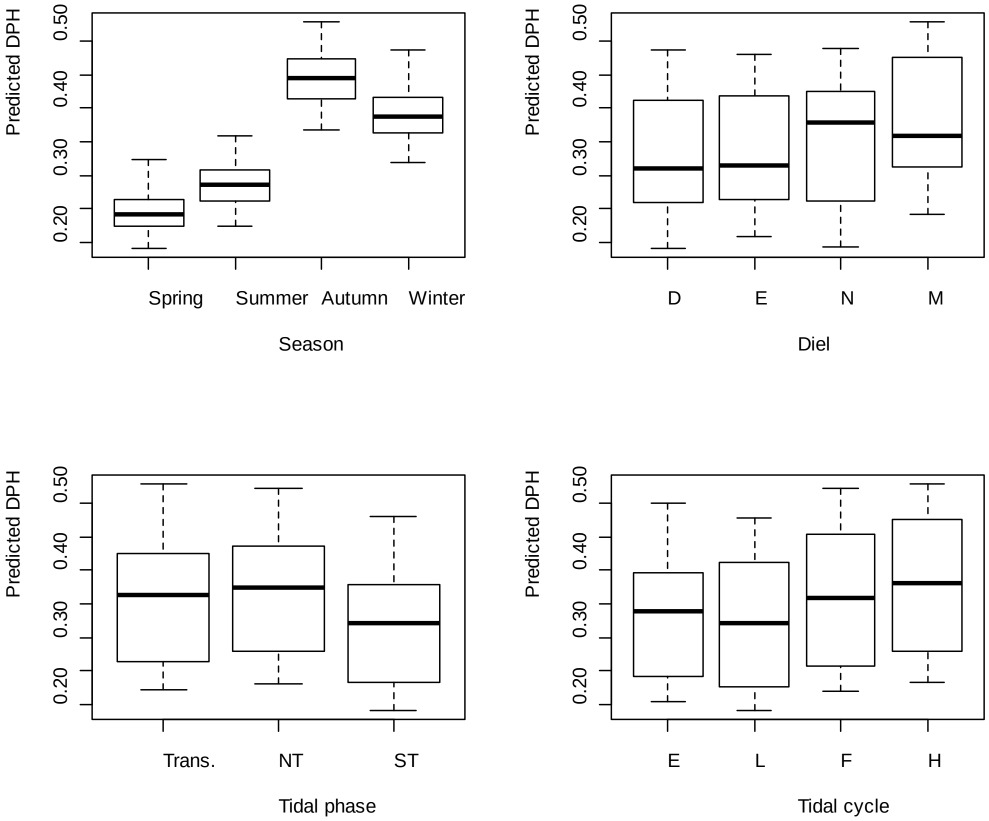


Figure 5.7: Predicted proportion of detection positive hours, in the narrow band high frequency channel at Spiddal (Galway Bay) 2009 across the four variables of season; diel, where D =day, E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high

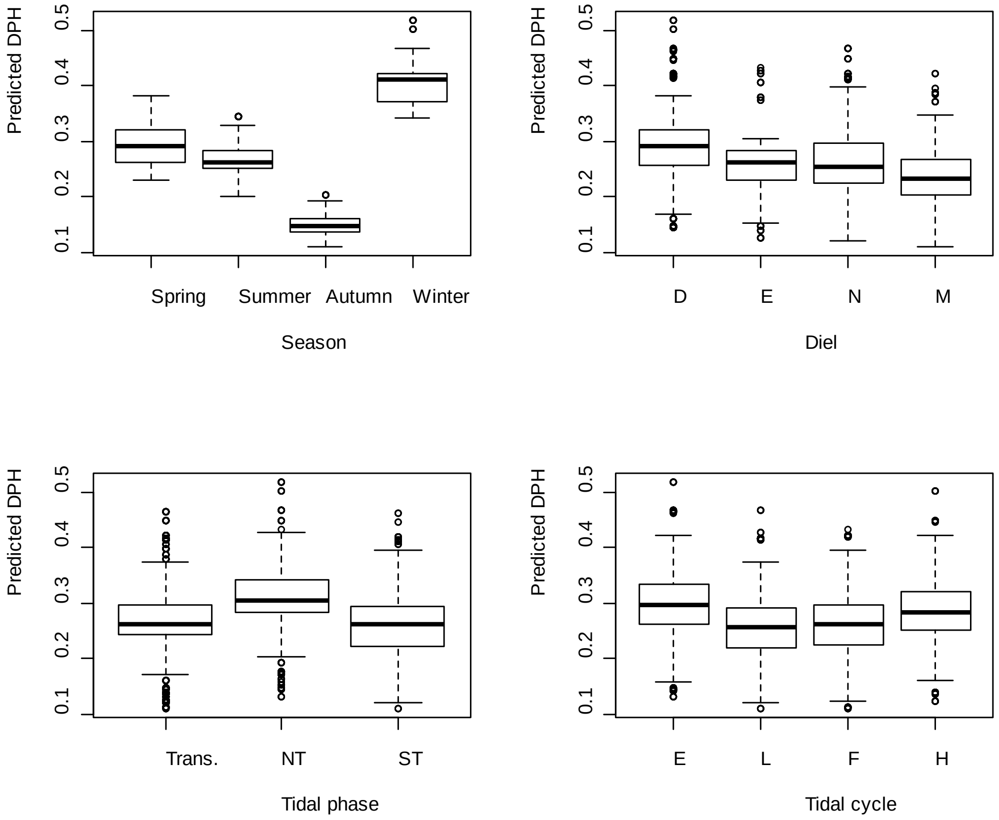


Figure 5.8: Predicted proportion of detection positive hours, in the narrow band high frequency channel at Spiddal (Galway Bay) 2010 across the four variables of season; diel, where D =day, E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high

Results from 2010 indicate a change in seasonal pattern. Season was shown to significantly affect DPH (χ^2=113.8, p<0.0001), where a peak in harbour porpoise occurrence was observed during winter but, in contrast to results from 2009, autumn contained fewest NBHF detections. Results highlight diel cycle to contain significant variation, although in reference to Figure 5.8, a distinct diel pattern is unclear and the comparatively low chi-squared value derived for this variable reflects this (χ^2=25.1, p<0.0001). A significant variation across tidal phase (χ^2= 16.7, p=0.0008) concurs with 2009 findings, with a rise in detections during neap tide. Results suggest a significance of tidal cycle (χ^2=23.1, p=0.0001), with a slightly higher level of detections during an ebbing tide.

On inspection of the raw dataset at Spiddal, October 2009, was shown to have a much higher DPM count than any other month, with 5606 DPMs. There were no data collected for October 2010. The distinct rise of detections in October 2009 coincides with the last month of autumn, and it is suspected that this is causing the drastic change in seasonal pattern described above. Continuing this dataset will allow better assessment of the seasonal pattern.

Moneypoint

The data were first analysed using detections in the Dolphin channel and, secondly, using both NBHF and Dolphin detections. When NBHF detections were included, a similar pattern of presence was found. Data could not be analysed by year due to inconsistent sampling across years. The model including all the four variables was deemed the best fit. It was decided that the model analysing detections in the Dolphin channel only gave the best fit to the dataset and in keeping with the analyses from the other study sites, the results of the Dolphin-only model are described below.

All four variables were found to significantly affect the presence of bottlenose dolphins at this site. The predicted proportions of detection positive hours across all variable levels are given in Figure 5.9 to illustrate the pattern of bottlenose presence at this site. Results showed that tidal cycle had the greatest level of significance (χ^2= 427.7, p<0.0001), with the highest proportion of detections occurring during an ebbing tide and at slack low tide. Seasonal differences in bottlenose dolphin presence were found to be significant ($\chi^{2=}$364.1, p<0.0001), and from the predicted proportion of DPH, it is accepted that winter and summer have a higher detection rate than both autumn and spring. Significant variance in DPH across diel cycle (χ^2=323.1, p<0.0001) can be attributed to a higher level of DPH during night and morning. Results also show that significantly more DPH are predicted during spring tide in comparison with neap tide (χ^2=305.7, p<0.0001).

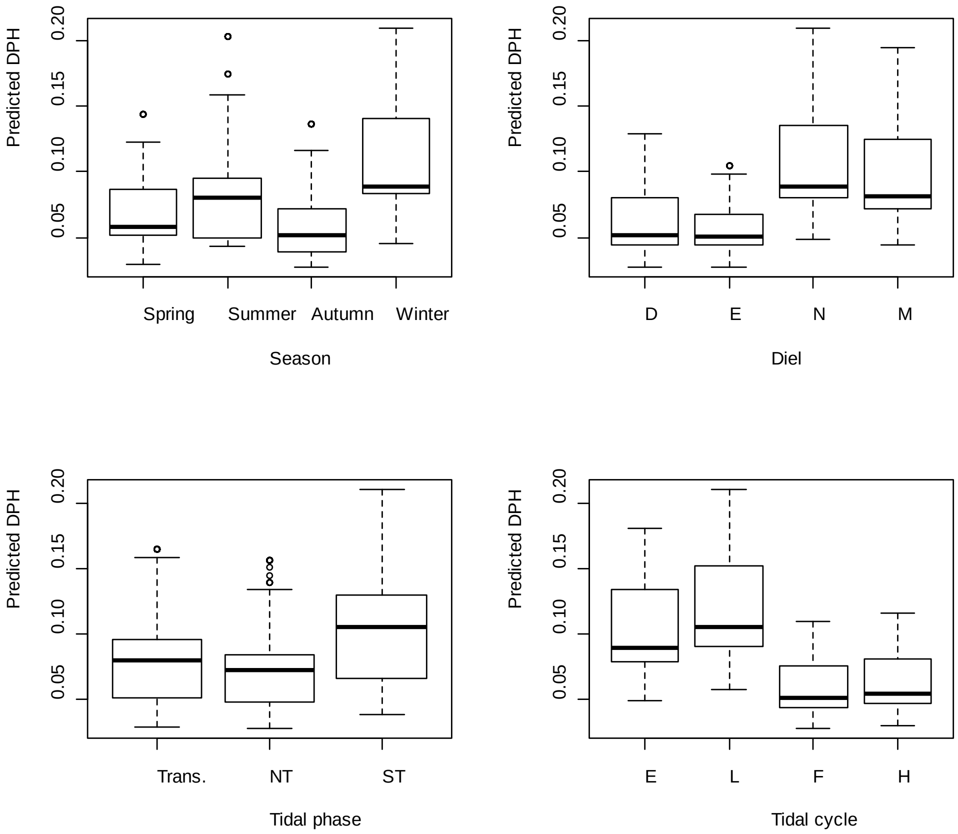


Figure 5.9: Predicted proportion of detection positive hours in the dolphin channel at Moneypoint across the four variables of season; diel, where D =day; E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high

Foynes

Data were analysed using detections in the Dolphin channel. Data were first analysed by year. Both 2009 and 2010 displayed similar patterns and so a combined model across years is presented here. The model including all four variables (season, diel, tidal cycle and tidal phase) was deemed the best fit; all four variables were found to significantly affect DPH at this site. Season was shown to significantly affect the presence of bottlenose dolphins (χ^2=183.3, p<0.0001), and this can be seen in Figure 5.10, with a peak in detections during spring and gradually decreasing throughout summer and autumn, with winter showing the lowest predicted detections. Variation across diel cycle was found to be significant (χ^2= 133.6, p<0.0001), with a pattern of higher detections across night and morning, and lower detections in day and evening. Significant variation across tidal phase (χ^2= 194.9, p<0.0001) in contrast to Moneypoint can be explained by a predicted rise in detections during neap tide. Results show that tidal cycle had a significant effect (χ^2=179.4, p<0.0001), which was most likely due to a decrease in detections during slack high tide.

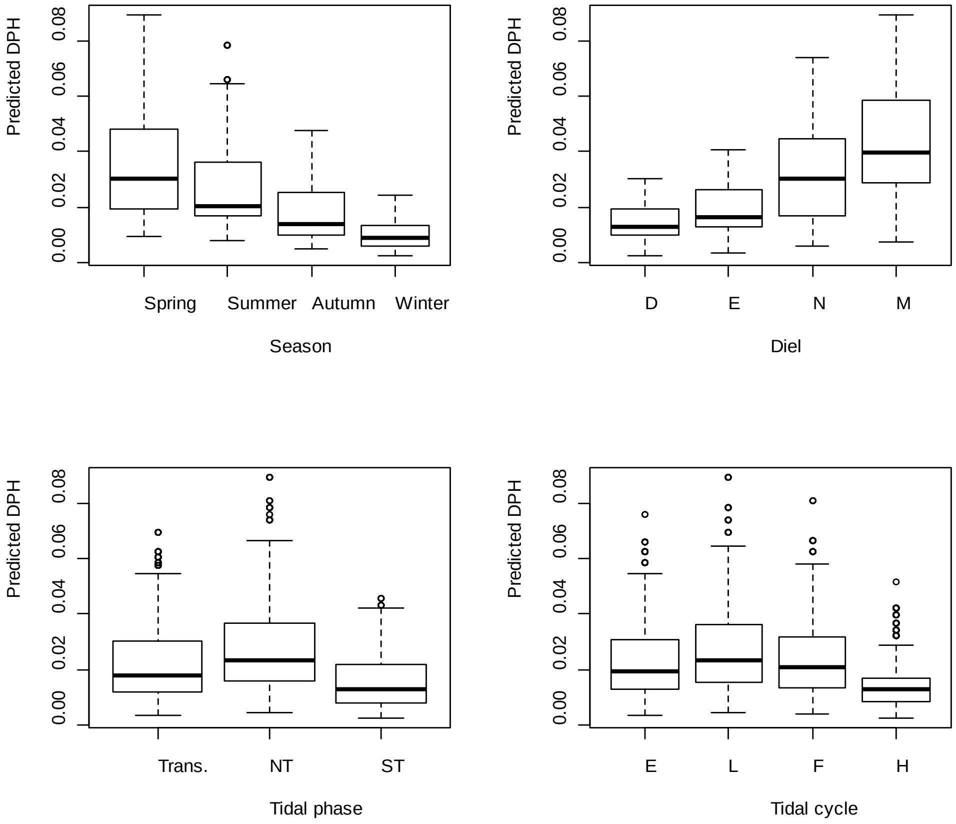


Figure 5.10: Predicted proportion of detection positive hours, in the dolphin channel at Foynes across the four variables of season; diel, where D =day, E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high

Blasket Islands

Data were analysed using detections in the NBHF channel and location consisted of three sites: the Gob, Wild Bank and Inishtooskert. Data could not be analysed by year as monitoring ran from July 2009 to June 2010. Additionally, the data from the Gob could not be analysed by season or tidal phase due to lack of replicates. A GLM including diel was deemed the best fit for the Gob dataset. Results showed that diel significantly affected harbour porpoise presence and this is likely due to a predicted increase in detections during the daytime phase ($p<0.0001$, Figure 5.11).

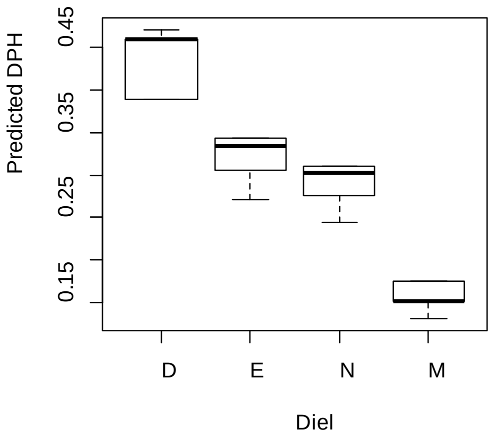


Figure 5.11: Predicted proportion of detection positive hours, in the narrow band high frequency channel at the Gob across the variable of diel, where D =day, E= evening, M= morning and N = night

Results from the Wild Bank indicated that the model assessing the three variables of season, diel and tidal phase was the best fit (Figure 5.12). Tidal cycle is, therefore, assumed to have no significant effect on presence. Deployments showed a significant seasonal effect on the presence of harbour porpoises at this site. This could be attributed to a rise in detections during the summer months (χ^2= 178.0, p<0.0001). A significant pattern of presence across diel cycle was also found, clearly evident in Figure 5.12, with a predicted peak during daylight hours also found at the Gob (χ^2= 199.9, p<0.0001) = 0.0). Tidal phase was also significant, with predicted detections peaking during the neap phase (χ^2= 105.8, p<0.0001).

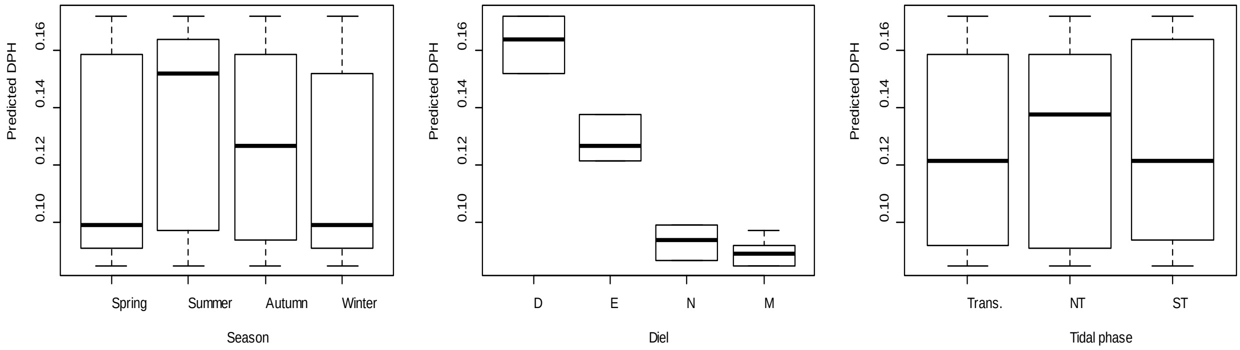


Figure 5.12: Predicted proportion of detection positive hours, in the narrow band high frequency channel at Wild Bank across the three variables of season; diel, where D =day, E= evening, M= morning and N = night; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high

Analysis of the Inishtooskert dataset showed a significant pattern in harbour porpoise presence according to season (χ^2= 13.4,p = 0.0098) and diel (χ^2= 20.5, p = 0.00041), while tidal phase and tidal cycle were not significant.

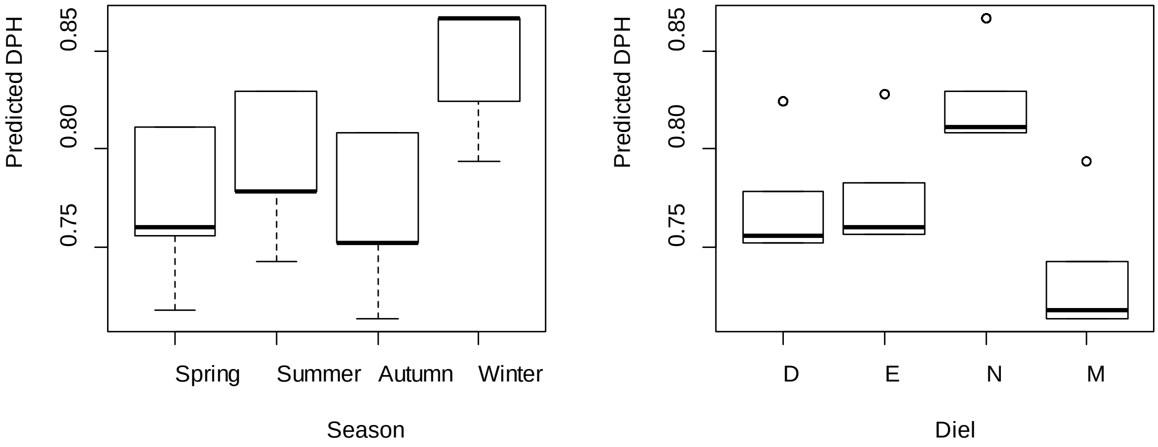


Figure 5.13: Predicted proportion of detection positive hours in the narrow band high frequency channel at Inishtooskert across the two variables of season and diel, where D =day, E= evening, M= morning and N = night

5.3.3. *Encounter Rate*

The echolocation encounter rate is the total number of echolocation encounters within each phase divided by the mean duration of each phase (hours), multiplied by the number of recording days for each deployment period. An echolocation encounter was defined as a group of click trains that are separated by periods of silence, with a minimum duration of 10 minutes (Carlström, 2005; Todd *et al*, 2009). This was also investigated as an estimate of harbour porpoise and bottlenose dolphin occurrence at the study sites. This technique analyses click train data and has the ability to reduce the potential bias introduced by a small number of highly vocal individuals. The method involves individual encounters, which typically last less than five minutes as opposed to detection positive hours analysed in the GLMM model above.

Data were extracted using C-POD.exe and the train detection algorithm was run on the CP.1 files to produce CP.3 files. All data from CP.3 files were then exported into Excel.xlsx, with rows containing information on individual clicks trains. Train detection analysis is based on a probability model, using the prevailing rate of arrival of clicks to derive a probability of the absence of a click in each successive time slot, as defined by the current inter-click interval (ICI) and train regularity (Chelonia Ltd). Only acoustic detections under the train filter “Hi” and “Mod”, which included both high and moderate probability cetacean click trains, were used in the analyses.

Encounter rate analyses have been carried out in previous studies and are necessary for comparative purposes. However, this analysis is more primitive in that it could not account for the high proportion of 0's across the dataset or variability between POD units. The encounter rate was calculated and analysed for three variables: diel, tidal phase and tidal cycle. The effect of season was not investigated as individual SAM units may have only been used during one season and, thus, had potential to bias results. As this is a more primitive method of analysis, evening and morning phases were excluded. Previous work found these periods to be transitional (Todd *et al*, 2009). Data was analysed by non-parametric methods as the data could not be transformed to fulfil the critical assumptions of ANOVA.

Harbour porpoise

There were no statistically significant differences found for harbour porpoise echolocation encounter rate in either Galway Bay or the Blasket Islands (p=0.2248). However, in all three study sites in the Blasket Islands, the highest encounter rate occurred during the day (Table 5.4).

Table 5.4: Summary of encounter data across sites for each of the factors of diel, tidal phase and tidal cycle

Summary of encounter data				
Factor	**Gob**	**Inishtooskert**	**Wild Bank**	**Spiddal**
		Diel		
Day	0.5	0.73	0.6	2.06
Night	0.29	0.47	0.28	1.79
		Tidal.phase		
Spring	0.03	0.17	0.03	0.14
Neap	0.03	0.18	0.04	0.14
		Tidal.cycle		
Low	0.63	0.54	0.93	3.5
Flood	0.77	0.57	0.86	3.88
High	0.75	0.55	0.77	4.05
Ebb	0.64	0.68	0.79	3.94

Bottlenose dolphin

Significant differences were detected between diel phases for both study sites, Foynes (Kruskal-Wallis, one-way ANOVA d.f. = 1, p = 0.02497) and Moneypoint (Kruskal-Wallis, one-way ANOVA, d.f. = 1, p = 0.01272). Night was found to have a significantly higher echolocation encounter rate than day. Significant differences were also detected within the tidal cycle for Moneypoint (Kruskal-Wallis, one-way ANOVA d.f. = 3, p = 0.03835). *Post-hoc* testing revealed this difference to exist between flood and low (p = 0.02622) and flood and ebb (p = 0.01748), with a significantly lower echolocation encounter rate observed within the flood cycle. There were no significant differences found within tidal phase at either study site (Table 5.5). Where long-term datasets exist for areas of high density using multiple SAM units, the most appropriate statistical tests include GLMM, as demonstrated during the present study. Where datasets are from low density area, then the encounter rate analyses could be more appropriate, although caution must be taken when using multiple SAM units.

Table 5.5: Summary of encounter data across sites for each of the factors of diel, tidal phase and tidal cycle

Summary of encounter data		
Factor	**Moneypoint**	**Foynes**
Diel		
Day	0.47	0.08
Night	0.82	0.03
Tidal.phase		
Spring	0.06	0.01
Neap	0.04	0.01
Tidal.cycle		
Low	1.55	0.31
Flood	0.77	0.25
High	1.13	0.23
Ebb	1.58	0.36

5.4. **Discussion**

The aim of the present study was to acoustically explore the occurrence of small cetaceans at three sites (two already designated candidate SACs) on the west coast of Ireland. The efficacy of SAM as a monitoring technique, which could potentially be used to partially fulfil statutory monitoring obligations, was also assessed. Under the EU Habitats Directive (92/43/EC), Ireland is required to maintain the total national population of Annex II species (harbour porpoise and bottlenose dolphin) at *FCS* through ensuring that there is a sufficiently large habitat of suitable quality available to support the long-term survival of these species. Criteria necessary to warrant and support an area for cSAC designation include the "*continuous or regular presence*" of the species (subject to seasonal variation), a "*good*" density estimate for the area, and a good adult-to-calf ratio in comparison to adjacent areas. If an area can be shown to support the above criteria and can be highlighted as an area essential to the life and reproduction of the species, then it should be considered for cSAC designation (Johnston *et al,* 2002). An assessment of *FCS* of a species needs to be underpinned with precise scientific knowledge. SAM data will provide information to fulfil part of these criteria but fails to inform on density and absolute abundance. SAM does have the power to identify important spatial and temporal trends at and between sites which could not be collected through visual means on the same time scales or budgets.

SAM data collected during the present project from the Shannon Estuary and from the Blasket Islands are the longest datasets collected to date from Irish SACs. The Blasket Islands is an already designated cSAC for the harbour porpoise and a long-term dataset from this site will provide a comparison for other potentially important sites for this species around the country. The Shannon Estuary cSAC dataset provides critical information on the occurrence of bottlenose dolphins trends within this relatively highly industrialised area. The continuation of long-term SAM at these two sites will serve to inform management on the conservation status of Annex II species and help towards meeting our requirements under EU law.

The generation of a density estimate from acoustic data has been attempted by Tougaard *et al* (2006), although this method is not widely adopted and needs to be refined before it can be used proficiently. As the C-POD will only provide information on echolocating animals, silent or non-echolocating individuals will remain undetected. This should be less likely for the harbour porpoise, as a study by Akamatsu *et al* (2007) found that they produce a sonar click train every 12.3 seconds, while 90% of the periods with no echolocation lasted only 20 seconds or less. Hence, the authors concluded that harbour porpoises seem to continuously echolocate. In the event of constant echolocation, this should reduce the number of false negatives associated with acoustic monitoring of the species as they should not go undetected for longer than 20 seconds if in range of the device. Field trials carried out during the present study generated a detection range of 441m for harbour porpoises and 797m for bottlenose dolphins. Although C-PODs are recognised as a valuable monitoring tool, some researchers have expressed concern as regards differing sensitivities between units and, therefore, the comparability of data between POD versions, sensitivities and region (Dähne *et al*, 2006). A study by Kyhn *et al* (2008), who focused on the predecessor of the C-POD (T-POD), found that the more sensitive a POD was in the laboratory, the more clicks it recorded in the field. The authors tested the performance of 10 individual units and found differences between them all. Hence, the authors conclude that calibrations are necessary in order to gather comparable results from differing units and across locations. Dähne *et al* (2006) examined the variation between two version 4 T-PODs and found a 7% variation between the units, which they conclude as being a good performance by comparison with the amount of variation associated with visual monitoring. Berrow *et al* (2009a) carried out field calibrations using 9 T-PODs (versions 4 and 5) and found a 6% variation between the most and least sensitive units. Results from field calibrations during the present study suggest that an acceptable variation between units of 20% DPM across hourly segments will still allow for comparison of data between units and locations. This variability can be further taken into account during statistical analyses through the use of POD ID as a random factor.

Long-term SAM carried out during the present study in Galway Bay and Blasket Islands showed that the harbour porpoise was the most frequently detected species. However, as the bottlenose dolphins are resident in the Shannon Estuary, no other species were recorded at this site. Exploration of the dataset for an effective index of activity across sites and factors was carried out. A monitoring index of %DPM was chosen. This index can be generated across various temporal scales and, therefore, can be used to compare activity between sites. The highest long-term index for harbour porpoise (% of Detection Positive Minutes across all minutes monitored) was recorded in Galway Bay at the Spiddal site (3.4), while the Blasket Islands was at 1.04 (Inishtooskert), 0.51 (Wildbank) and 4.14 (The Gob). Caution should be taken when comparing these results since the data from The Gob is only across two months in comparison with the longer-term datasets from all other sites. For bottlenose dolphins, Moneypoint, at 0.44, had a higher overall index than Foynes (0.14). These results highlight the importance of having a detailed knowledge of porpoise trends at a site, especially when targeting abundance estimation at certain times of the year. If abundance estimation is carried out during the summer months, it may not give a true reflection of the overall population and may not indicate the overall importance of an area. Further temporal trends were also found to be evident in the long-term harbour porpoise acoustic datasets. These data were analysed to determine if diel cycle had a significant effect on the presence of the harbour porpoise. Results showed harbour porpoises are more active nocturnally at Spiddal, and at Inishtooskert, but the opposite results were found for Wild Bank, with a peak evident during the daytime phase. This highlights the difference in site usage by the same species across short geographical scales. Previous SAM studies carried out in the Blasket Islands, but over a shorter timescale, reflected the findings of this study. Berrow *et al* (2008) also showed localised temporal variation across very short geographical distances (c10km), where porpoises were found to be more acoustically active at night at Inishtooskert but were more active during daylight hours at the Wild Bank. Cox *et al* (2001) had similar results to the Spiddal and Inishtooskert datasets, where they found porpoise echolocation detection rates were higher at night than during the day in the Bay of Fundy. In Newport Bay, on the south-west coast of Wales, Pierpoint *et al* (1999) also found that the levels of harbour porpoise activity were consistently higher at night. In Kamon Strait, Japan, Akamatsu *et al* (2008), using static stereo even recorders (A-tags, detection distance of 126m), found finless porpoises were detected only during the night, which was opposite to the shipping traffic which occurred during the daytime. Teilmann *et al,* (2007), using satellite-linked dive recorders, found that harbour porpoises dive continuously both day and night, with peak activity occurring during daylight hours. This is also true for the Wild Bank study site. Since harbour porpoise diel trends on the west coast of Ireland have been found to differ geographically, this emphasises the fact that the reliance upon visual monitoring alone is a poor measure of their occurrence in an area, especially if they are more active at night.

The reasons for increased nocturnal activity are uncertain but could be linked to an increase in prey abundance or activity in the absence of light, as suggested by Todd *et al* (2009). This hypothesis was further explored as part of the present study and results are presented in Chapter 4. Further analyses of the porpoise acoustic dataset from Galway and the Blasket Islands explored the incidence of significant temporal trends such as the effect of tidal state and tidal phase. Results showed no significant variation in harbour porpoise detections in response to tidal state or cycle at the Blasket Island Wild Bank site and a small significance of tidal phase at Inishtooskert, with detections peaking during the neap phase. A significant effect of tidal phase and cycle was recorded in Spiddal, with a higher level of detections during a neap phase and an ebbing tide (2010). This is a similar result to Pierpoint *et al* (1999), who found greater harbour porpoise activity during an ebbing tide. The long-term data set from the Shannon Estuary is the most comprehensive knowledge base collected on this resident group of bottlenose dolphins since studies commenced on this population in 1993. Dolphins were recorded throughout the year but different temporal trends were identified between short geographical distances within the cSAC. A significant seasonal effect was determined at Moneypoint, where peaks were recorded in activity during the summer and winter months. Data from Foynes showed a different pattern, with peaks occurring during the spring and summer. The distance between these two sites, Foynes and Moneypoint, is circa 21km, with Foynes located further up the estuary, approximately 60km from Loop Head. Elsewhere, in Cardigan Bay cSAC, where another group of resident bottlenose dolphins are found, SAM results showed peaks in detection in April which continued into December (Simon *et al,* 2010). Results from the Shannon Estuary fail to show a peak in the autumn, as was shown in Cardigan Bay. This decrease in detections during the autumn was recorded at both sites and, therefore, would suggest that a dolphins are either moving further downriver or leaving the estuary altogether. This could be in association with a change in prey type. Further temporal trends were also evident over diel cycle, where more detections were recorded during morning and night-time phases. Philpott *et al* (2007) did not highlight a significant diel pattern, but the SAM duration was over a much shorter time scale. Tidal cycle was found to be significant at Moneypoint, where more detections were recorded over the ebbing and slack low tidal phases. This was in accordance with previous studies carried out in the estuary (Philpott *et al,* 2007). With regard to tidal phase, the two study sites showed opposing patterns, where more detections were recorded during the spring phase at Moneypoint and during the neap phase at Foynes. An additional concern was highlighted in the Shannon data, where a proportion (6%) of the total overall detections was recorded in the NBHF channel. This is of concern as no porpoises occur within the Shannon Estuary and especially not circa 60km up river from Loop Head. No records of any porpoises have been recorded west of Kilcredaun, and further evidence of the misidentification of dolphin detections classified by the C-POD as NBHF were found, where simultaneous visual sightings record bottlenose dolphins in the vicinity of the POD (J O'Brien and S Hansen per obs.). These dolphin clicks recorded in the porpoise channel have an average frequency of 101 kHz, which is not unusual as bottlenose dolphins have been recorded at 120 and 130 kHz in Hawaii, where individuals altered their frequency in response to background noise (Au, 1993). The characteristics of these misidentified clicks were quite uniform, of a very narrow band and of high frequency, which all suggest harbour porpoise. However, these click trains are composed of very long clicks and occur in the middle of a dolphin encounter. Furthermore, these click trains have no frequency trend throughout and are composed of several very similar trains, which occur in close succession, therefore, eliminating the possibility of off axis clicks. It is unclear as to why dolphins are changing their click repertoire at these sites, but it may be due to the topography of the areas or to metal structures in the vicinity, as both sites take advantage of jetties as mooring points. One limitation with the C-POD is the inability to differentiate between dolphin species. A low number of dolphin detections was recorded in the Blasket Islands sites (0.05% DPM) and in Spiddal (0.015% DPM). As species could not be determined and the rate of detection was so low, these data were not statistically analysed. However, it is likely that the ability to discriminate dolphin species within the C-POD data successfully will progress as its development is ongoing at Chelonia.

In summary, SAM using C-PODs can provide high resolution data in time but has limited spatial coverage. This can be overcome with the deployment of many units within an area to achieve a more even spatial coverage. If multiple units can be used in a programme, the strategic placing of moorings would enable the tracking of movements within an area. Results from the present study highlight how seasonal as well as temporal trends, such as diel and tidal influences, can be detected through SAM. In fact, the results suggest that seasonal trends can be detected much more readily through SAM than through visual methods (O'Brien *et al*, 2008). Localised temporal trends were detected acoustically in all datasets, across season, diel, tidal phase and tidal cycle. Fine-scale temporal differences could not be detected through visual methods alone.

Long-term monitoring of sites, both SACs and non SACs, can provide baseline data, especially for EIAs if activities such as dredging, pile driving or underwater blasting were to take place in an area. It is imperative to build an extensive knowledge base of temporal trends in an area in order to predict when animals are least likely to be affected. Temporal variations such as season, diel and tidal phase were found to influence both harbour porpoise and bottlenose dolphin presence on the west coast of Ireland, and this highlights the need for SAM, as results from visual data alone provide poor temporal coverage and do not truly represent the habitat usage by these populations. If human activities have an impact on harbour porpoises or dolphins, then visual monitoring alone would be insufficient to mitigate against disturbance as it would not provide information on, for example, diel cycles. SAM alone is currently not advanced enough to highlight specific areas as SACs (Skov and Thomsen, 2008), but it can contribute to the effective conservation of inshore cetacean species by providing data on fine-scale habitat use.

6. SPECIES AND HABITAT ASSESSMENTS

6.1. Introduction

SAM can be used to effectively assess habitat use of cetacean species and is particularly useful for the study of behaviour, such as feeding strategies, approach behaviour and communication. Significant effects of diel pattern have been described in the foraging behaviour of harbour porpoise (Carlström, 2005; Todd *et al*, 2009) and bottlenose dolphin (Allen *et al*, 2001). These species are protected under Annex II of the EU Habitats Directive. Therefore, in order to ensure the FCS of species and areas of importance, it is imperative to identify habitat usage, e.g. feeding and breeding grounds. During species and habitat assessments, SAM devices were set according to the manufacturers' guidelines to detect harbour porpoise and dolphin species, as described in Chapter 5. Data were extracted from SD cards using C-POD.exe, and the train detection algorithm was run on the CP.1 files to produce CP.3 files. All data from CP.3 files were then exported into Excel.xlsx, with rows containing information on individual clicks trains. Train detection analysis is based on a probability model, using the prevailing rate of arrival of clicks to derive a probability of the absence of a click in each successive time slot, as defined by the current inter-click interval (ICI) and train regularity (Chelonia Ltd). Only acoustic detections under the train filter "Hi" and "Mod", which included both high and moderate probability cetacean click trains, were used in the analyses (Table 6.1).

Table 6.1: Train values setting used during train analyses

Train Values		
	Min	Max
Modal kHz	20	225
N in train	5	400
Clicks per second	1	2000
Mean SPL	1	225

The various species of odontocetes that echolocate have different characteristics associated with their click production, such as click duration, inter-click interval *ICI*, frequency, source level and range. The use of biosonar by porpoises and dolphins has been extensively studied (Au, 1993), and has shown that porpoise and dolphin sonar characteristics differ greatly from each other, making it possible to differentiate between these species. Harbour porpoises use echolocation signals for foraging and orientation (Verfuß *et al,* 2005), and these signals are characterised as being narrow-band, high frequency, between 110 and 150 kHz, with a detection range (for a single fish of ingestible size) of up to 30m, while an average click has a duration of 2µs with a mean source level of 150dB re 1µPa @ 1m (Møhl and Andersen, 1973; Goodson and Sturtivant, 1996; Au *et al,* 1999; Carlström, 2005; Villadsgaard *et al,* 2007; Verfuß *et al,* 2007). Harbour porpoises also have a low frequency component to their click (2 kHz), which Møhl and Andersen (1973) suggest may have communication value. Boat sonar and echo sounders are the only sounds in the sea which are similar to harbour porpoise sonar, as other sounds are more broadband, have longer durations and occur at lower frequencies (Kyhn *et al,* 2008).

Bottlenose dolphins also have a highly developed sonar system for discriminating between, recognising and classifying objects (Azzaili *et al*, 1999; Pack *et al,* 2002; Branstetter *et al,* 2003; DeLong *et al,* 2006). Evans (1973) reported that bottlenose dolphin echolocation clicks are broadband, of between 200 Hz and 150 kHz, with a peak energy at 30-60 kHz, and with a source level of 40-80dB *re* 1 µbar @ 1m. In contrast, Au (2000) described bottlenose dolphins' echolocation clicks as having peak frequencies of 120 and 130 kHz, with a source level of 220dB re 1µPa @ 1m, and duration of 40 to 60µs. More recently, Dos Santos and Almada (2004) described bottlenose dolphin clicks as having peak frequencies at 70 kHz, close to the optimum hearing frequency of best hearing for bottlenose dolphins. Unlike harbour porpoises, bottlenose dolphins do not constantly echolocate. Studies in Sarasota Bay found that bottlenose dolphins can often swim for 10 minutes without echolocating and that their use of echolocation varied depending on water clarity (Au 2000). Studies have shown that when dolphins were feeding in clear water, they rarely echolocate, but when they were feeding over grass flats, echolocation was used more often.

6.2. Material and Methods

Feeding buzzes and click bursts have been described in many odontocete species. See Leeney *et al*, 2011 (Heaviside's dolphin); Herzing, 2000 (bottlenose dolphin); Miller *et al*, 1995 (narwhal, *Monodon monoceros*). Variation in *ICI* has been used as an indicator of certain behaviours in cetaceans (Wahlberg, 2002; Carlström, 2005; Koschinski *et al*, 2008; Akamastu *et al*, 2010; and Leeney *et al*, 2011). The minimum *ICI* (MinICI) has been deemed the most appropriate value as the software often splits trains when the *ICI* is long (Carlström, 2005). This has been employed in recent cetacean studies using T-PODs (Todd *et al*, 2009; and Leeney *et al*, 2011). Carlström (2005) deemed a MinICI of less than 10ms (MinICI<10ms) to be an appropriate identification of probable foraging, based on the shape of frequency distribution graphs generated from the mean of the distribution of the MinICIs. Verfuβ *et al* (2008) classified a harbour porpoise feeding buzz as the terminal section of the approach phase. The terminal part could be further divided into two sections that differ in click pattern. During the first section, *ICIs* were reduced from around 50ms to below 10ms, sometimes in an oscillating pattern. The second section was characterised by relatively constant *ICI* of around 1.4 to 1.6ms. This usually occurs at distances of less than 1m from the target object. Selecting trains with MinICIs of less than 10ms should, therefore, encapsulate both phases of the feeding buzz for the harbour porpoise.

Bottlenose dolphins have been described with *ICIs* of 19-45ms when investigating targets 20 to 120m away (Au, 1993), and *ICIs* of 10-25ms when investigating targets at 1m (Richardson *et al,* 1995). Zimmer (2011) has also described buzzes or pulse trains in bottlenose dolphins with a mean *ICI* of 1.3ms. Another delphinid species, the spinner dolphin (*Stenella longirostris*), has been found to have a bimodal pattern of *ICIs*, describing a peak in click trains with *ICIs* of 1.5 to 10ms and another peak with longer and more variable *ICIs* (Thomas *et al*, 2003).

6.3. Results

During the present study, graphs of MinICI were generated for NBHF trains detected at Spiddal and the Blasket Island cSAC sites, including the Gob, Inishtooskert and Wild Bank, as per Carlström (2005), (Figures 6.1 - 6.4). These figures were used to confirm the appropriateness of a MinICI<10ms categorisation for probable foraging behaviour in the harbour porpoise clicks trains. Graphs of MinICI were also generated for dolphin trains detected in the Shannon Estuary cSAC at Moneypoint and Foynes (Figure 6.5 and 6.6), displaying a bimodal pattern similar to that described by Thomas *et al* (2003). From these findings, a MinICI<10ms was also chosen to categorise probable foraging behaviour in bottlenose dolphins.

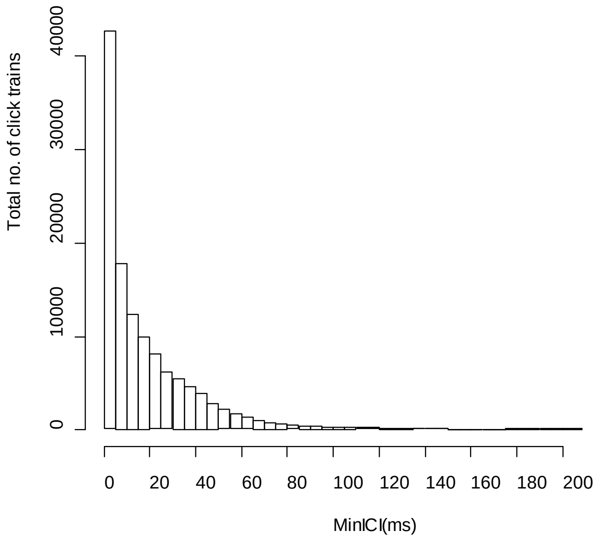


Figure 6.1: Frequency distribution of minimum inter-click intervals (MinICI) of narrow band high frequency (NBHF) trains detected at Spiddal in Galway Bay

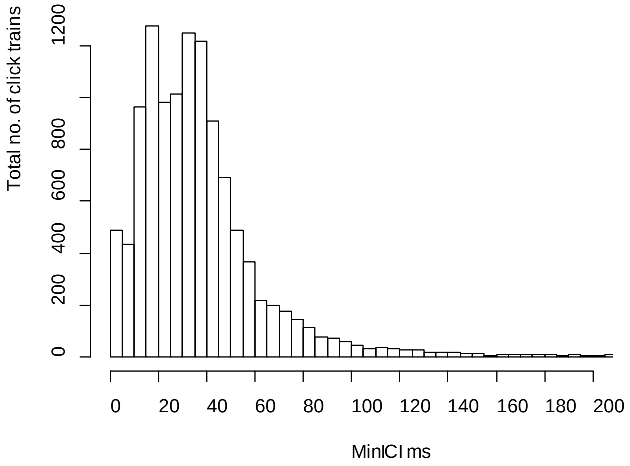


Figure 6.2: Frequency distribution of minimum inter-click intervals (MinICI) of narrow band high frequency (NBHF) trains detected at the Gob, in the Blasket Islands cSAC

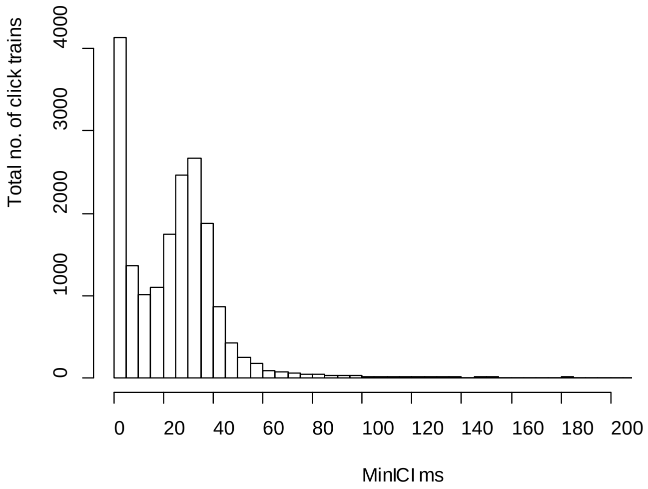


Figure 6.3: Frequency distribution of minimum inter-click intervals (MinICI) of narrow band high frequency (NBHF) trains detected at Insihtooskert, Blasket Island cSAC

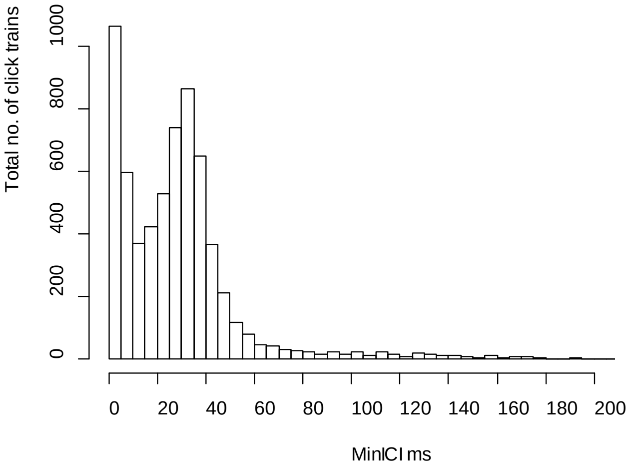


Figure 6.4: Frequency distribution of minimum inter-click intervals (MinICI) of narrow band high frequency (NBHF) trains detected at Wild Bank, Blasket Island cSAC

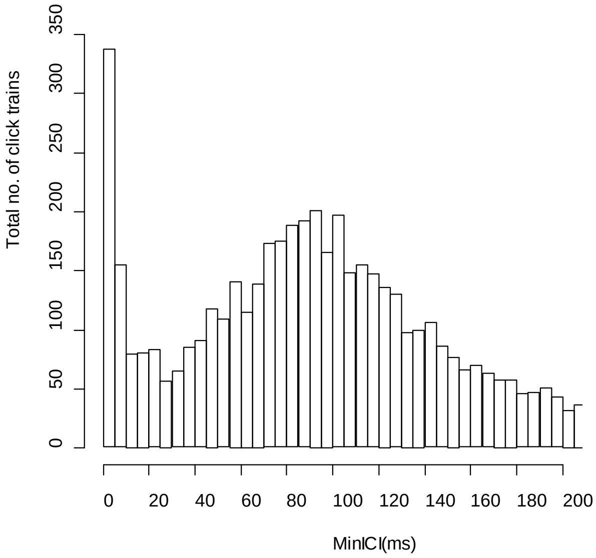


Figure 6.5: Frequency distribution of minimum inter-click intervals (MinICI) of Dolphin trains detected at Foynes in the Shannon Estuary

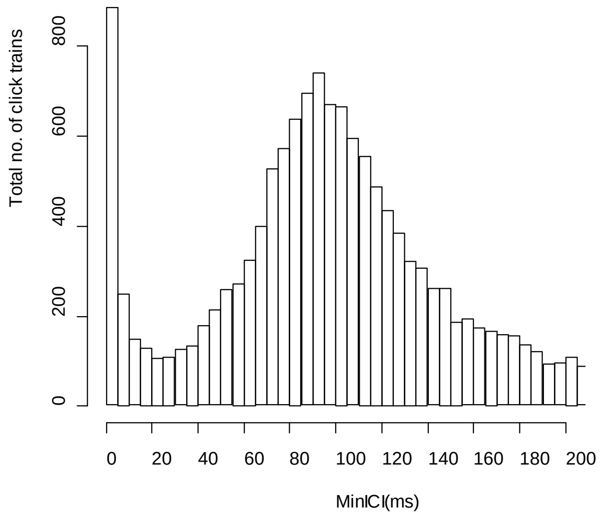


Figure 6.6: Frequency distribution of minimum inter-click intervals (MinICI) of Dolphin trains detected at Moneypoint in the Shannon Estuary

6.3.1. *Click train results*

A total of 144,216 NBHF click trains were recorded at Spiddal using C-PODs over the deployment period. The average number of clicks per train was 15, with on average 175.5 clicks recorded per second, and with an average frequency of 130.7 kHz across all deployments. Click trains were classified into two categories based on the data presented above, where the category foraging was applied to trains with MinICI<10ms. All other trains were defined as “Other” as no definite behaviour category could be attributed. Results showed 41% (60,386 trains) of the total click trains recorded fell under the category foraging, highlighting the site at Spiddal as a very important feeding area.

At Moneypoint, a total of 14,169 dolphin click trains were recorded. The average number of clicks recorded per train was 14.5, with an average of 37.5 clicks recorded per second at an average frequency of 72.6 kHz. These click trains were also classified into two categories based on the data above, where the category foraging was applied to trains with MinICI below 10ms, and all other click trains were defined as the behavioural category “Other”. Of the total, 1,060 (7% of total trains) trains were classified as foraging. Preliminary exploratory analyses showed no peaks in foraging trains across season, suggesting Moneypoint as an important feeding site year round. As highlighted in Chapter 5, a number of clicks were recorded in the NBHF channel in the Shannon Estuary, even though harbour porpoises are not known to occur here. Of these, a total of 171 trains (1% of total click trains) were recorded at Moneypoint, where the average number of clicks per click train was 15.6, with an average of 175.8 clicks recorded per second at an average frequency of 127.7 kHz.

At Foynes, the dolphin click trains were treated as before. A total of 5,113 click trains were recorded over the duration, with 9.4% (483 trains) classified as foraging. The average number of clicks per train classified in the dolphin category was 13.2, with an average of 40.4 clicks recorded per second at an average frequency of 68 kHz. Preliminary exploratory analyses showed no peaks were evident in foraging behaviour across diel or tidal cycle, but autumn showed a substantial peak, with a total of 22% of total foraging clicks recorded. A total of 89 NBHF trains were recorded at Foynes (2% of overall click trains), where the average number of clicks per click train was 14.9, with an average of 68.3 clicks recorded per second at an average frequency of 130 kHz.

In the Blasket Islands, deployments took place at three locations. From Inishtooskert, a total of 19,438 NBHF click trains were recorded. The average number of clicks per click train was 11.5, with on average 133 clicks recorded per second at an average frequency of 129 kHz. Of the total, 5,572 (27%) trains were classified as foraging. From data at Wild Bank, a total of 7,328 NBHF click trains were recorded. The average number of clicks per click train was 9.4, with on average 84 clicks recorded per second at an average frequency of 129 kHz. Of the total, 1,717 (23%) trains were classified as foraging. From the shorter dataset at the Gob, a total of 11,632 NBHF click trains were recorded over a 52-day duration. The average number of clicks per click train was 14.1, with, on average, 52 clicks recorded per second at an average frequency of 134 kHz. Of the total, 926 (8%) trains were classified as foraging.

6.3.2. *Long-term SAM model of habitat use*

To investigate the pattern of habitat use at each of the monitoring locations, click train data were analysed across the four previously examined variables of season, diel, tidal phase and tidal cycle. A MinICI<10ms was used as a proxy for foraging behaviour in both harbor porpoise and bottlenose dolphins. All statistical analyses of the data were carried out using the programme R. A generalized linear mixed effect model (GLMM) was fitted to the binomial data, using the glmer function in the lme4 package developed for R where MinICI<10ms = 1, termed “feeding buzzes” (foraging) and >10ms = 0 (not foraging). Akaike’s information criterion (AIC) and a histogram of fitted residuals were used as diagnostic tools for model selection. C-POD ID was included in the GLMM model as a random factor to take into account intra POD variability over the project duration. Wald chi-squared tests were computed for each variable and predicted proportions of MinICI<10ms were extracted across all levels and displayed as box plots using the HH package developed for R.

6.3.3. *Galway Bay*

C-PODs were deployed for 572 days at the Spiddal site, from which 144,216 NBHF click trains were extracted for analyses. The model containing all four variables was deemed the best fit for NBHF click trains in Galway Bay, indicating that season, diel, tidal phase and tidal cycle all significantly affect foraging behaviour of harbour porpoise in this area (Figure 6.7). Season was found to be the most significant variable (χ^2 = 3282.4, P>0.001), with the highest levels of feeding buzzes during winter. Within tidal cycle (χ^2 = 100.4, P>0.001), the highest level of feeding buzzes was found during an ebbing tide (Figure 8.6), and results also show that the diel category "night" contains the highest predicted proportion of feeding buzzes (χ^2 = 1053.4, P>0.001). Tidal phase was found to be the least significant predictor of feeding buzzes (χ^2 = 13.9, P>0.001), and the low chi-squared value indicates that this variable may only be highlighted due to the large dataset. Large datasets can exhibit mathematically significant patterns even when there is no biological significance, but the use of the chi squared value in this instance allows for correct interpretation of the data.

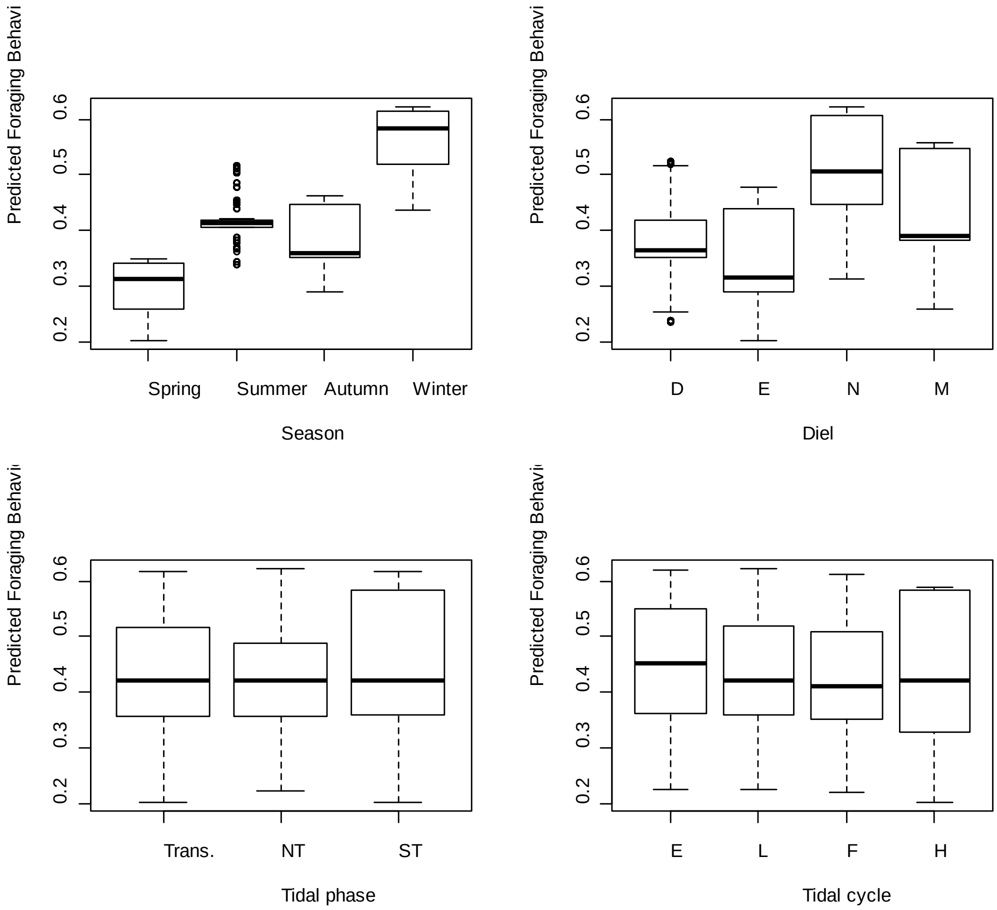


Figure 6.7: Predicted proportion of NBHF (narrow band high frequency) click trains with minimum inter-click intervals of less than 10ms (MinICI<10ms) in Galway Bay across the four variables of season; diel, where D =day, E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high

6.3.4. *Moneypoint*

C-PODs were deployed for a total of 641 days at Moneypoint, from which 14,169 Dolphin click trains were extracted for analyses. The model that best fitted the dataset at Moneypoint was the model containing three variables (diel, tidal phase and tidal cycle), (Figure 6.8). Results of the diel cycle gave the highest chi squared value (χ^2 = 121.6, P>0.001), indicating this variable has a greater effect on feeding buzzes than tidal cycle and phase. Neap tide (χ^2 = 100.3, P>0.001) was found to contain the lowest proportion of feeding buzzes. Within tidal cycle, a peak in the feeding buzzes was clearly seen during a flooding tide (χ^2 = 100.9, P>0.001).

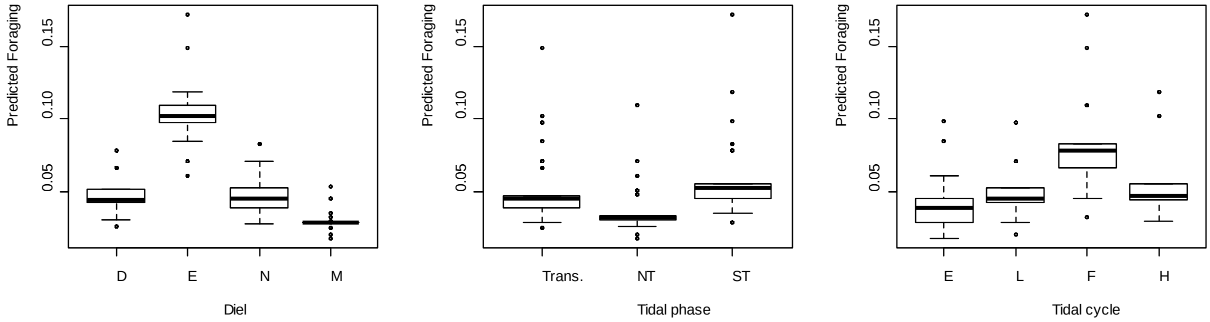


Figure 6.8: Predicted proportion of Dolphin (detections in the Dolphin channel) click trains with minimum inter-click intervals of less than 10ms at Moneypoint in the Shannon Estuary cSAC across the three variables of diel, where D =day, E= evening, M= morning and N = night; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high; and tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide

6.3.5. *Foynes*

C-PODs were deployed for a total of 591 days at the Foynes study site, from which 5,113 dolphin click trains were extracted for analyses. Season, diel and tidal phase were highlighted as significant predictors of feeding buzzes (Figure 6.9). Season was shown to be the most significant variable (χ^2 = 195.6, P>0.001), with the highest proportion of feeding buzzes during the winter months (Figure 8.6). Results from the model suggest that diel (χ^2 = 54.2, P>0.001) and tidal phase (χ^2 = 43.5, P>0.001) have less of an effect on the level of feeding buzzes than season.

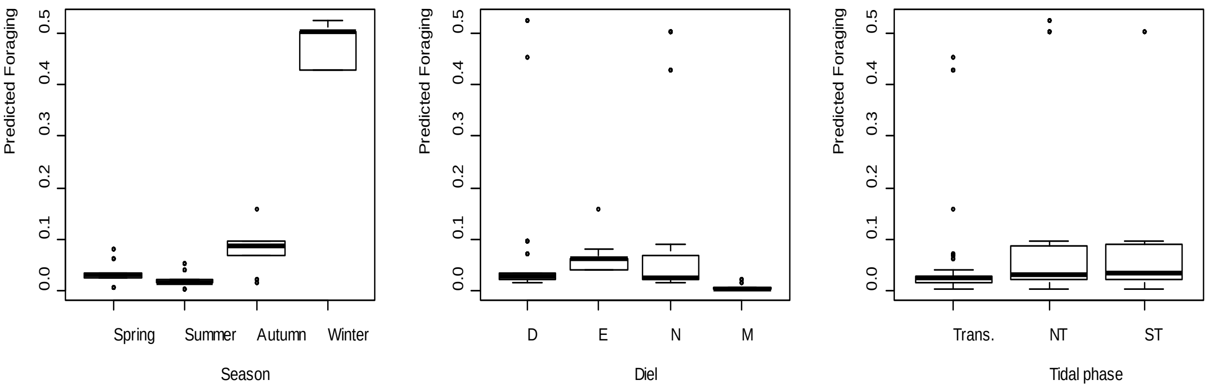


Figure 6.9: Predicted proportion of dolphin (detections in the dolphin channel) click trains, with minimum inter-click intervals of less than 10ms at Foynes in the Shannon Estuary cSAC across the three variables of season; diel, where D =day, E= evening, M= morning and N = night; and tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide

6.3.6. *Blasket Islands*

C-PODs were deployed for 605 days in the Blasket Islands sites, during which 38,398 NBHF click trains were extracted for analyses. The data were analysed separately, according to site, in order to assess fine scale differences in site usage. Three variables were found to significantly affect the level of foraging behaviour of harbour porpoise at Inishtooskert and at Wild Bank (Figure 6.10). At Inishtooskert, diel was shown to be the most significant variable ($\chi^2 = 598$, P>0.001), with a peak in feeding buzzes during the day and morning phases. Tidal cycle also significantly affected the level of feeding buzzes ($\chi^2 = 157.9$, P>0.001), with a predicted rise in foraging click trains during a flooding tide. Seasonal peaks in foraging were also observed during the autumn ($\chi^2 = 38.7$, P>0.001).

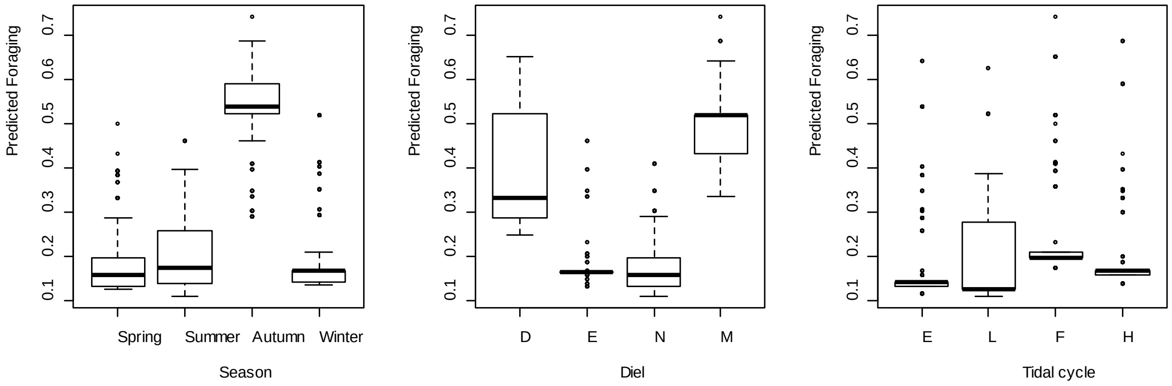


Figure 6.10: Predicted proportion of NBHF (narrow band high frequency) click trains with minimum inter-click intervals of less than 10ms in the Blasket Islands cSAC at Inishtooskert across the three variables of season; diel, where D =day, E= evening, M= morning and N = night; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high

At Wild Bank, both seasonal and diel were the most significant variables (χ^2 = 132.8, P>0.001, χ^2 = 129.8, P>0.001), with a peak in predicted feeding buzzes during the summer, evening and night-time phases. Tidal cycle also significantly affected the level of feeding buzzes (χ^2= 63.9, P>0.001), with a predicted rise in foraging click trains during flooding and ebbing tides.

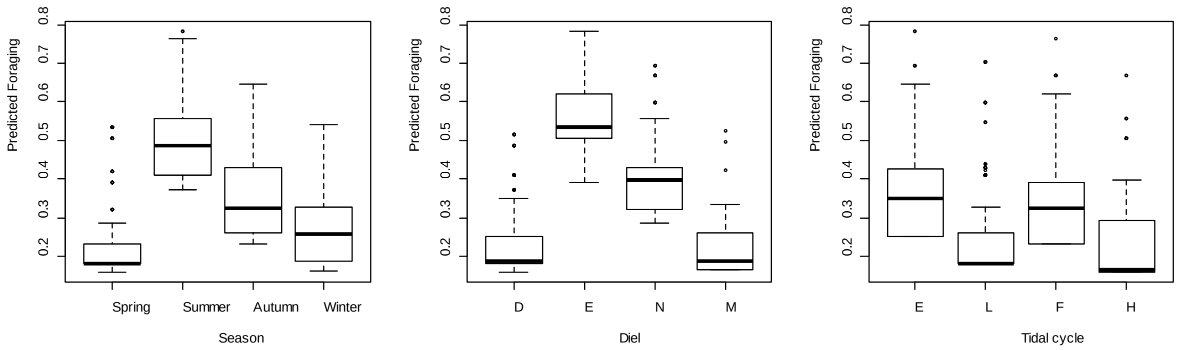


Figure 6.11: Predicted proportion of NBHF (narrow band high frequency) click trains with minimum inter-click intervals of less than 10ms in the Blasket Islands cSAC at Wild Bank across the three variables of season; diel, where D =day, E= evening, M= morning and N = night; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high

The dataset from The Gob was over a short duration (N=52 days) and, therefore, seasonal and tidal phase effects could not be analysed. Also, only a single unit was deployed, eliminating the need for the GLMM with POD ID as a random factor. A GLM was carried out. Diel was the most significant variable, with a predicted peak in feeding buzzes during the night-time phase (P>0.001).

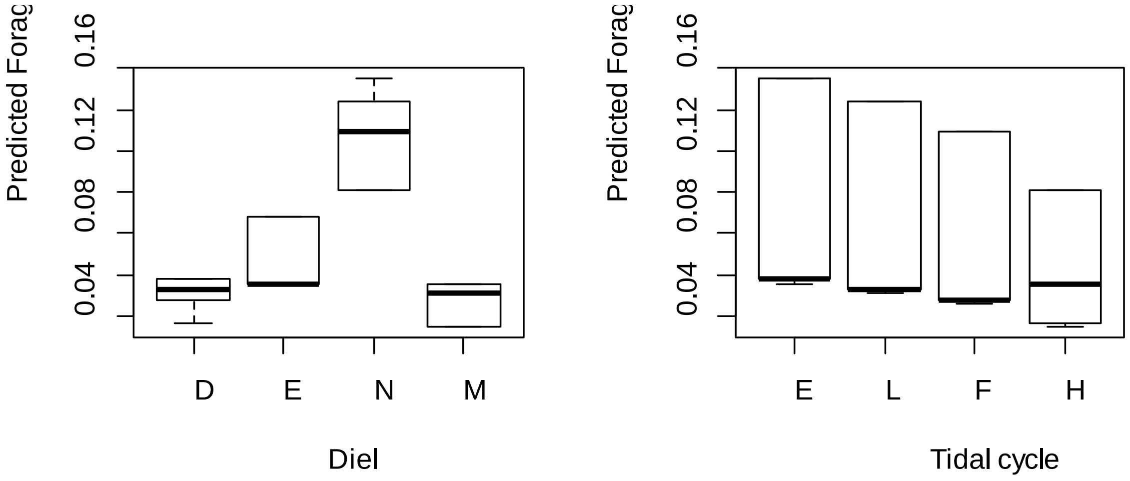


Figure 6.12: Predicted proportion of NBHF (narrow band high frequency) click trains with minimum inter-click intervals of less than 10ms in the Blasket Islands cSAC at The Gob across the two variables of diel, where D =day, E= evening, M= morning and N = night, and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high

6.4. Discussion

Results show that click train analyses can be used to highlight important areas by identifying specific behaviours which describe how animals use a site. For example, the Spiddal dataset highlights the area as an important feeding site (44%) for harbour porpoise year round, with a distinctive peak during the winter months. Additionally, at the Blasket Islands cSAC, patterns in habitat use could be identified over small geographical distances (c10km) as multiple sites were monitored. This was also found by Berrow *et al* (2009a), who carried out short–term monitoring (June to Sept) at both of these sites (Wild Bank and Inishtooskert) using T-PODs. The data from the present study is not directly comparable with Berrow *et al* (2009a) as behaviour analyses deal with individual click trains and not presence absence as determined from DPMs. However, results do show that the use of both methods (presence/absence or behaviour) allows the depiction of small fine scale differences across small geographical areas.

Results from the present study are limited in that only a single behaviour was identified. This was due to time constraints, and because it was not possible to carry out a full investigation similarly to Koshchinski *et al* (2008) using T-POD data. It would be extremely valuable to establish a method for quick identification of, for example, alarm and dominance calls within a dataset, and this would serve to highlight and reinforce the importance of specific areas. The ability to identify behaviour types from acoustic dataset provides an invaluable insight into how animals use a site. This has implications for the conservation of habitat and of the species.

7. TOWED ACOUSTIC SURVEYS ON PLATFORMS OF OPPORTUNITY

7.1. Introduction

Monitoring cetaceans through Passive Acoustic Monitoring surveys (PAM) can be done using Platforms of Opportunity (POPs) or dedicated survey platforms (Evans and Hammond, 2004). POPs surveys are preferable because they provide very low cost platforms and may cover large areas over extended periods where the high cost of hiring vessels is not incurred. However, a major constraint is the lack of an *a priori* survey route design. Furthermore, the speed of the vessel cannot be controlled (Evans and Hammond, 2004). Ferry companies crossing the Irish and Celtic Seas have provided space for researchers for many years, resulting in a better understanding of the distribution of cetaceans along these routes (Brereton *et al*, 2001). Also, the two national research vessels, R.V. *Celtic Voyager* and R.V. *Celtic Explorer*, have been used as POPs for cetacean surveys several times (Wall *et al,* 2006). Cetaceans live in an acoustic world and attempts have increasingly been made to develop PAM techniques. PAM is a method to determine the presence and distribution of cetacean species by listening for their sounds. These studies can be done using towed hydrophone arrays or static equipment, including fixed hydrophones (Berrow *et al*, 2006).

The use of PAM in cetacean conservation identifies two main components for its application, "detection" and "classification". Detection is the individualisation of acoustic signals, while classification refers to species-specific acoustic identification of these signals (Yack *et al,* 2009). Traditionally, acoustic surveys have been conducted using observer-based methods of analyses, usually by eye, of acoustic files, which is time consuming and requires a highly trained technician. Therefore, automated detection and classification methods are being developed (Yack *et al,* 2009).

PAM greatly improves the detection rate for odontocetes (Gordon *et al,* 1999), and in recent years, it has become increasingly widespread for cetacean observations (Moore *et al,* 2006). The combination of both visual and acoustic methods can improve the efficiency of cetacean surveys (Weir *et al,* 2001). Therefore, many studies incorporate both visual and acoustic techniques in order to complement the data of the research.

There are potential disadvantages to using PAM. Firstly, towing a hydrophone is often not feasible on vessels that are already towing gear that can include fishing nets or acoustic arrays. Vessels generate noise as they move through the water. This noise can mask the vocalizations and affect the range capability of the acoustic gear. Therefore, quiet vessels are ideal platforms for this kind of study (Gordon *et al,* 1999). Furthermore, cetaceans are not always vocalizing (Evans and Hammond, 2004) and this implies no detection or false negatives. From an economic point of view, passive acoustic techniques require highly qualified PAM operators and expensive equipment but can contribute to an offshore data by making data acquisition possible during the night-time hours and in adverse weather conditions. Ship time is expensive and, therefore, the amount of data collected should be maximised at all times, and PAM facilitates this.

7.2. Materials and Methods

For the present study, PAM was carried out on board the Irish national research vessel R.V. *Celtic Explorer*, a 65.5m vessel travelling at an average speed of 7-10 Knots. PAM surveys were, where possible, carried out concurrently to visual surveys while on dedicated and opportunistic cruises. PAM took place 24 hours a day, where possible, depending on weather conditions and what activity the ship was engaging in (i.e. CTDs, fishing, etc. Table 7.1). The R.V. Celtic Explorer complies with the noise requirements of ICES CRR Report 209 and is acoustically silent, providing an ideal platform for the collection of high quality acoustic data with minimal interference from vessel engine noise. In total, six PAM surveys were carried out, two of which were on dedicated cetacean cruises.

During surveys, a towed hydrophone array was deployed from the R.V. *Celtic Explorer.* This consisted of a 200m array having two hydrophone elements (HP-03) situated 25cm apart in a fluid-filled tube towards the end of the cable. The hydrophone was connected to the vessel with a bungee cord to avoid tension on the main line. The cable and array is designed to be negatively buoyant by the weight of the cable in order to tow it under the surface at a depth of between two to five metres, depending on the speed of the vessel. The 200m cable contains wires that conduct power from the battery attached at the dry end (MAGREC Ltd HP-27st buffer box) and carries it to the preamplifiers in the fluid-filled tube at the wet end of the array. The buffer box is attached to a laptop computer and a National Instruments DAQ-6255 USB soundcard is connected to the output of the buffer-box and, through USB, into the laptop. This sound card allows for the detection of sounds outside the capability of the computer soundcard. Two channels were sampled at 192 kHz, re-coding acoustic events with a 2-96 kHz frequency range. A dedicated laptop was installed with PAMGUARD (ver.1.5.01) Beta software for data acquisition. A 2TB external hard drive provided additional storage and a backup facility for the data collected. Raw recordings were stored on the laptop and backed up to the hard drive daily. The software PAMGUARD (www.pamguard.org; Gillespie *et al,* 2008) was used on board. PAMGUARD allowed for the collection of real-time acoustic data while the hydrophone was deployed, storing the data as wav. files on the computer along with GPS data and user-input information in an access database.

During some surveys, where at least two MMOs were on board, the PAM computer was monitored and the observer made notes of any detections using the user input facility on PAMGUARD. Information was directly stored in the main access database. During night-time transects, the PAM computer was either monitored or left to run unsupervised, with raw recordings being stored to the laptop and backed up to hard drive for later analysis. The hydrophone system (MAGREC HP-03) did not allow the detection of baleen whales as their vocalizations were outside the frequency capabilities of hydrophone.

Table 7.1: Name of the acoustic surveys carried out, and their respective dates. Abbreviations will be used from now on in the analysis

	PAM Surveys		
	Survey name	**Abbreviation**	**Date**
1.	Cetaceans on the Frontier	CFS 1	18-31 Aug 2009
2.	NPWS Habitat Mapping	NPWS	3-21 Sept 2009
3.	FSS Deep-water	DEEP	2-15 Dec 2009
4.	Oceanographic and Climate Change	CLIMATE	5-17 Feb 2010
5.	Cetaceans on the Frontier II	CFS 2	18 Feb-1 Mar 2010
6.	OSS Oceanographic	OSS	16-22 May 2010

7.2.1. *The aims of PAM during the present study were:*

Species identification and evaluation of data analyses

- To identify vocalizations to species level using the observer-based method of analyses (manual).
- To group vocalizations into acoustic encounters.
- Where identification of vocalizations to species level is not possible, simultaneous visual data (if available) is used to classify detections.

Mapping cetaceans distribution and abundance

- To map acoustic encounters identified and to highlight important areas of species distribution and abundance through PAM.

Testing the efficacy of PAMGUARD in identifying vocalizations

- To test the efficacy of the automated method of analyses carried out using PAMGUARD to identify odontocetes vocalizations (clicks and whistles) through the comparison with the results obtained using the observer-based method of analyses. To evaluate advantages and disadvantages in using the automated method of analyses.

7.2.2. *Acoustic data analyses*

Prior to analysing the data, a reference library was generated using all available literature and to compile a reference database of species-specific vocalization and echolocation characteristics for odontocetes species in Irish waters (see Pierini, 2011). This database served as a reference library for which to refer when identifying vocalizations to species level in the absence of visual confirmation. The reference library was compiled by trawling through an extensive literature collection and compiling relevant acoustic information. When classifying the vocalizations to species level, the characteristics of the vocalizations had to fit within the values of frequencies described in the reference databases created. If not, then the detection was downgraded to the category "unidentified dolphin" or "unidentified cetacean". The software Adobe Audition was used to look at spectrograms of all acoustic files. An excel spread sheet was compiled and information about detections identified in the .wav file were recorded.

Three categories were created in order to classify detections within all acoustic files:

- <u>Vocalization</u>: each single sound (click, whistle, moan, buzz, or burst pulse sound) detected.
- <u>Acoustic detection</u>: each group (each sighting of odontocete species was classified as an individual group) of animals recorded by the hydrophone.
- <u>Acoustic encounter</u>: Different *acoustic detections* were grouped together into the category *acoustic encounter* when the delay between the end time of one and the start time of the next *acoustic detection* was less than ten minutes. If the time frame between encounters did not exceed ten minutes then it was not considered as a new *acoustic encounter*.

Whistle identification to species level, took into account the following parameters:

- Start Frequency: frequency at which the whistle starts (Hz).
- End Frequency: frequency at which the whistle ends (Hz).
- Minimum Frequency: frequency at the lowest point of the whistle (Hz)
- Maximum Frequency: frequency at the highest point of the whistle (Hz).
- Frequency Range: the range of frequencies (Hz) spanned by the whistle calculated as: maximum frequency – minimum frequency.

Click identification to species level also followed parameters found in the reference library:

- Frequency Range: the range of frequencies (Hz) spanned by the click calculated as: maximum frequency – minimum frequency.
- Maximum Frequency: frequency at the highest point of the click (Hz).
- Minimum inter-click interval (ms): minimum elapsed time between two consecutive clicks.
- Maximum inter-click interval (ms): maximum elapsed time between two consecutive clicks.
- Average inter-click interval (ms): average elapsed time between two consecutive clicks.

Where possible, visual datasets, which were collected concurrently with PAM surveys, were used to facilitate identification to species level. If a detection could not confidently be identified to species level, the acoustic encounter was downgraded to "unidentified dolphin" or "unidentified cetacean". Up to 300 visual sightings were collected by the visual observers of which 51matched with PAM recordings.

7.2.3. *Mapping cetaceans distribution and abundance*

All acoustic encounters involving acoustic effort were mapped using ArcGIS 9.3. This allowed for additional data for offshore surveys where species distribution could also be plotted from PAM. 50x50km squares were generated to identify the total area covered by the towed hydrophone and to calculate the relative abundance of acoustic encounters for each square by dividing total number of acoustic encounters in each square by the total acoustic effort (km) in each square. Surveys were carried out in the offshore environment and covered various habitat types (Figure 7.1).

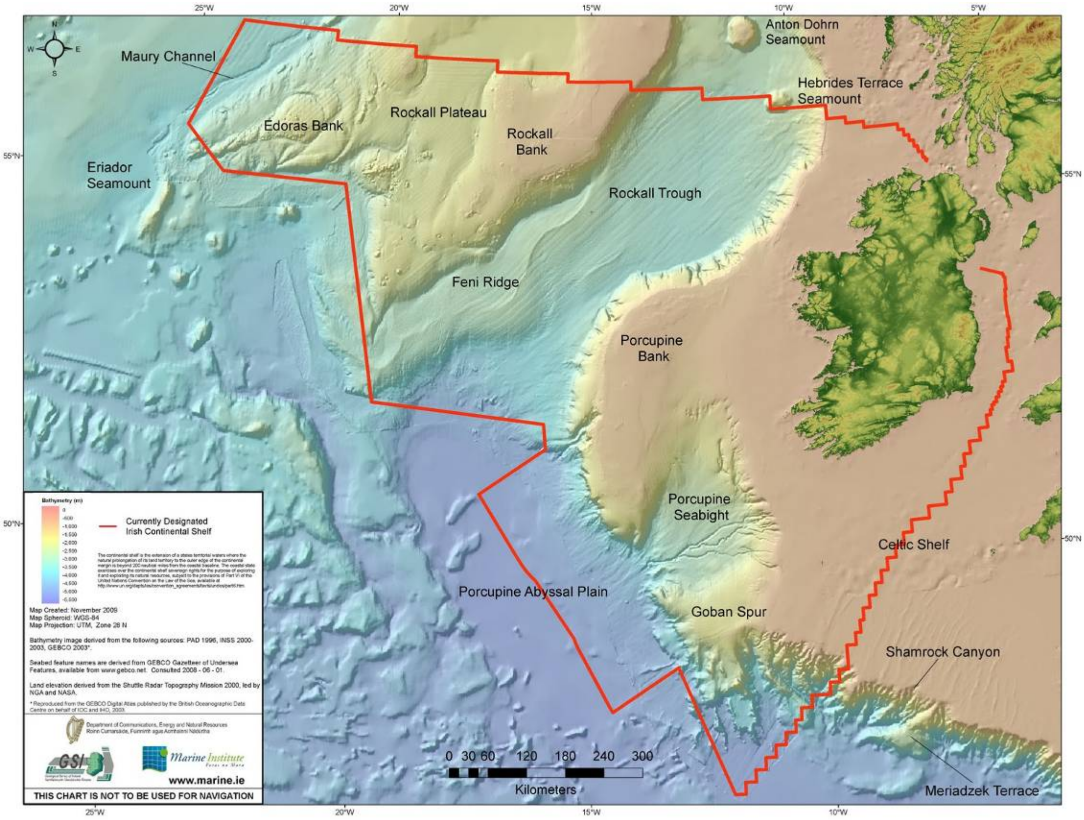


Figure 7.1: Map of Irish waters including offshore habitats © www.marine.ie

7.3. Results

Out of 79 days at sea with PAM equipment, it was only possible to deploy the array on 55 days. It was not possible to deploy the towed hydrophone 24 hours a day on all surveys due to the ships' main survey objectives, such as fishing and CTDs, and due to bad weather conditions. A total of 533 hours of acoustic effort was collected over the 55 days and the data analysed (Figure 7.2).

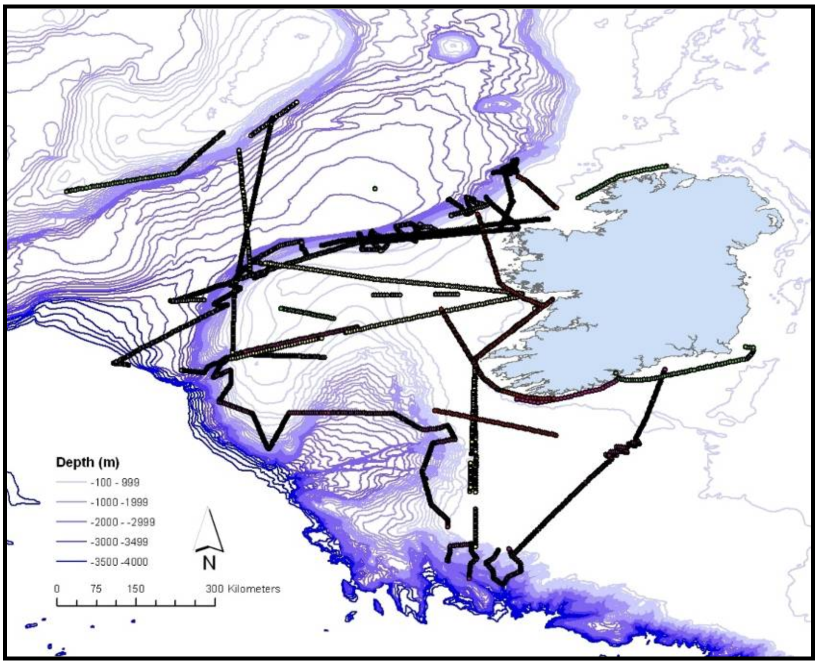


Figure 7.2: Map showing the total PAM effort carried from the R.V Celtic Explorer

A total of 422 acoustic encounters were identified. The number of acoustic encounters, divided into different species categories, where possible, is shown in Table 7.2**.** Acoustic encounters were grouped into five categories. It was not possible to identify 323 acoustic encounters to species level. These unidentified acoustic encounters were, therefore, downgraded to the two categories of “unidentified dolphin” and “unidentified cetacean”. The remaining 99 acoustic encounters were identified to species level, identifying three species: sperm whale, harbour porpoise and long finned pilot whale.

Table 7.2: Total number of acoustic encounters identified to species level when possible using the observer-based method of analyses in Adobe Audition 1.0. Unidentified acoustic encounters are showed as the two categories "unidentified dolphin" and "unidentified cetacean"

Acoustic Encounters		
Species detected	Abbreviation	PAM confirmation
Sperm whale	**SP**	**73**
Pilot whale	**PW**	**24**
Harbour porpoise	**HP**	**2**
Unidentified dolphin	**UID**	**309**
Unidentified cetacean	**UIC**	**14**

Not all of the 323 acoustic encounters previously identified as "unidentified dolphin" (309 encounters) and "unidentified cetacean" (14 encounters) were successively matched to the visual data (sightings) acquired concurrent to while the hydrophone was recording. A total of 41 unidentified dolphin acoustic encounters were visually identified as common dolphin (36 encounters), long finned pilot whale (1 encounter) and bottlenose dolphin (4 encounters). A total of 8 unidentified cetacean acoustic encounters were identified as long finned pilot whale (6 encounters), sperm whale (1 encounter) and northern bottlenose whale (1 encounter) (Figure 7.3).

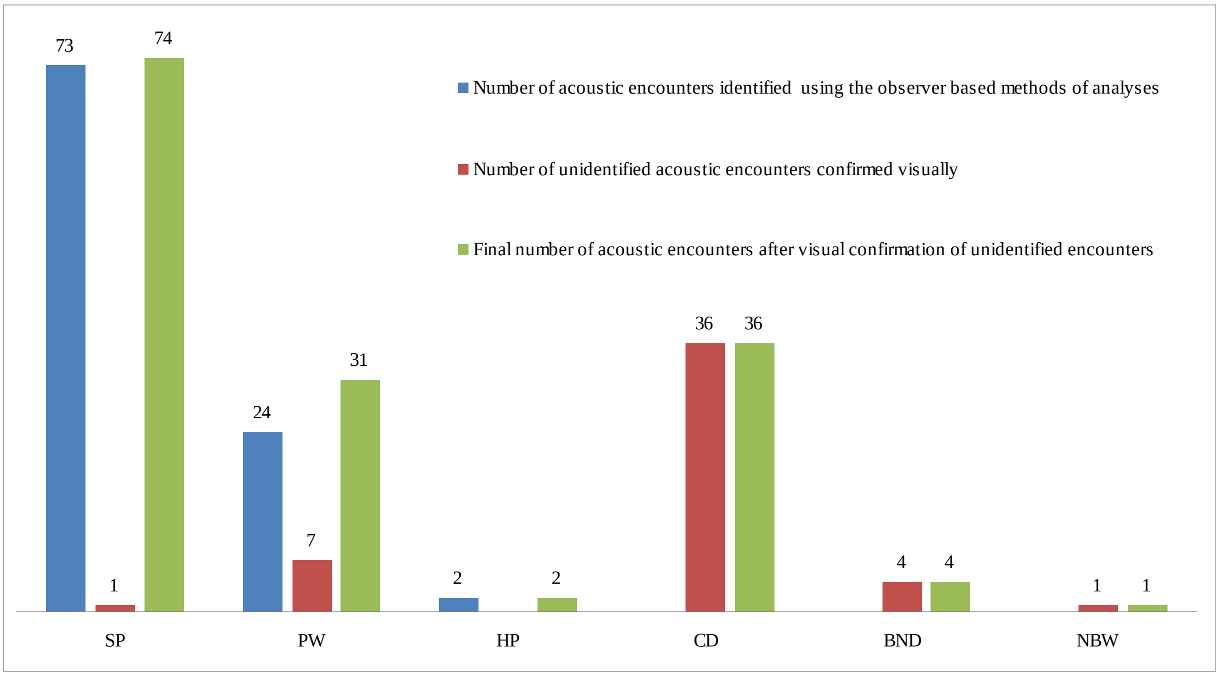


Figure 7.3: Number of acoustic encounters for each species detected. In blue is the total number of acoustic encounters identified using the observer-based method. In red is the number of unidentified acoustic encounters (unidentified dolphin encounters and unidentified whale encounters) confirmed to species level after correlating with the visual sightings database. In green is the final number of acoustic encounters including both acoustic encounters identified with the observer-based method and those identified after correlating the unidentified encounters with the visual database. Abbreviations: SP (sperm whale), PW (long finned pilot whale), HP (harbour porpoise), CD (common dolphin), BND (bottlenose dolphin), NBW (northern bottlenose whale)

For the remaining 268 unidentified dolphin acoustic encounters and 6 unidentified cetacean acoustic encounters, it was not possible to confirm the species because these acoustic encounters happened at night in the absence of visual surveys. Therefore, visual sightings data were not available for the species confirmation of these unidentified acoustic encounters (Figure 7.4). Unidentified dolphin acoustic encounters and unidentified cetacean acoustic encounters not confirmed by sightings were left classified as unidentified dolphins or unidentified cetaceans acoustic encounters.

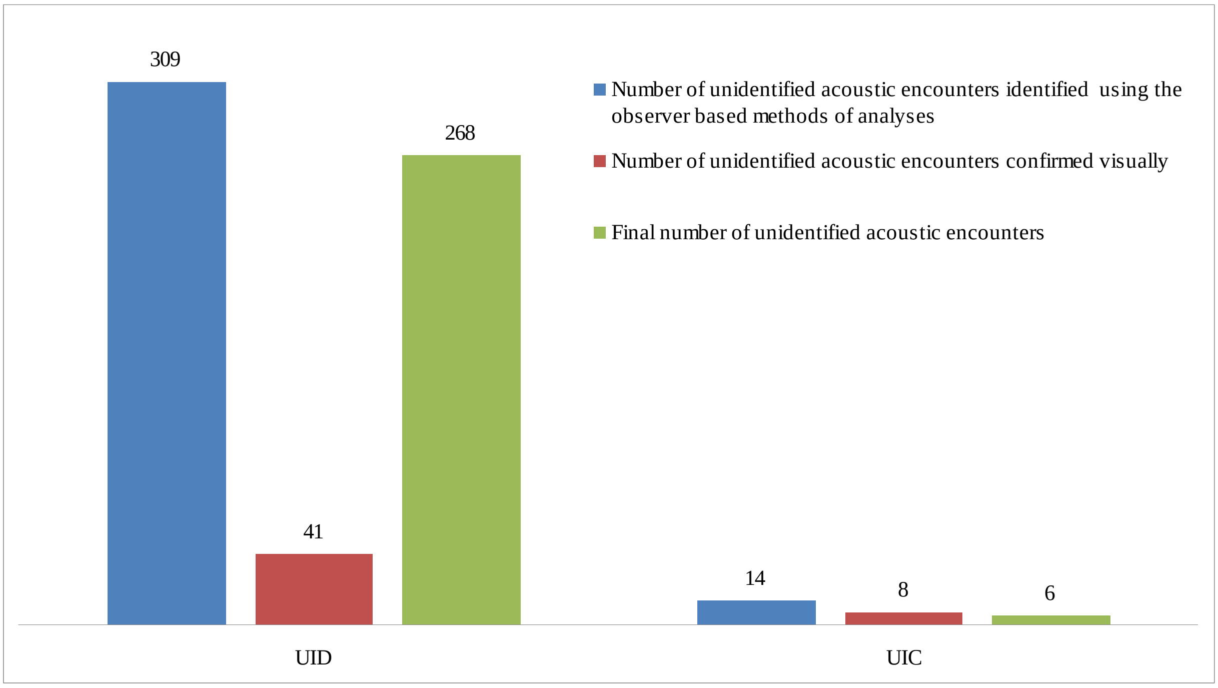


Figure 7.4: Overview of unidentified dolphin and unidentified cetacean acoustic encounters. The amount of unidentified dolphin and unidentified cetacean acoustic encounters is shown before (blue) and after (green) the correlation with visual sightings data. The number of acoustic encounters identified to species level after the correlation with the visual sightings data is shown in red

7.3.1. *Survey effort and geographic coverage*

Sperm whales were mainly detected along the shelf slope. A high number of acoustic encounters were detected over the Porcupine Bank slope, but few acoustic encounters were recorded over the southern edge of Rockall Bank and over the deep waters of the Rockall Trough. One acoustic encounter was recorded on the shelf over the Porcupine Seabight (Figure 7.5). The highest number of sperm whales detections was recorded over the Porcupine Bank slope, the deep waters of the Rockall Trough and the Porcupine Bank slope (Figure 7.6).

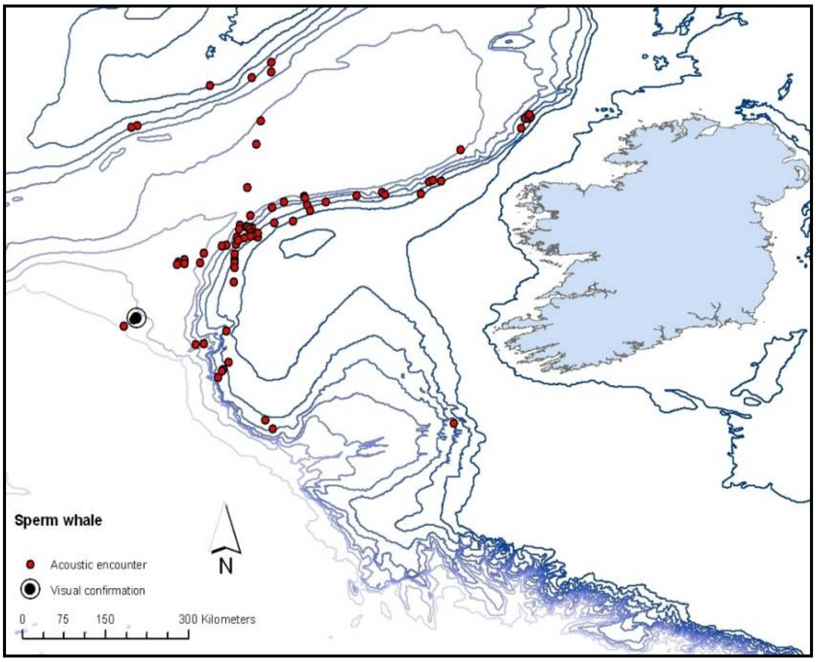


Figure 7.5: Distribution of acoustic encounters of sperm whale

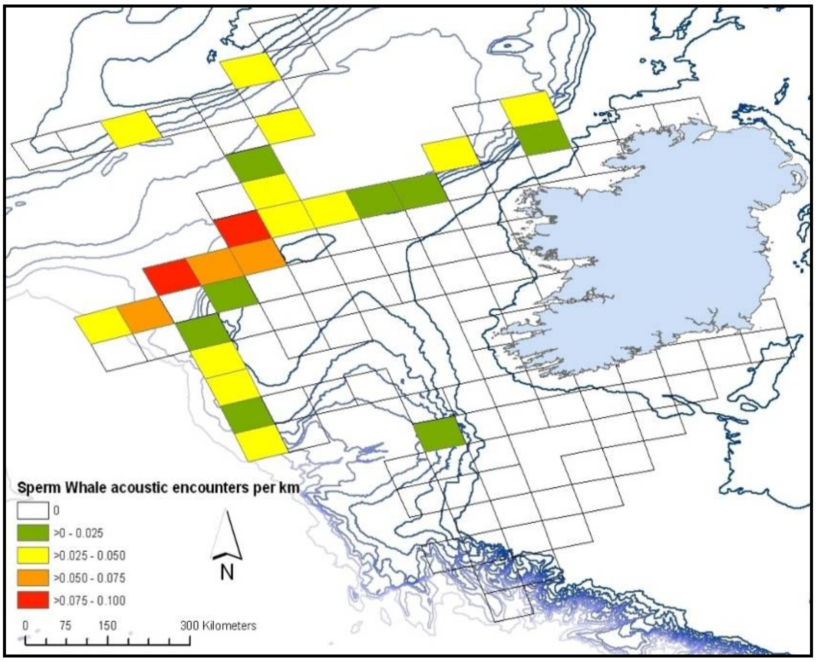


Figure 7.6: Sperm whale acoustic encounters per km

Long-finned pilot whales were mainly detected along the shelf slope, with a few noted over the southern edge of Rockall Bank and over the Rockall Trough. Furthermore, pilot whales were detected in the south west Irish EZZ waters, over the Goban Spur (Figure 7.7). High detection rates for pilot whales were encountered on the shelf of the Goban Spur (Figure 7.8).

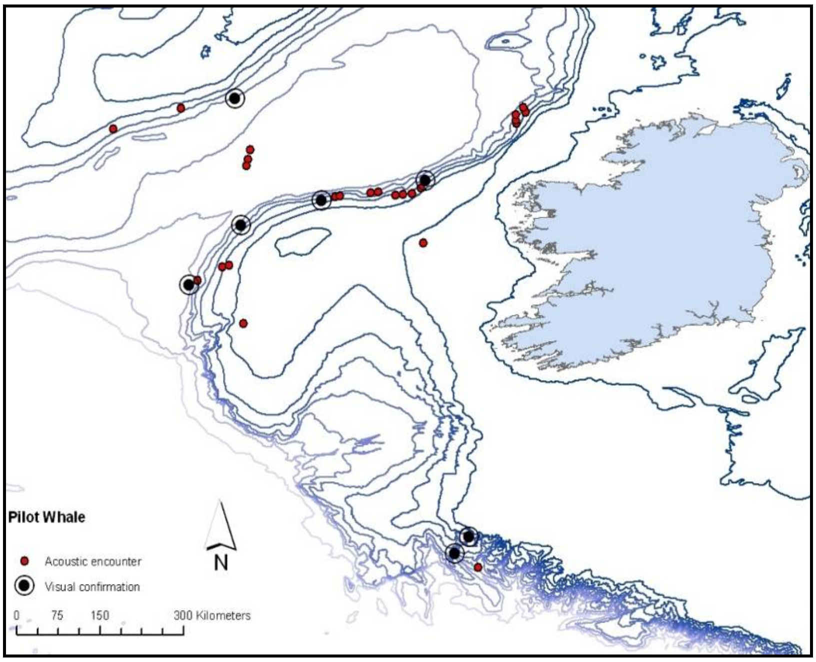


Figure 7.7: Distribution of acoustic encounters of long finned pilot whale

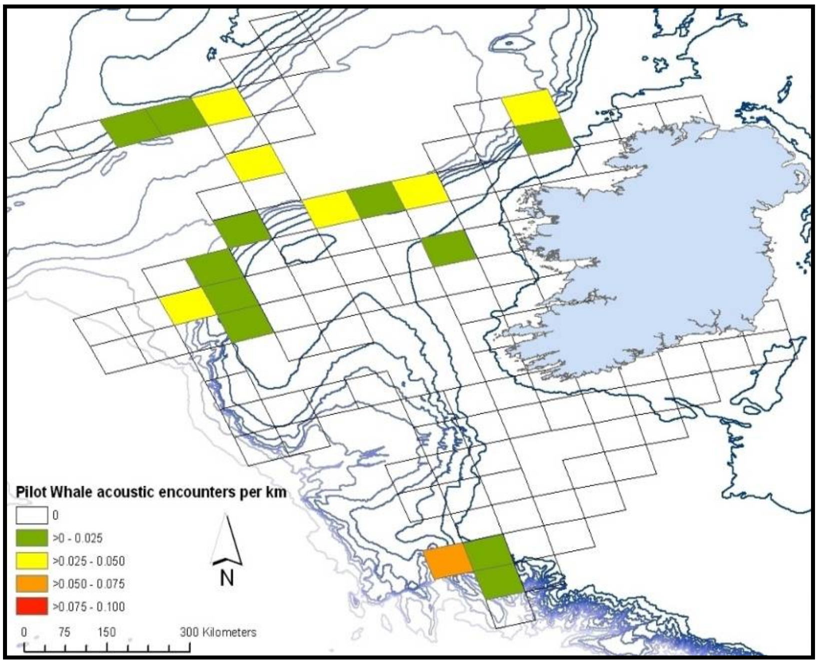


Figure 7.8: Long finned pilot whale acoustic encounters per km

Only two acoustic encounters of harbour porpoise were detected and were located near shore along the Irish north-west coast (Figure 7.9). The relative detection per km was low (Figure 7.10).

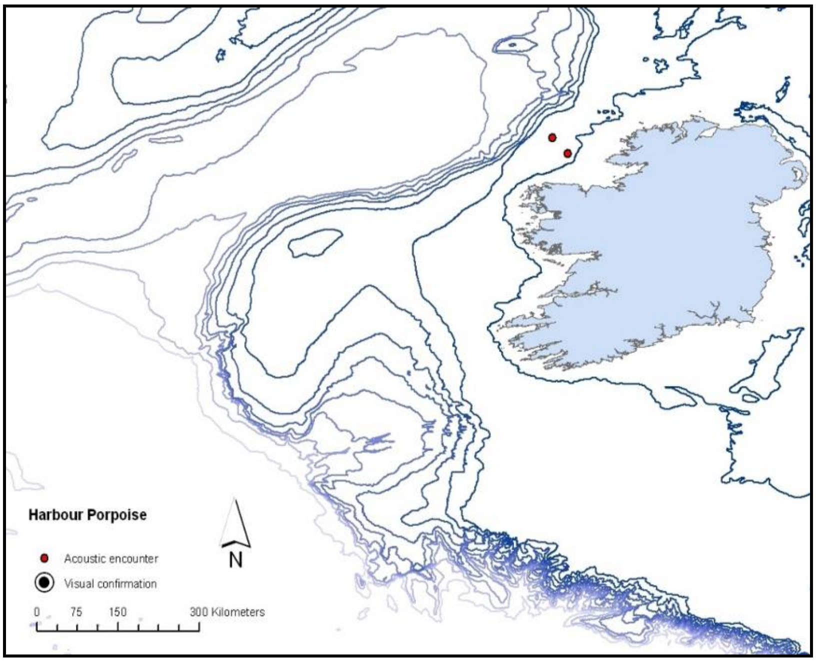


Figure 7.9: Distribution of acoustic encounters of harbour porpoise

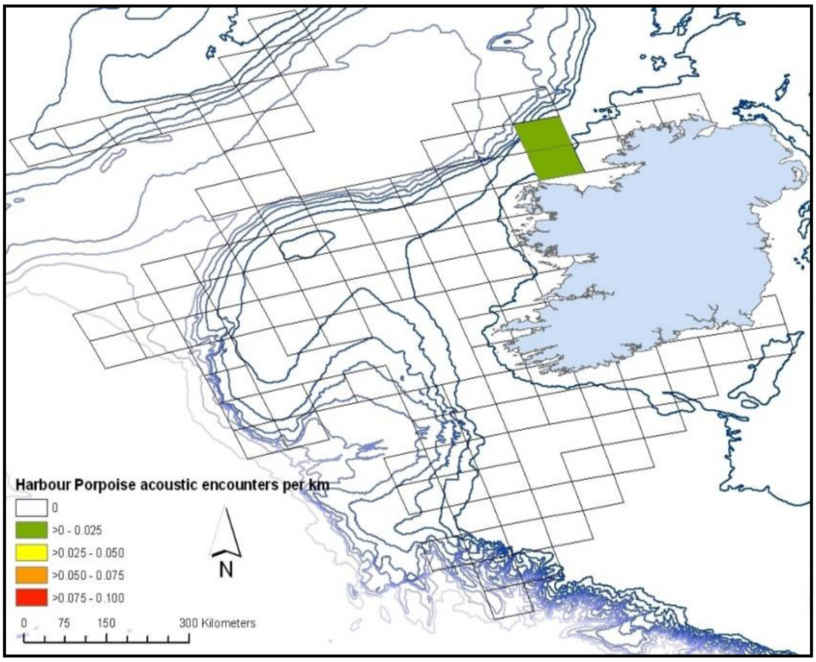


Figure 7.10: Harbour porpoise acoustic encounters per km

A single acoustic encounter of the northern bottlenose whale was recorded on the Porcupine Bank shelf edge (Figure 7.11).

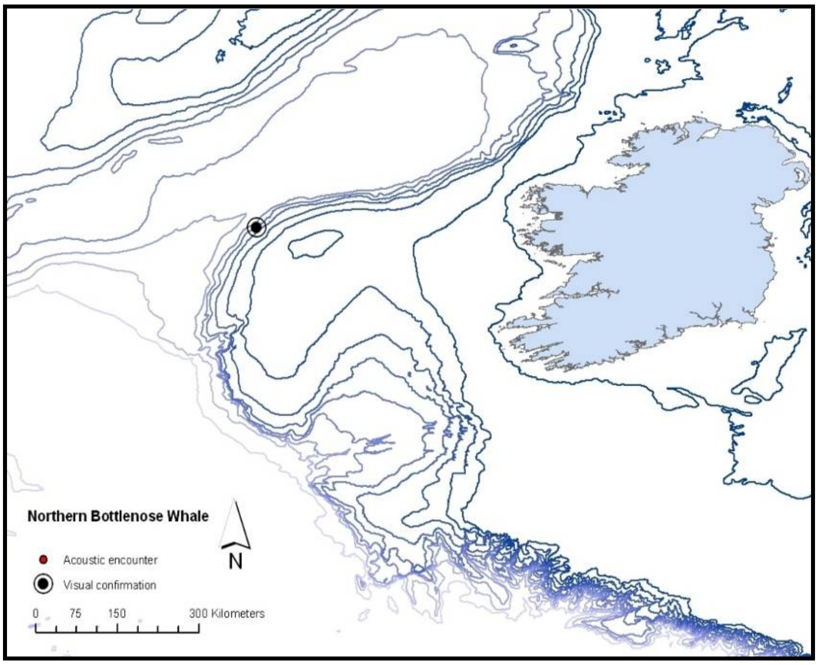


Figure 7.11: Distribution of acoustic encounters of northern bottlenose whale

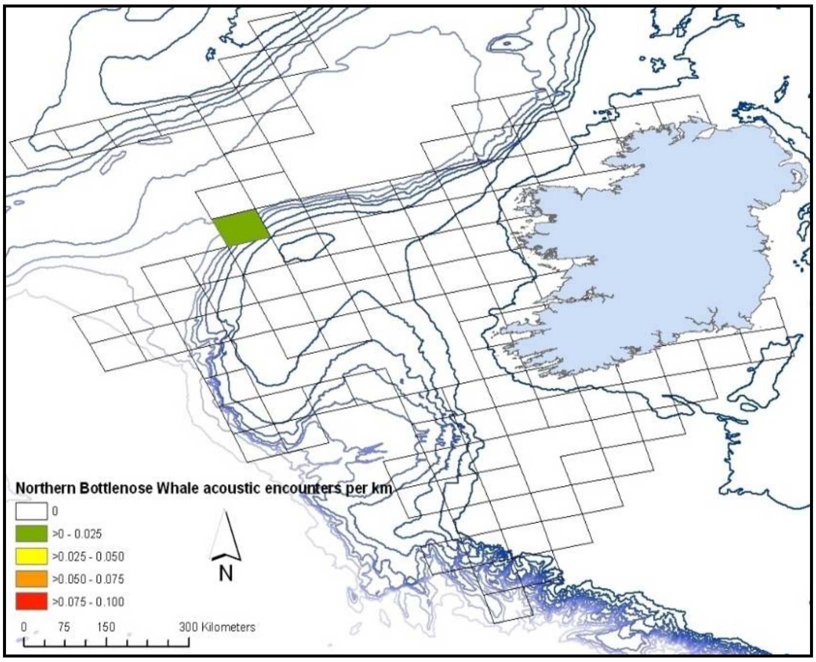


Figure 7.12: Northern bottlenose whale acoustic encounters per km

Acoustic encounters of common dolphins were widespread. A significant number of detections were recorded over the shelf slope and the Goban Spur, but also over the Porcupine Seabight shelf and closer inshore. Only one encounter was detected in the waters of the Rockall Trough next to the Rockall Bank slope (Figure 7.13). The distribution of common dolphin was detected over Goban Spur and over the Porcupine Bank shelf (Figure 7.14).

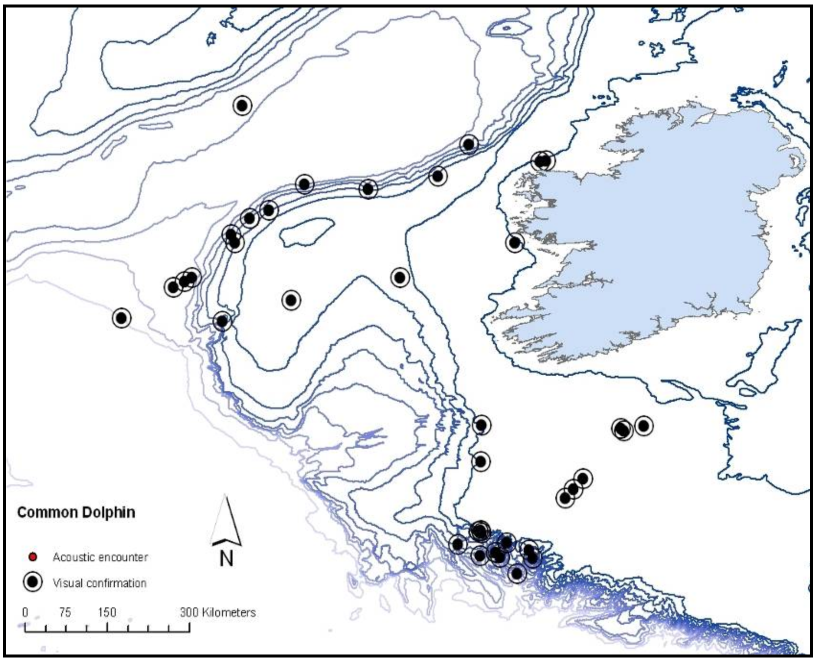


Figure 7.13: Distribution of acoustic encounters of common dolphin

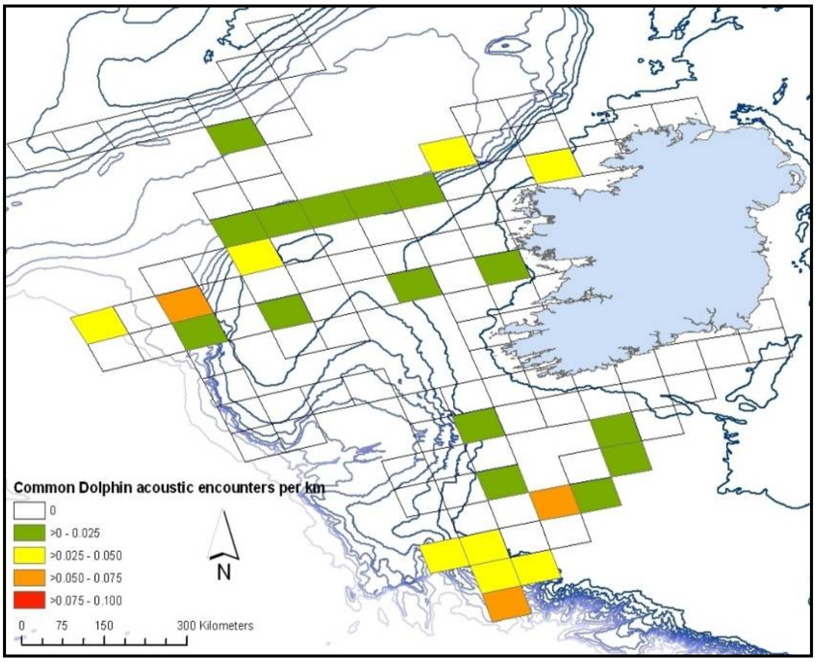


Figure 7.14: Common dolphin acoustic encounters per km

Bottlenose dolphins were recorded along the Porcupine Bank shelf. Detection duration was longest over the Porcupine Seabight shelf (Figure 7.15).

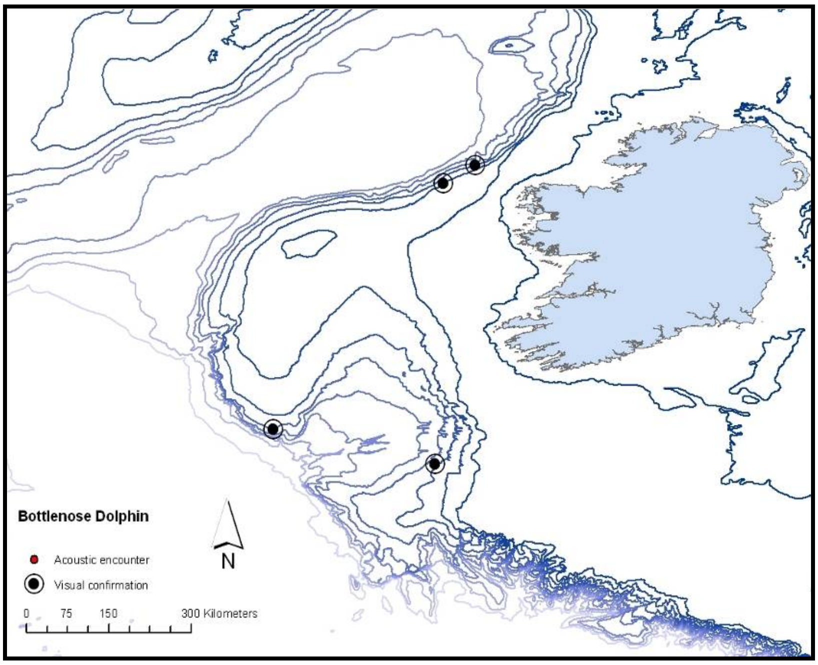


Figure 7.15: Distribution of acoustic encounters of bottlenose dolphin

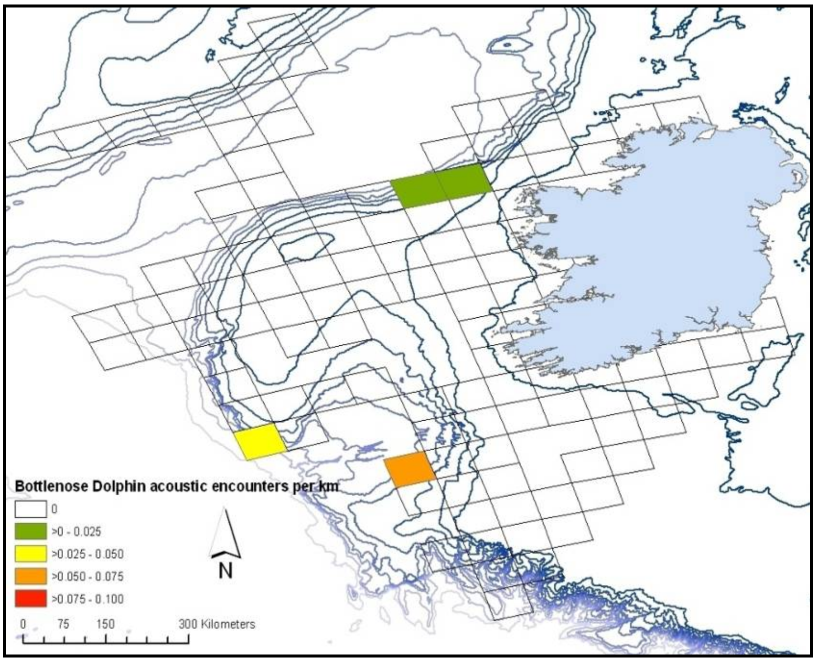


Figure 7.16: Bottlenose dolphin acoustic encounters per km

Unidentified dolphin acoustic encounters had a wide distribution and were recorded both offshore and inshore close to the Irish coast (Figure 7.17).

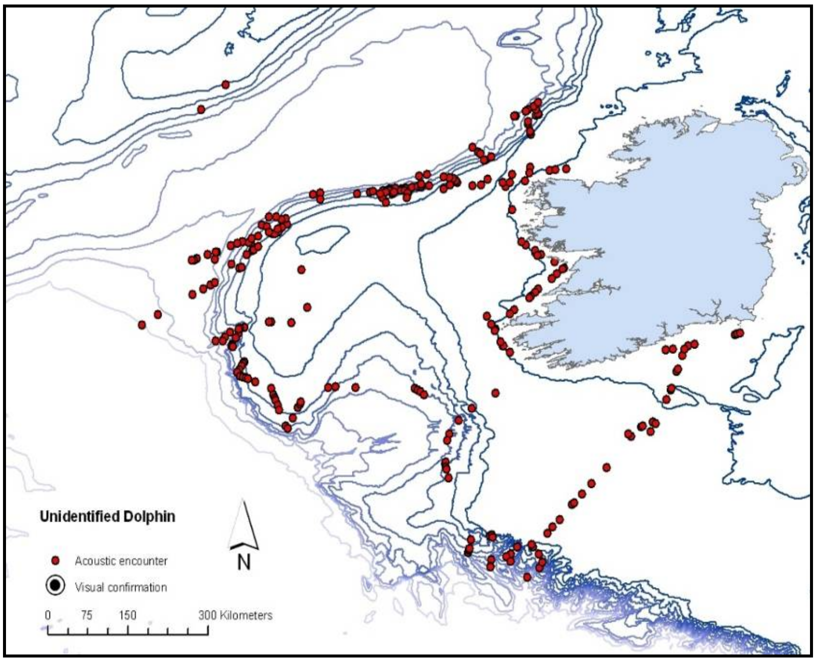


Figure 7.17: Distribution of acoustic encounters of unidentified dolphin

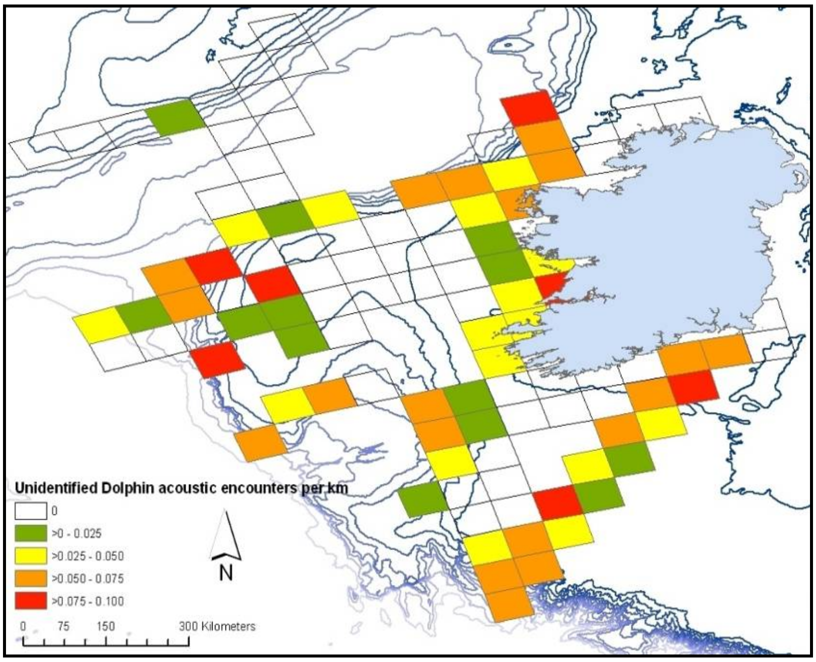


Figure 7.18: Unidentified dolphin acoustic encounters per km

Unidentified cetacean acoustic encounters were few, and were recorded on the shelf edge. One was recorded over the Goban Spur and one closer inshore (Figure 7.19).

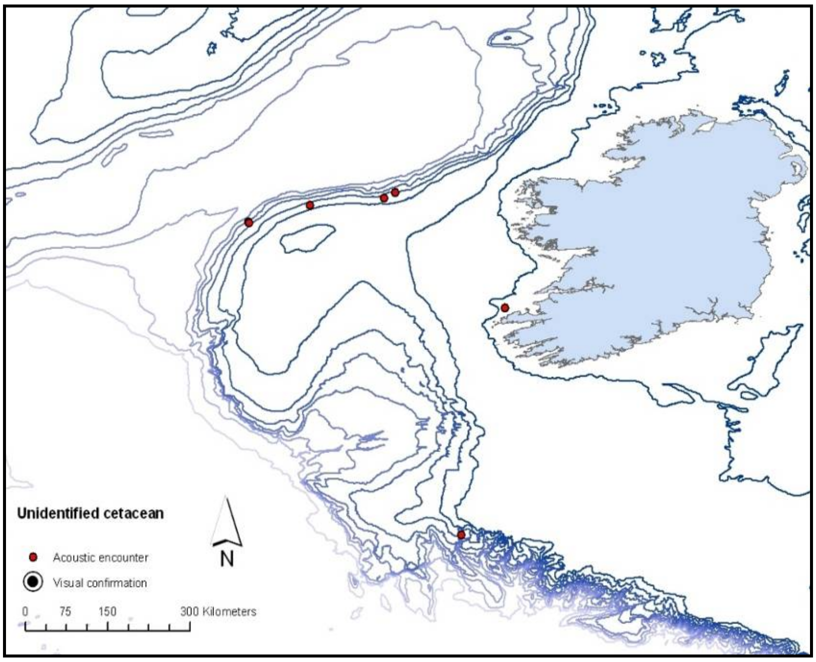


Figure 7.19: Distribution of acoustic encounters of unidentified cetaceans

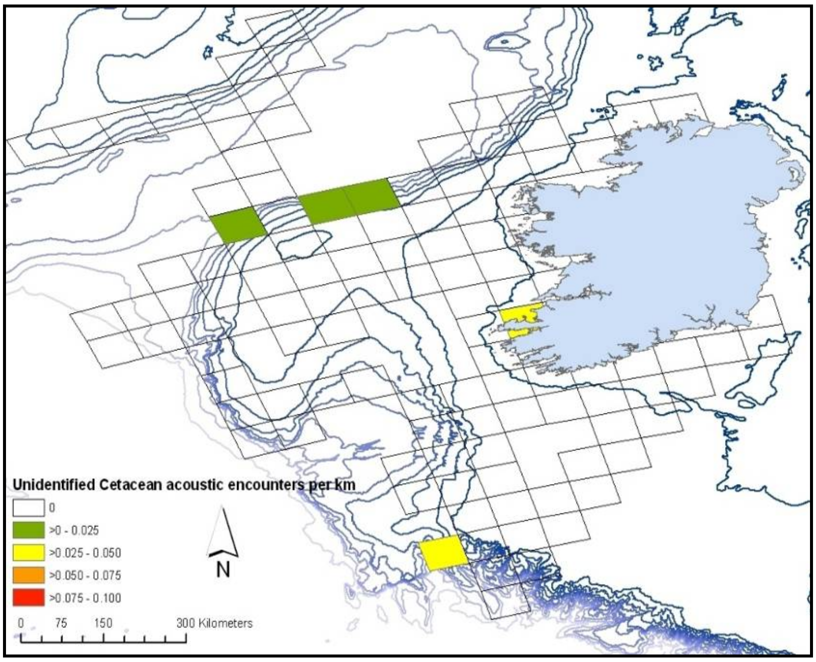


Figure 7.20: Distribution of Unidentified cetacean acoustic encounters per km

7.3.2. *Testing the efficacy of PAMGUARD in identifying vocalizations*

PAMGUARD was tested as an automated method of analysing the acoustic dataset. It was run to detect and identify odontocetes' vocalizations (clicks and whistles) within a file and to extract such information to an access database. A cross comparison of methods was carried out whereby PAMGUARD was set as an automated method, and an observer analysed the same data by eye and extracted information under the same parameters. The observer-based method was the most accurate method of extraction. The total number of vocalizations detected with both methods of analyses is shown in Figure 7.21.

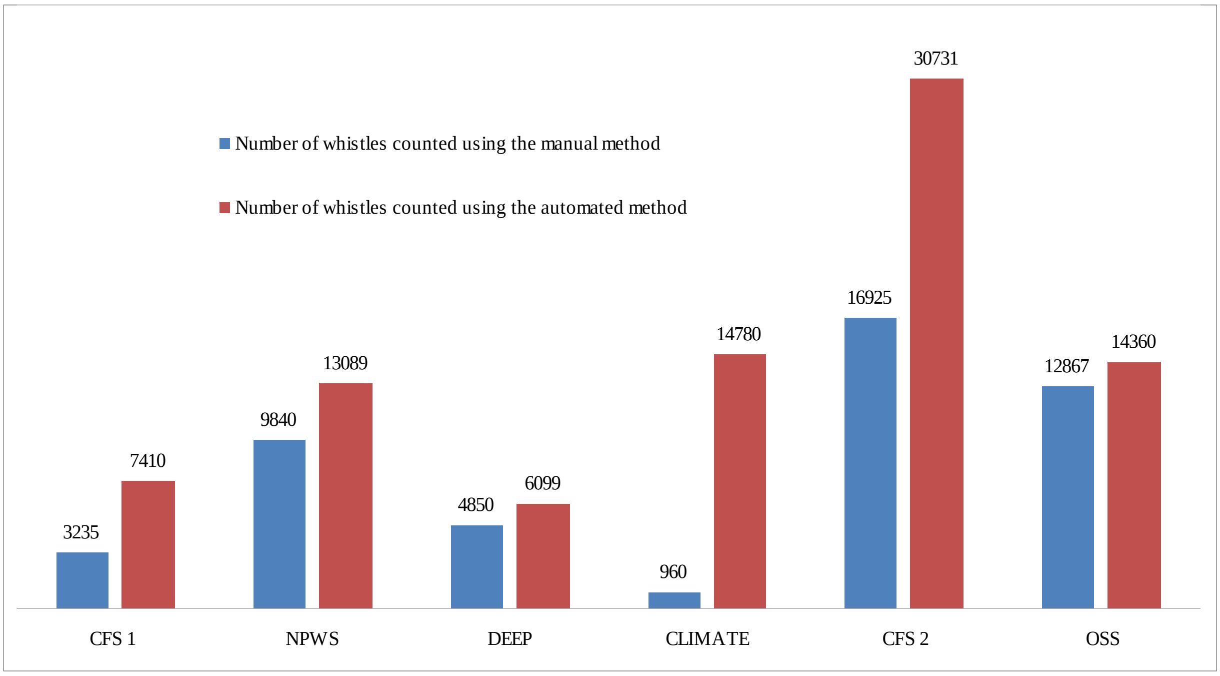


Figure 7.21: Number of whistles for each survey counted with both the observer-based method and the automated method of analyses

The number of whistles and clicks detected with the automated method was always higher than the number of whistles detected using the observer-based method, although this surplus of detections varied between surveys

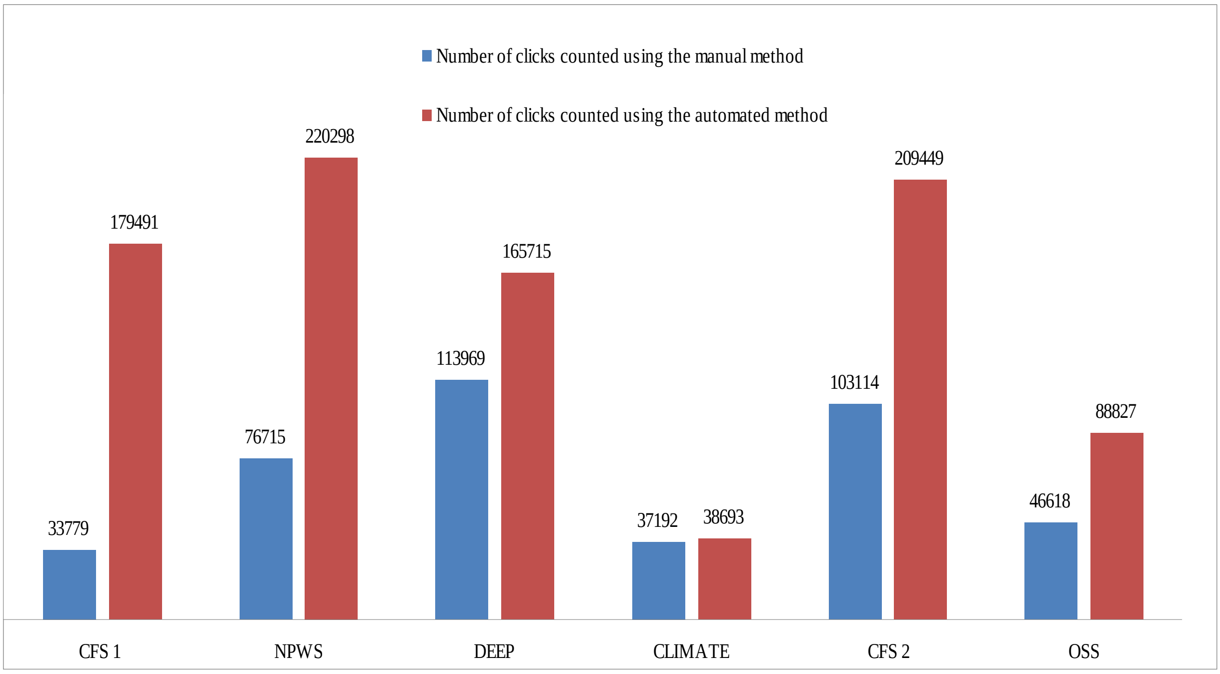


Figure 7.22: Number of clicks for each survey counted with both the observer-based method and the automated method of analyses

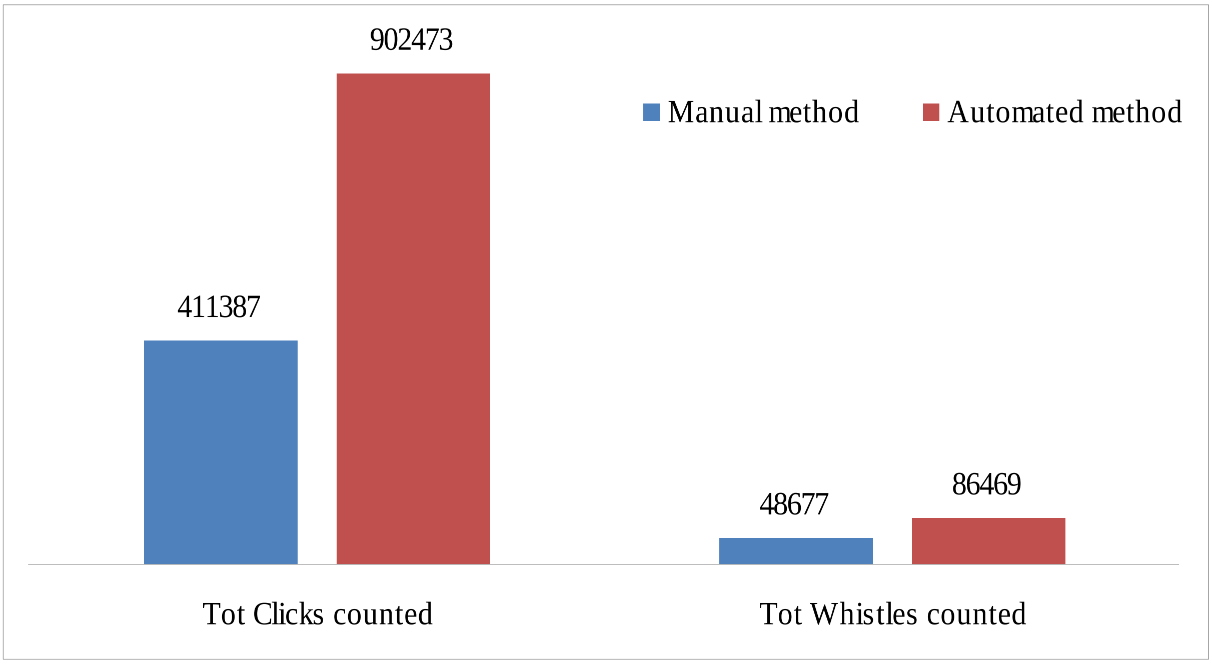


Figure 7.23: Number of clicks for each survey counted with the observer-based method and the automated method of analyses

The number of whistles detected with the automated method in comparison with the observer based method was always greater. In order to statistically analyse them, a “proportion” value was generated by dividing the total number from the observer-based method with the count from the automated method in order to represent the probability of success. Results showed the proportion value generated as the observed probabilities of success were always <1. Therefore, the null hypothesis of equal detection power of the two methods of analyses (proportion=1) was rejected (Table 7.3). A graphic representation of the exact binomial test results is shown in Figure 7.24 (two-sided exact binomial test) and Figure 7.25 (one-side exact binomial test).

Table 7.3 Counts of clicks and whistles from the observer-based method (human) and automated method (software PAMGUARD) of analyses, proportion and p- value. Counts are divided by survey name and detection type. The p-value comes from an exact binomial test with null hypothesis proportion=1.Proportion comes from dividing the number of detections collected with the observer-based method per number of detections collected with the automated method

Survey	Detection	Observer	Count	Proportion	p-value
CFS1	W	Human	3235	0.43	<2.2e-16
CFS1	W	Software	7410		
CFS1	C	Human	33779	0.18	<2.2e-16
CFS1	C	Software	179491		
NPWS	W	Human	9840	0.75	<2.2e-16
NPWS	W	Software	13089		
NPWS	C	Human	76715	0.34	<2.2e-16
NPWS	C	Software	220298		
DEEP	W	Human	4850	0.79	<2.2e-16
DEEP	W	Software	6099		
DEEP	C	Human	113969	0.68	<2.2e-16
DEEP	C	Software	165715		
CLIMATE	W	Human	960	0.06	<2.2e-16
CLIMATE	W	Software	14780		
CLIMATE	C	Human	37192	0.96	<2.2e-16
CLIMATE	C	Software	38693		
CFS2	W	Human	16925	0.55	<2.2e-16
CFS2	W	Software	30731		
CFS2	C	Human	103114	0.49	<2.2e-16
CFS2	C	Software	209449		
OSS	W	Human	12867	0.89	<2.2e-16
OSS	W	Software	14360		
OSS	C	Human	46618	0.52	<2.2e-16
OSS	C	Software	88827		

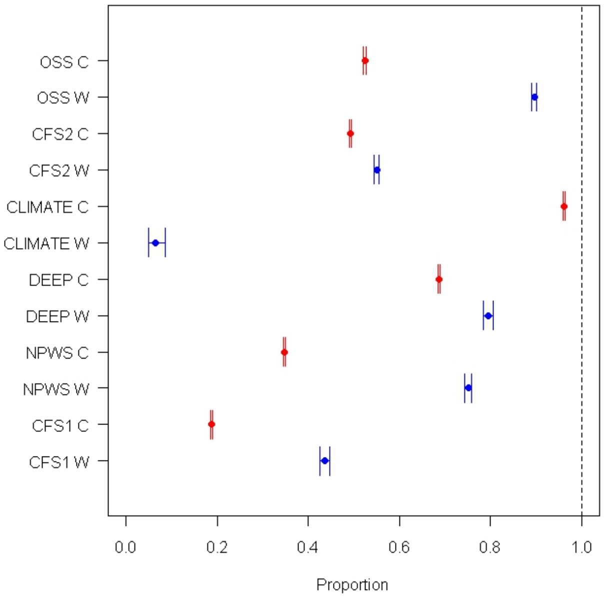


Figure 7.24: Graphic representation of the results from the exact binomial test (two-sided). The graphic shows the estimated proportion and 95% confidence intervals on the estimated proportion from the two-sided exact binomial test. Whistles detections are in blue. Clicks detections are in red. Estimated proportion is evidenced by a circle. All values analysed were significantly less than one. Any proportion within the confidence interval is statistically not different to the estimated proportion

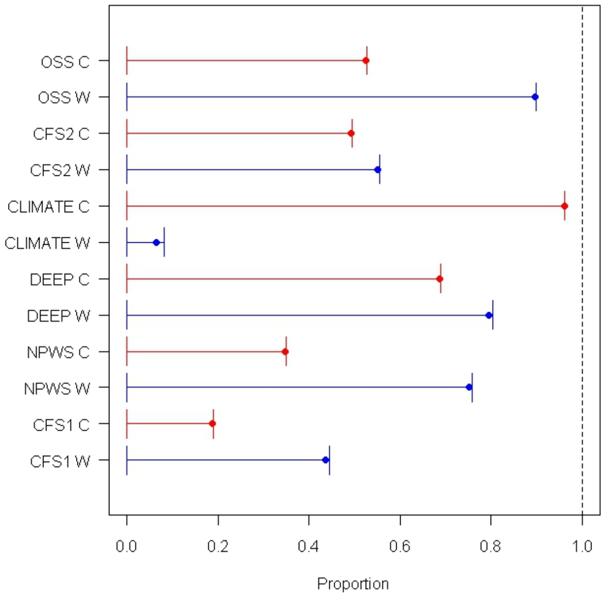


Figure 7.25: Graphic representations of the results from the exact binomial test (one-side). The graphic shows the estimated proportion and 95% confidence intervals on the estimated proportion from the one side exact binomial test. Whistles detections are in blue. Clicks detections are in red. Estimated proportion is evidenced by a circle. All values analysed were significantly less than one. Any proportion within the confidence interval is statistically not different to the estimated proportion

The sperm whale was the most detected cetacean using the observer-based method of analyses of the audio files. Sperm whale sounds are highly distinctive (Sparks *et al,* 1993), and are broadband clicks with a welldefined click train (Morrissey *et al,* 2006) and inter clicks intervals (Figure 7.26). These characteristics make sperm whales the most amenable to acoustic detection methods (Barlow and Taylor, 2005). The high number of acoustic encounters of sperm whales during the present study reflects the fact that their vocalizations can be heard at very long distances from the vessel. Sperm whale clicks have, in fact, been recorded by a towed linear array at a distance of 18 km from the boat (Sparks *et al,* 1993).

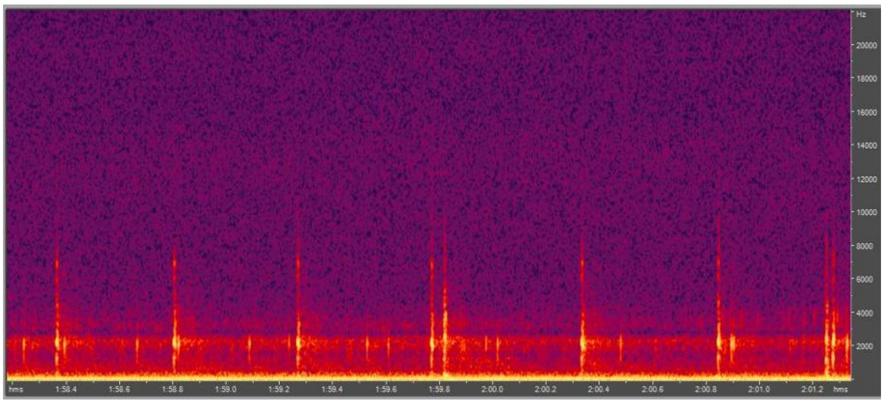


Figure 7.26: Low frequency sperm whale clicks, with defined inter click intervals detected with the observer-based method using the spectrogram view in Adobe Audition 1.0

Identification of long finned pilot whale vocalizations was possible through the use of whistle characteristics. Pilot whales emit distinctive low frequency whistles at frequencies between 4 and 7 kHz (Tarusky, 1979; Busnel and Dziedzi, 1966), which allow differentiation of their whistles from those of common and bottlenose dolphin species. However, it was often noted during analysis that low frequency whistles of pilot whales could be masked by vessel noise and water flow over the hydrophone element in adverse weather (Figure 7.27). Therefore, it was necessary to have the visual sightings data in order to confirm these pilot whale acoustic encounters.

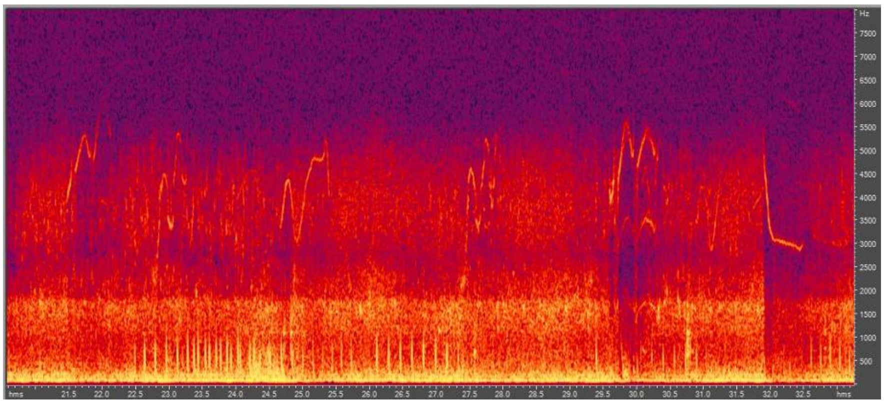


Figure 7.27: Low frequency pilot whale whistles, sometimes masked from background noise, detected with the observer-based method using the spectrogram view in Adobe Audition 1.0

Although harbour porpoise clicks are extremely diagnostic, due to frequency and *ICI* (Figure 7.28), only two acoustic encounters were identified.

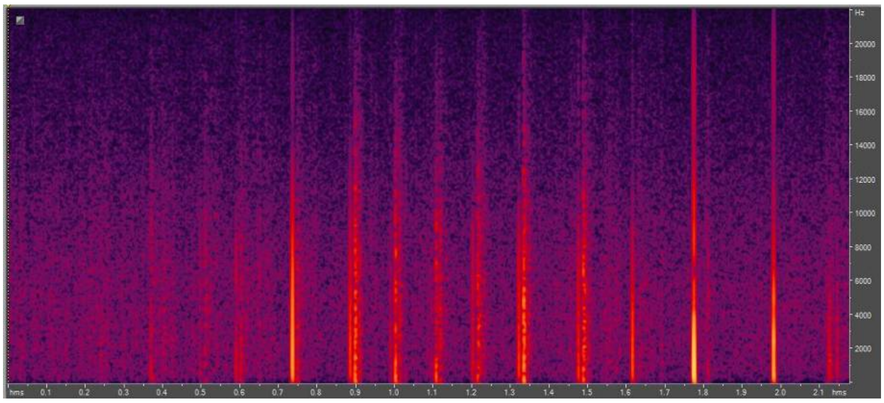


Figure 7.28: Harbour porpoise high frequencies clicks detected with the observer-based method using the spectrogram view in Adobe Audition 1.0

It was not possible to identify dolphin vocalizations to species level in the absence of visual confirmation. This was due to large overlaps in acoustic characteristics between species. The identification to species level of a northern bottlenose whale was possible due to simultaneous visual confirmation. Identification of their vocalizations to species level is very difficult because their known frequency ranges between 3 and 16 kHz for whistles (Winn *et al,* 1970) and between 0.5 and 22 kHz (Winn *et al,* 1970; Hooker *et al,* 2002), overlapping with dolphin ranges.

7.4. Discussion

From a first overview of acoustic results, it is evident that information can be gathered on habitat preference for specific species. As with visual data, acoustic detections can be plotted as a means for evaluating species distribution. This is a valuable asset to a survey, as it can be carried out during the night and in adverse weather conditions. However, there are limitations, in that species identification can prove difficult and a lack of information on abundance can bias datasets. Additionally, it is recommended than an observer or PAM operator is always assigned to acoustic collection. This facilitates ease of identification of detections within a dataset but also allows for ease of identification and analyses after a survey has been completed. It is also recommended that PAM analyses be carried out by a trained observer, as results from the automated setting of the PAMGUARD software give a very different account of results and have a very high false positive rate, especially for whistle detection (Pierini, 2011). PAM should be used as an accompaniment to visual observations to maximize the data return for a survey, especially during adverse weather and night-time hours, but should not be relied solely as a survey technique.

Sperm whale was the most frequently detected cetacean species using the observer-based method of analyses of the audio files. Sperm whale sounds are highly distinctive (Sparks *et al,* 1993), consisting of broadband clicks with a well-defined click train (Morrissey *et al,* 2006) and inter-click intervals. These characteristics make sperm whales the most amenable to acoustic detection methods (Barlow and Taylor, 2005). The high number of acoustic encounters of sperm whales in this study could reflect the fact that their vocalizations can be heard at very long distances from the vessel. Sperm whale clicks have in fact been recorded by a towed linear array at a distance of 18 km from the boat (Sparks *et al,* 1993).

Identification of long finned pilot whale vocalizations was also possible from the analyses of whistle characteristics. Pilot whales emit distinctive low frequency whistles at frequencies between 4 and 7 kHz (Tarusky, 1979; Busnel and Dziedzi, 1966), which allow differentiation of their whistles from those of common and bottlenose dolphin species.

Although harbour porpoise clicks are strongly diagnostic because of their high frequencies and *ICI*, only two acoustic encounters were identified. This is most likely due to harbour porpoises having a distribution close to land (Wilson and Berrow, 2006) and most of these surveys were carried out offshore. Furthermore, harbour porpoises are elusive and tend to avoid new sounds in the environment (Cox and Reid, 2004). Therefore, an approaching vessel will influence porpoise behaviour and they could exhibit avoidance behaviour and disappear quickly. The limited detection range of the acoustic equipment for harbour porpoise, which is estimated at around 200m to 300m due to their high frequency clicks, could also influence detection probability.

It was impossible to identify dolphin vocalizations to species level in the absence of visual confirmation. This is due to an overlap in frequency use. The identification to species level of the acoustic encounter of the northern bottlenose whale was possible only because at the same time there was a sighting next to the vessel. Identification of their vocalizations to species level is very difficult because their known frequency ranges, between 3 and 16 kHz for whistles (Winn *et al,* 1970) and between 0.5 and 22 kHz (Winn *et al,* 1970; Hooker *et al,* 2002), makes their recorded vocalizations easy to confuse with dolphin vocalizations.

From the mapping results of acoustic detections, it is evident that the different species encountered have different habitat preferences from the shallow waters of the continental shelf (<200m) to the deep water (>2,000m) offshore, including the shelf edge which seems to be an important habitat for most of the species encountered. Sperm whales show preference for deep waters (Rice, 1989), as found from acoustic detections (all in waters >1,000m). Sperm whales feed primarily on cephalopods

(Kawakami, 1980; Jaquet and Gendron, 2001), which are available at great depth. Therefore, their habitat use is thought to be linked to their prey habitat. Sperm whales were recorded mostly off the edge of the continental shelf along the shelf slope, with high abundance over the Porcupine Bank slope. Long-finned pilot whale acoustic encounters were predominantly recorded in waters exceeding 1,000m depth. Their distribution is thought to be related to the occurrence of their prey (Bloch *et al*, 2003), mostly composed of pelagic cephalopods (Cañadas and Sagarminaga, 2000).

Common dolphins were recorded in both inshore and offshore waters reflecting their already known distribution along the west coast of Ireland (Gordon *et al,* 1999). Their high abundance in Irish waters is underlined by the fact that this species is one of the most commonly stranded cetaceans around the Irish coast (Berrow and Rogan, 1997).

Bottlenose dolphin encounters were recorded offshore along the Irish shelf edge. Although this species tends to be distributed primarily next to the coast, it can also be found in offshore waters (Wells and Scott, 1999). While the importance of coastal waters for bottlenose dolphins is known (Berrow et al, 1996), little is known about the presence of this species in offshore Irish waters. The Irish shelf edge seems to be an important habitat for offshore bottlenose dolphins. Further studies need to be carried out in order to better understand their distribution along this critical habitat.

Yack *et al,* 2009 carried out an evaluation of the efficacy of PAMGUARD in identifying and counting cetacean vocalizations (whistles and clicks) within wav files. Results from the present study, where a manual observer method was used to extract data in comparison with the PAMGUARD programme, showed large discrepancies between the two methods. A large discrepancy in click detections was also reported by Yack *et al* (2009) when using the same software. Both automated "click detector" and "whistle detector" applications in PAMGUARD were configured in order to collect vocalizations in a wide range of frequencies. An intermediate detection threshold was decided on for PAMGUARD in an effort to equalize the number of missed detections to the number of false detections collected. If the objective of this research had been more species specific, a more specific whistle and click detector within PAMGUARD should have been created.

PAMGUARD almost never missed "true clicks". However, PAMGUARD stored a lot of false click detections. Since the number of "true clicks " missed detections from PAMGUARD was very low, the use of this automated software should be considered in order to save time with the analyses of the acoustic data. It should be used at the beginning of the analyses to identify the periods of clicking along the audio files (obviously, it will collect both "true clicks" and "false clicks"), avoiding re-analysing the spectrogram where nothing was detected. However, once PAMGUARD has analysed the files, periods of click detections within the audio files should always be re-analysed with the observer-based method of analysis in order to eliminate false detections ("false clicks"). False click detections can be recognized easily with the observer-based method. In this way, it will be possible to reduce the time spent on the analyses because it will not be necessary to go manually through those audio files where PAMGUARD did not detect clicks.

PAMGUARD missed numerous "true whistles" present in the audio files. Entire files with whistles were ignored by the automated analyses. PAMGUARD cannot be considered useful software for the detection of whistles. For the detection of whistles, therefore, the observer-based method of analyses should be considered, at this time, as the best option to use. It is recommended that PAMGUARD click detector should be used in order to automatically detect clicks and save time. However, the observer-based method should be always used *a postori* in order to re-analyse periods of clicks collected by PAMGUARD in order to delete PAMGUARD false detections. PAMGUARD should not be used to analyse sound files for the presence of odontocete whistles. Whistles should be detected using the observer-based method of analysis.

8. DEEP SAM

8.1. Introduction

Little is known of the distribution and ecology of deep diving cetacean species within the Irish EEZ. This is primarily due to their offshore distribution and the fact that some deep-diving cetacean species spend up to 95% of their lives beneath the surface (Watwood *et al,* 2006; Barlow and Gisiner, 2006). These species include sperm whale (*Physeter macrocephalus*), pygmy sperm whale (*Kogia breviceps*), pilot whale (*Globicephala melas*) and the five species of beaked whale recorded in Irish waters - northern bottlenose whale (*Hyperoodon ampullatus*), Cuvier's beaked whale (*Ziphius cavirostris*), Sowerby's beaked whale (*Mesoplodon bidens*), True's beaked whale (*Mesoplodon mirus*) and Gervais' beaked whale (*Mesoplodon europaeus*).

The conservation status of all deep-diving cetacean species in Irish waters was listed as 'unknown' in the last report on the 'Status of EU protected habitats and species in Ireland' (NPWS, 2008). Under the IUCN Red List 2011 (IUCN, 2011) sperm whales are listed as 'vulnerable' and Cuvier's beaked whale is listed as 'least concern'. All other deep diving cetacean species occurring in Irish waters are listed as 'data deficient'.

Though it is known which species of beaked whale occur off the Irish coast, the extent of their occurrence, whether they are resident or migratory or the extent to which they rely on specific habitat types such as subsea canyons are all unknown. The existing evidence, based on modelling and sightings data, suggests that beaked whales have a distribution that is restricted by habitat requirements. These data also suggest that beaked whale distribution is more habitat-specific than that of other deep diving species such as sperm whales or pilot whales (NPWS, 2008).

Surveys conducted under EU and national research programmes in recent years have led to a better understanding of our unique offshore habitats and the species that live within them (Weaver *et al,* 2004; INFOMAR, 2011). Distribution data from both acoustic and visual cetacean surveys indicate that subsea canyon systems represent a high value habitat for many species of cetaceans, including dolphins, beaked whales and sperm whales (Wall *et al,* 2009, 2010; Wall and O'Brien. 2009).

Ecological modelling has suggested that canyon systems lying along the continental shelf slopes to the west of Ireland represent important habitat for beaked whale species.[10] There is evidence to support this in surveys conducted by the IWDG from 2006 to 2008 over canyon systems on the north slopes of the Porcupine Bank, where a high number of sightings of breaching beaked whales were recorded (Wall *et al,* 2009, 2010). The extent of canyon habitat within Irish waters is significant within a European context (Weaver *et al,* 2004), placing an onus on Ireland to identify key habitats for beaked whales and to monitor and protect them.

Current visual and towed passive acoustic monitoring (PAM) survey methods are almost completely ineffective for beaked whales (Barlow and Gisiner, 2006). More recently, there has been a focus on the development of static PAM devices that can be deployed at the depths at which beaked whales forage and vocalize with positive results (McDonald *et al,* 2009). During PReCAST initial trial, deployments of a deep-water version of the C-POD, which is rated to depths of 2,000m+, were conducted to assess its suitability for long-term monitoring of deep diving odontocetes, such as beaked whales and pilot whales.

8.2. **Materials and Methods**

A Deep C-POD was deployed on the mooring for the M6 Weather Buoy during the first Cetaceans on the Frontier Survey conducted on board the R.V. *Celtic Explorer* in August 2009. The M6 weather buoy was located at 53.07482°N 5.88135°W in 3,200m water depth (Figure 8.1). The Deep C-Pod was attached to the buoy's cable at 500m, with the hydrophone element facing down to the ocean floor (Figure 8.2).

An additional deep C-POD was deployed on bottom mooring within a canyon system on the north slope of the Porcupine Bank during the same research cruise. This second Deep C-POD was recovered in December 2009. However, the C-POD was found to have an engineering defect which caused it to malfunction and, thus, no data was recovered from it.

Figure 8.1: Location of M6 weather buoy

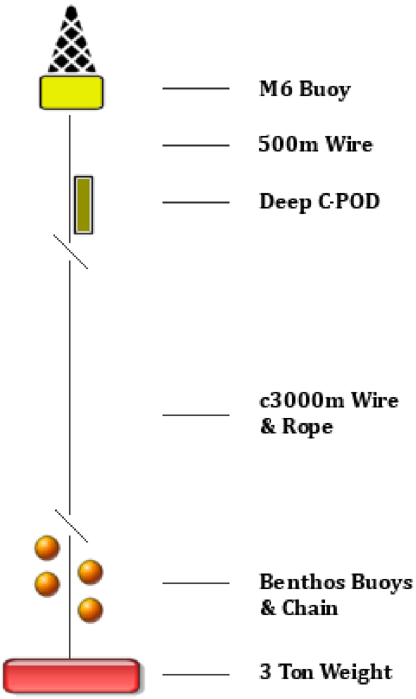


Figure 8.2: M6 mooring design with Deep C-POD attached at 500m

The Deep C-POD was recovered in May 2011, when the M6 Weather Buoy was renewed, and was replaced with another Deep C-POD to enable ongoing data collection.

8.3. Results

8.3.1. *Logged Data*

The Deep C-POD logged click, temperature and angle data for a continuous 211 days. This is the longest continuous recording period achieved by any C-POD to date (Table 8.1).

Table 8.1: Deployment period (dates), logging period (days logged by pod), total detection positive minutes and number of detection events (clusters of click trains separated by periods of ten minutes or more) logged by the Deep C-POD placed on the M6 Buoy in 2009

Mooring no.	Pod ID	Deployment period	logging period	days logged [a]	DPM	No. detection events
M6	439	28.08.2009 - 14.05.2011	28.08.2009 - 26.03.2010	211	5780	1621

a - Discounting deployment and recovery days

8.3.2. *Environmental data*

Hourly values for water temperature and POD angle, which equates to the level of current experienced by the mooring, were derived from the data. Water temperature was relatively constant from August 30th 2009 to January 22nd 2010, fluctuating by 1.4°C (Figure 8.3), between 9.2°C and 10.6°C, with no evident temporal pattern (Figure 8.4). Between January 23rd 2010 and March 25th 2010, water temperatures dropped, to a minimum of 6.8°C on February 26th, before rising again. Temperatures during this period fluctuated by 3.7°C (figure 8.4), between 6.8°C and 10.5°C, again with no evident temporal pattern. No correlation was found between hour and temperature.

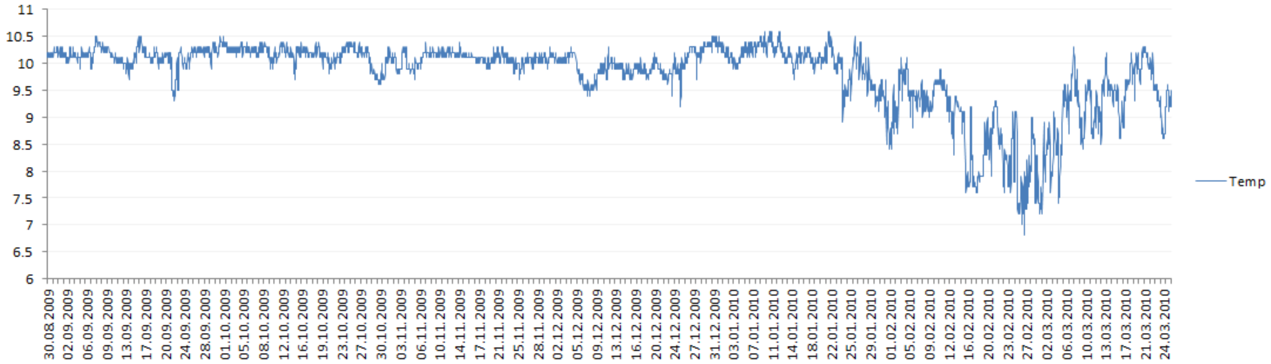


Figure 8.3: Hourly water temperature readings recorded at the M6 Buoy from 30.08.2009 – 25.03.2010

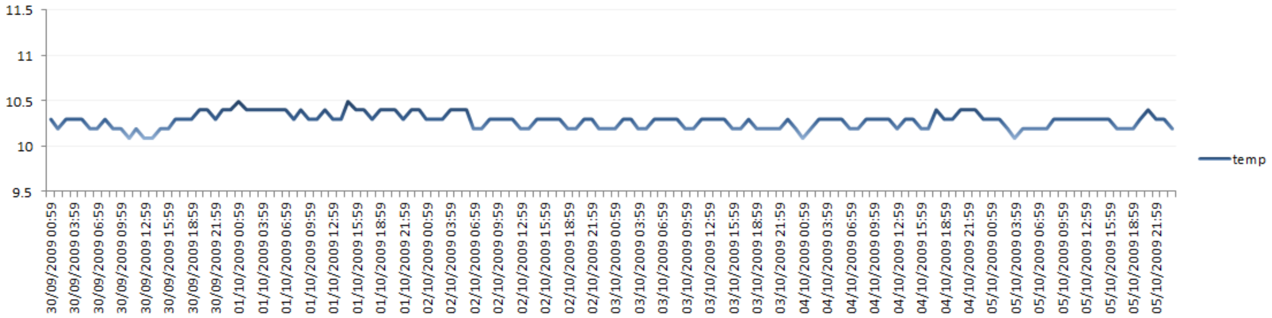


Figure 8.4: Hourly water temperature readings recorded at the M6 Buoy from 30.09.2009 – 05.10.2009

POD angle readings fluctuated by a maximum of 36 degrees during the deployment, indicating the strength of current encountered by the POD. No regular temporal spacing was evident in POD angle readings and no correlation was found between hour and POD angle (Figures 8.5 and 8.6). It should be noted that, unlike in the bottom set mooring at the study site, movement of the POD at M6 was affected by the movement of the mooring's surface buoy and, therefore, POD angle was affected by surface current, sea state and wind. A positive correlation was found between temperature and POD angle ($r = 0.327$, $n = 4992$, $p = 0.01$).

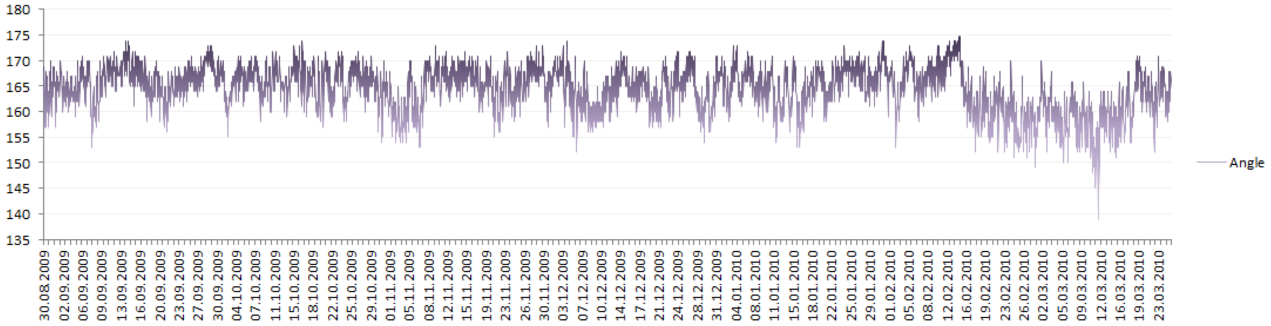


Figure 8.5: Hourly water POD angle readings recorded at the M6 Buoy from 30.08.2009 and 25.03.2010

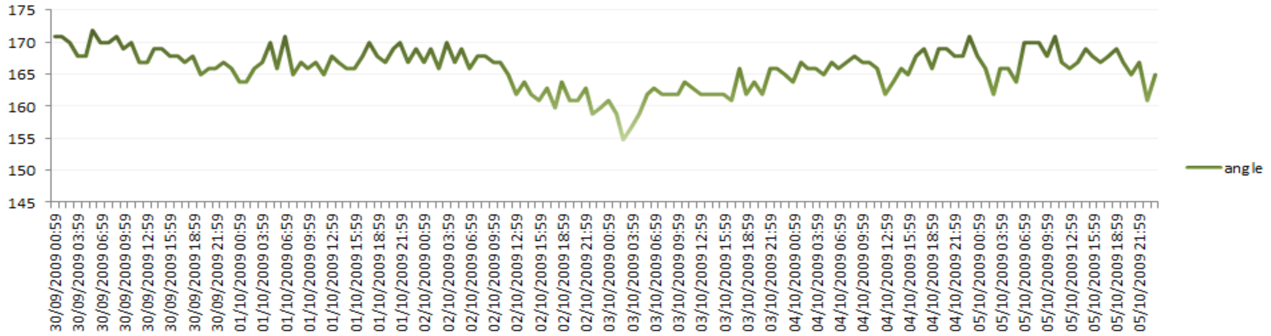


Figure 8.6: Hourly water POD angle readings recorded at the M6 Buoy from 30.09 – 05.10.2009

Temporal Variation in Cetacean Activity

Due to the generally clean nature of the dataset and the need to target beaked whale clicks, which have some characteristics similar to sonar noise (e.g. slow click rates and constant inter-click intervals (Frantiz *et al,* 2002; Baumann-Pickering *et al,* 2010), click train filters in CPOD.exe were set to 'Q-All' (all quality of click trains) for the analysis (Table 8.2). The data was examined visually for sonar detections but none was found. As the POD was located at 500m water depth, it was within the diving depth range of pilot whales and some oceanic dolphins (Klatsky *et al,* 2007).

Table 8.2: C-POD.exe filter settings for analysis of DPM for the deployment on the M6 buoy

Train Filter Settings			
Train Filters	**Setting**	**Click Filters**	**Setting**
Quality	All Q	kHz	0-255
Modal kHz	20-255	Click cycles	0-9999
N in Train	5	Raw SPL	0-9999
Click/s	Jan-00		
Mean SPL	1-255		
Species	All		

Cetacean activity (DPM/day) fluctuated at the M6 Buoy throughout the period of the deployment. An average of 196.5 DPM/day were recorded from August 30th 2009 to December 24th 2009, before falling to an average of 99.1 DPM/day from December 24th 2009 to March 25th 2010 (Figure 8.7).

nData with high SPL values were selected to target animals which were close to the Deep C-POD and, therefore, more likely to be deep diving species such as beaked whales. High SPL values in Deep C-POD data equate to louder received signals which typically come from on-axis clicks and animals in closer proximity to the hydrophone element (Møhl *et al,* 2000; Johnson *et al,* 2004). Click trains with an average SPL value of 60 or greater, representing the top 20% of avSPL values in the data (Table 8.3), were used to re-assess temporal variation in activity.

Table 8.3: C-POD.exe filter settings for analysis of High SPL DPM for the deployment on the M6 buoy

Train Filter Settings			
Train Filters	**Setting**	**Click Filters**	**Setting**
Quality	All Q	kHz	0-255
Modal kHz	20-255	Click cycles	0-9999
N in Train	5	Raw SPL	0-9999
Click/s	Jan-00		
Mean SPL	1-255		
Species	All		

All data with SPL High data from the M6 Buoy showed little difference in temporal variation in activity (DPM/day). The selection of High SPL data yielded daily activity (DPM/day) values on average 66% lower than SPL-All values. The data showed higher cetacean activity in the first four months of the deployment, followed by a decline in activity punctuated by brief periods of high activity (Table 8.4 and Figure 8.7).

Table 8.4: Average DPM/day values from SPL-All verses High SPL data

Train Filter Settings			
Period	**SPL Class**	**Average DPM/day**	**Ratio – av. DPM/day (period) : av. DPM/day (deployment)**
30.08.2009 – 24.12.2009	SPL-All	196.5	1.27
	High SPL	67.4	1.30

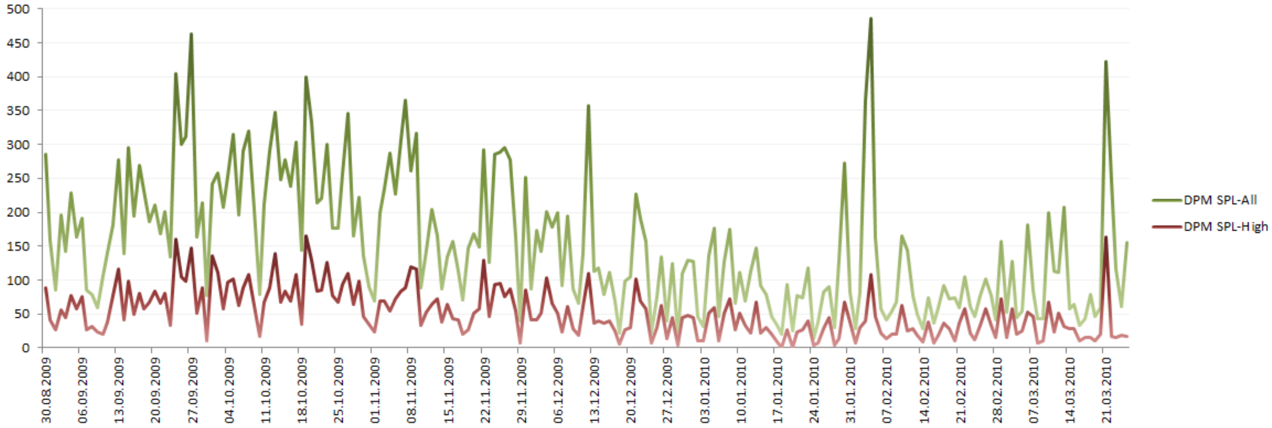


Figure 8.7: Temporal variation in activity (DPM/day) using SPL-All (green line) versus High SPL (red line) data at the M6 Buoy from 30.08.2009 to 25.03.2010 (data from deployment and retrieval days were excluded)

Clicks were recorded on all days of the deployment. The peak in cetacean activity (487 DPM/day) was recorded on the February 4th 2010 and the least active day (15 DPM/day) was recorded on January 24th 2010.

To assess diurnal and tidal patterns in the data, a sub sample of SPL-All data collected from September 20th 2009 to September 26th 2009 was examined. Fluctuations in activity (DPM/hour) presumably reflected the diving patterns of individuals or groups of cetaceans and/or the movement of cetaceans in and out of the detection range of the Deep C-POD. A total of 21 peaks in DPM were recorded in the sub sample. Detection encounters at the M6 Buoy (defined as periods of click detections separated by intervals of five minutes or more) ranged from 1 to 402 minutes in duration.

70% of encounters lasted nine minutes or less and 90% lasted 29 minutes or less (Figure 8.8). 14 of the encounters lasted longer than two hours.

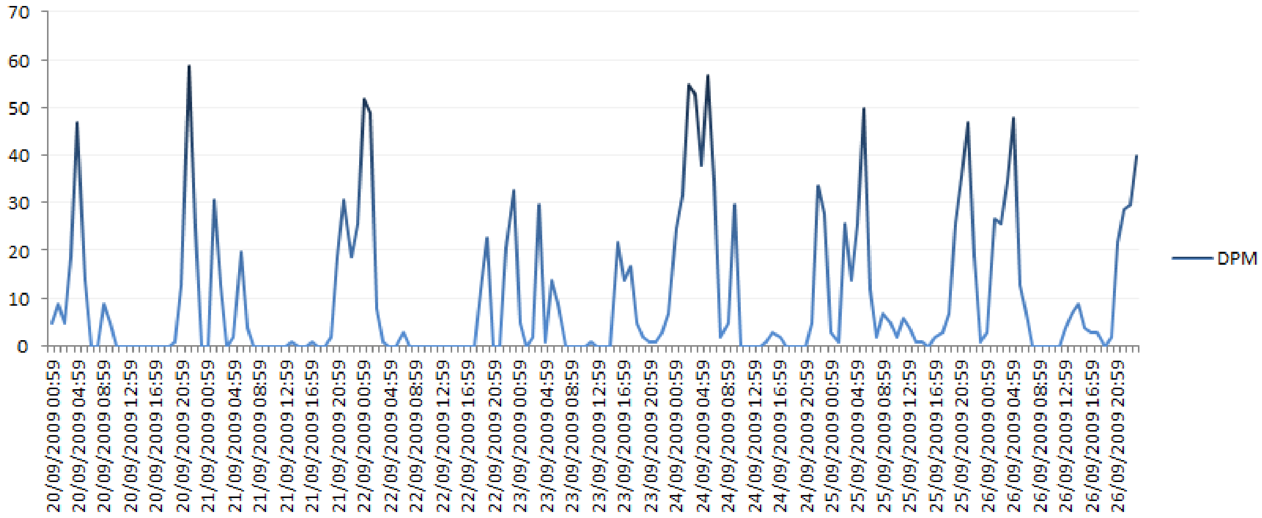


Figure 8.8: Hourly DPM values at the M6 Buoy from 20.09.2009 to 26.09.2009, showing fluctuations in cetacean activity detected by the Deep C-POD

All data set for the M6 Buoy showed a significant correlation between activity (DPM/hour) and time of day ($r = -0.065$, $n = 4992$, $p = 0.01$), with strong diel variation in cetacean activity (DPM/hour) evident (Figure 8.9).

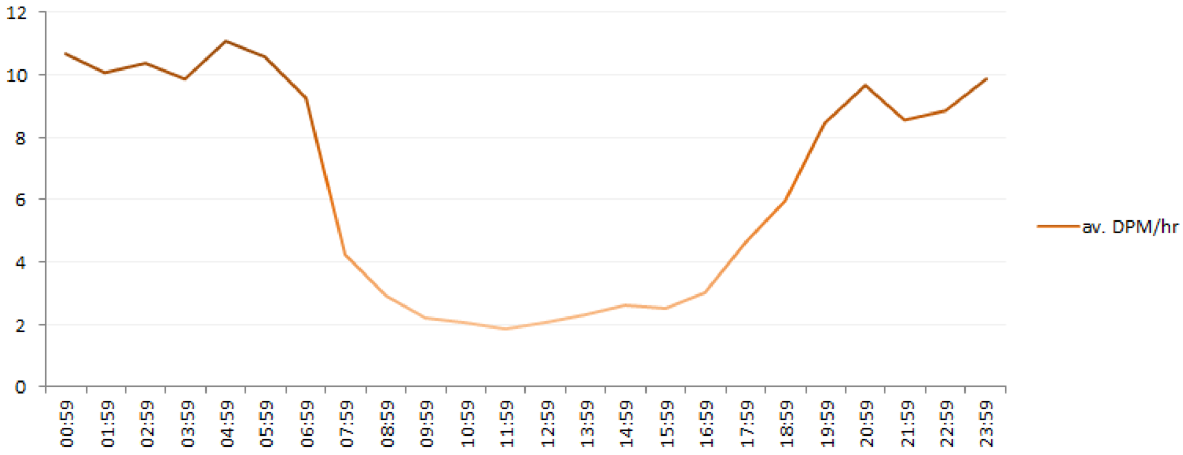


Figure 8.9: Average DPM/hr recorded for each hour of the day at the M6 Buoy from 30.08.2009 to 25.03.2010

A correlation was also found between activity (DPM/hour) and temperature (r = 0.135, n = 4992, p = 0.01), with cetacean activity increasing with temperature (Figure 8.10).

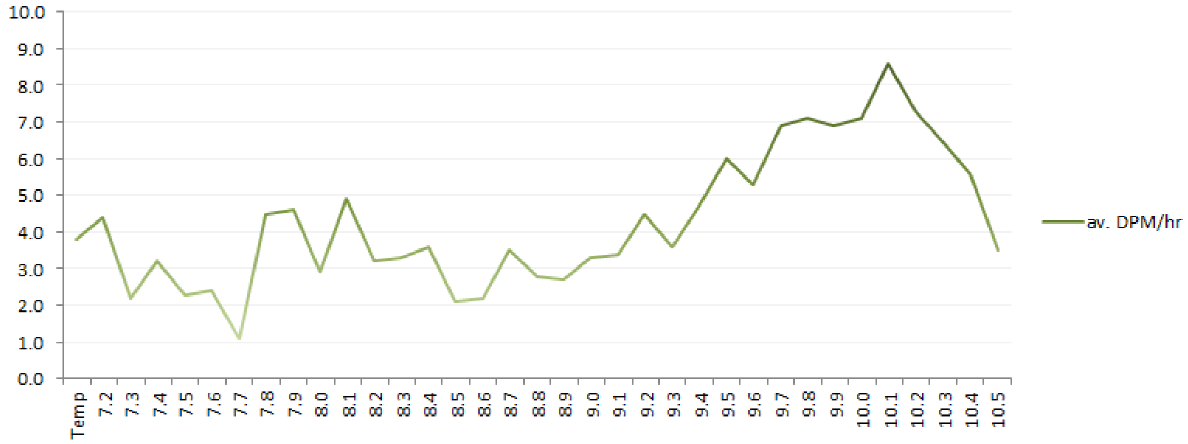


Figure 8.10: Average DPM/hr recorded for temperatures ranging from 7.2° to 10.6 °C at the M6 Buoy from 30.08.2009 to 25.03.2010

Species Present

The distribution of modal frequencies of SPL High data showed click trains with modal frequencies in the 25-40 kHz range, with a peak at 32-37 kHz. These frequencies cover the peak frequencies reported for a number of dolphin species and some beaked whale species. The presence of a strong diel variation in the data may indicate the presence of dolphin species, including pilot whale, at this location as diel variation has not been commonly reported for beaked whales (Tyack *et al,* 2006; Baird *et al,* 2008; Hooker and Baird 2009) but has been reported in a number of dolphin species

(Goold 2000; Soldevilla *et al,* 2010; Klatsky *et al,* 2007), including long-finned pilot whales (Baird *et al,* 2002; Baird *et al,* 2003).

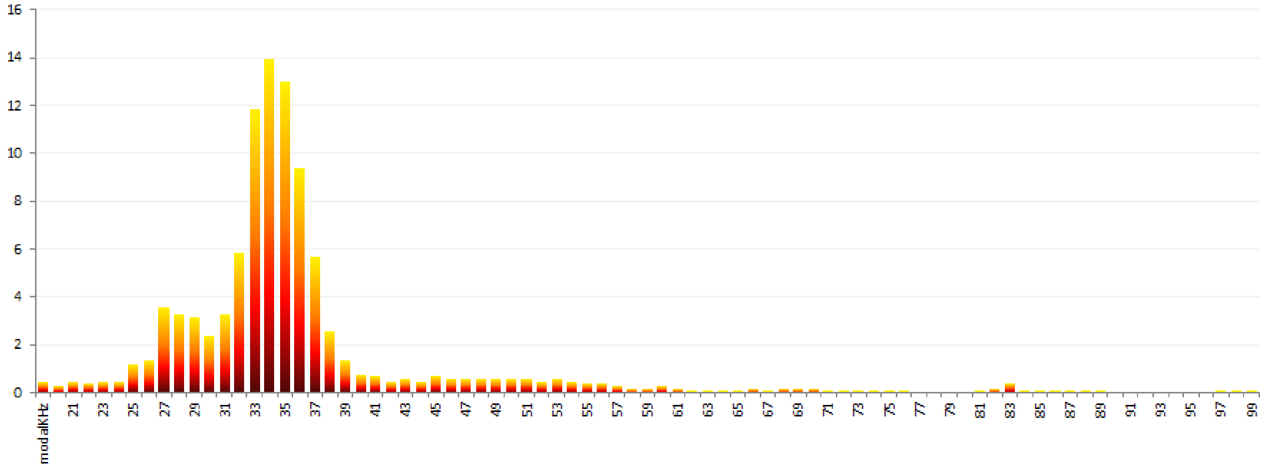


Figure 8.11: Histogram of modal frequency of SPL High encounters recorded during the deployment at the M6 Buoy

8.4. Discussion

The C-POD is a powerful tool for studying temporal variation in cetacean presence within selected marine habitats. Such data is very difficult to obtain in offshore marine habitats using visual techniques. Normal hydrophone data requires labour intensive analysis that results in a large degree of data sub sampling. The concurrent recording of temperature and angle data by the C-POD enables some degree of interpolation of cetacean activity data in relation to environmental variables.

Species discrimination techniques are still being developed for C-PODs and for acoustic sampling techniques in general. The further ability to discriminate species in C-POD data will require a wider availability of comparison C-POD data sets from known species encounters and perhaps the concurrent collection of real-audio data to enable click waveforms and spectrographs for individual clicks to be examined. The next generation of C-POD under development in 2012 will run some train detection on board and choose sample clicks to save in detail, thus helping in this area.

The C-POD data collected during PReCAST will be used in a wider analysis of deep water C-POD data under the DeepPAM project being conducted by the IWDG on behalf of the Department of Communications, Energy and Natural Resources. The DeepPAM project will use C-PODs and a deep water hydrophone system to assess the potential of static PAM systems for long-term monitoring of beaked whales in offshore habitats within the Irish EEZ.

9. STATIC ACOUSTIC MONITORING PROTOCOL

9.1. Units Required to Effectively Monitor an Area

If SAM is to be used as a means to fulfil monitoring obligations under the EU Habitats Directive and to contribute to reporting on FCS of a species, then a number of factors need to be considered. Firstly, the target species in an area needs to be identified and the appropriate type of SAM equipment chosen accordingly. The following is a recommended protocol for C-POD monitoring using existing knowledge built up over the duration of the present study:

1. C-PODs are most sensitive for detecting bottlenose dolphins and harbour porpoises within a 400-metre radius (Figure 9.2).
2. The size of the total area to be monitored should be calculated and stratified into defined geographical grids during the planning stage.
3. Depending on the target species, the study site should be divided into defined geographical coordinates, e.g. for harbour porpoise 10 X 10km grids (Figure 9.1) based on known home ranges for the species - a home range of 10kms per hour for harbour porpoise was calculated by Teilmann (2000). This will allow for a restricted stratified random sampling design and can be altered according to the number of PODs available to a study.
4. Four should be the minimum number of units deployed in small inshore study areas to ensure that statistically robust data can be collected. The number of PODs required should reflect the parameters or factors to be tested (e.g. fine scale diel or larger scales such as seasonal trends). Using an even number design for replication purposes can allow for parameters such as inshore and offshore trends to be explored in larger areas. The more units that can be deployed in an area, the more an informed evaluation of a site and successful monitoring indices will be generated.
5. When designing a project and taking into account equipment and mooring techniques, it is advised that at an absolute minimum of four units should be deployed in a defined area. This number is based upon the home range of target species and the detection range of the C-PODs. Additionally, it is advised to purchase double the number of units that are to be deployed at any one time. This has several advantages, such as eliminating replacement of batteries in the field, which serves to increase the longevity of units but also to reduce the cost of boat hire and eliminate the need for larger vessels.
6. If budget is a severe constraint, then it is advised to reduce the number of monitoring locations and to invest in secure moorings. It is responsible planning to choose a mooring design that is secure and appropriate for the study area as this will facilitate successful data

collection at the target site. It will also prevent gaps occurring in a dataset due to loss, interference or other problems that could be encountered. Where a long-term data set is collected, a gap in data acquisition can have detrimental effects on interpretation. It is better to get a complete cycle of monitoring at fewer sites than several interrupted sequences in acquisition from many sites.

The set-up plan presented below could be used across all types of monitoring sites for all species, as the more units deployed in an area, the more rapidly and more accurate a dataset can be generated and maintained. A minimum baseline number of four units was derived using the restricted stratified random sampling grid system (Figure 9.1). An even number of units is required in order to conform to this method. However, where only two units are used, the likelihood of loss and thus site replication is high. Additionally, where a site extends from the inshore to the offshore environment, a minimum of four units will allow for replication of this factor. Studies are currently ongoing in Wales on determining the minimum number of units needed to effectively monitor an area of defined size (Chelonia Ltd).

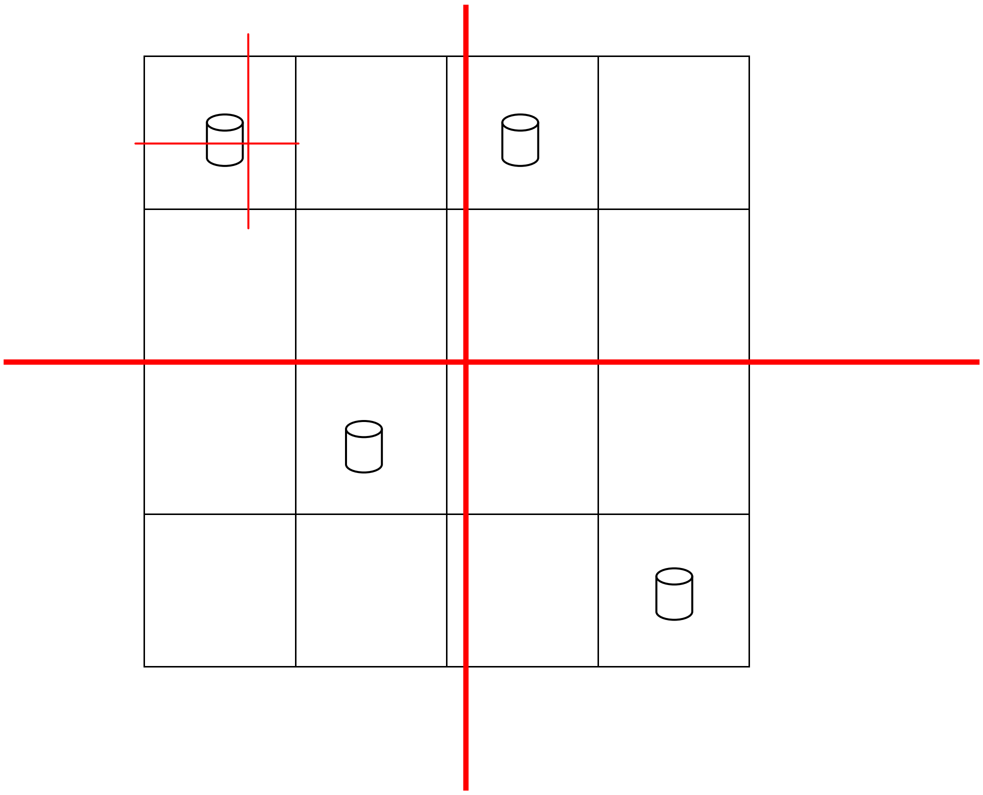


Figure 9.1: Defined geographical grid (10 X 10km) in order to assign POD position randomly, taking into account average hourly home range for a species. The figure shows the maximising of coverage of an area of 1600km² where only four units are available to a study

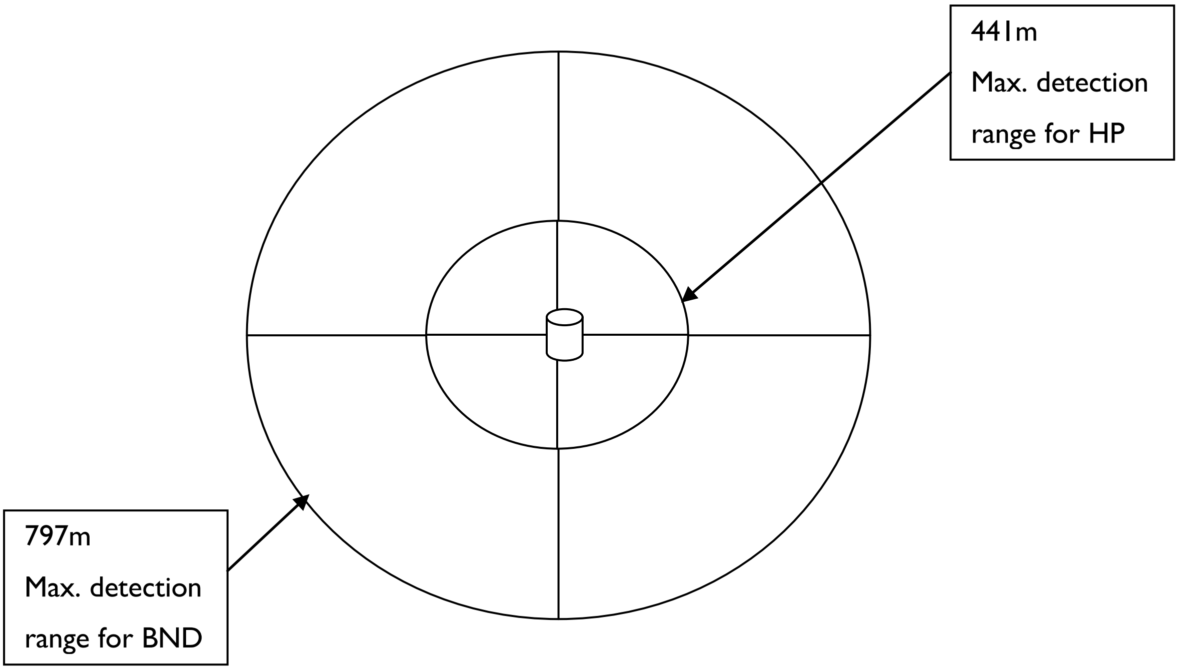


Figure 9.2: Detection ranges for the C-POD for bottlenose dolphins and harbour porpoises

9.2. Calibration of Equipment (C-PODs)

Chelonia Ltd, a UK based company and the sole manufacturers of C-PODs, calibrates all units to a standard prior to dispatch. However, these calibrations are carried out in test tanks, and, thus, Chelonia highly recommends that further calibrations are carried out in the field. Field calibrations aim to assess differences in sensitivity between newly acquired units and the annual testing of all equipment. This provides a means to identify problematic units and allows for a detailed inventory of a units history to be maintained. This is especially important where projects employ several units aimed at comparing detections across a number of sites. If units of differing sensitivities are used, then these data do not truly reflect the activity at a site. For example, a low detection rate may be attributed to a less sensitive pod with a lower detection threshold, which, in turn, leads to a lower detection range, while the opposite holds for a very sensitive unit. It is fundamental that differences between units are determined prior to their deployment as part of any project. Field trials are recommended to be carried out in high density areas so to ensure enough data is gathered over a short time scale (max. four weeks) in order to evaluate individual units. This reduces the amount of time units needed to be in the field for calibration and reduces the need to have multiple units deployed from the same mooring, which increases the chances of multiple losses. The field calibration of new units should be carried out in conjunction with a reference C-POD, where this unit is used solely for calibrations and, thus, deemed a reference. This allows for the incidence where new units are acquired over a project's duration at different intervals, to be calibrated with the reference POD, eliminating the need to deploy all units together. Field trials should be conducted when introducing new units and also every 12 months as standard to determine any degradation over time in POD sensitivity. A minimum of three units should be tested during a field trial to aid more informed data interpretation. When outlying units are continually highlighted, these units should be returned to the manufacturer for re-calibration when identified.

9.3. Deployment

The deployment of C-PODs can be carried out in many different ways, and mooring designs vary between research groups to suit their respective areas. Our past experience with bottom moorings and surface markers suggests these methods should be avoided if possible as they are vulnerable to interference. This influenced our decision to employ AR systems as a means to moor equipment, eliminating the need for surface markers and heavy mooring designs and, more importantly, giving no indication where SAM units are positioned. Various AR systems are available, and a number of companies design release units to suit specific projects. Lighter-weight models are more suitable for inshore waters as these models are functional to 500m. The battery life of a release unit can be a limiting factor but some models offer between 6 and 36-month options. The battery life of the acoustic release should ideally be longer than that of the SAM gear it is deployed with (four months for C-PODs). A recommended alternative to AR mooring arrays is to utilise already existing structures such as piers and jetties so to reduce the cost of mooring arrays and to facilitate ease of deployment and recovery. This was achieved very successfully in the Shannon Estuary cSAC (jetties) and in Galway Bay (Seilean wave energy device) over the duration of the project and without complications. Attempts were made to use the mid-bay buoy as a means of deployment but this resulted in the loss of equipment on two occasions and was, therefore, abandoned. The buoy was a very high energy site and, therefore, even the use of marine chain did not prevent losses.

9.4. Recovery

The battery life of a C-POD is expected to a maximum of four months, but this may vary across sites due to the level of background and ambient noise. In quiet areas, where noise levels are low, the battery may last longer. If the battery of an AR release lasts for six months, then the recovery of units would have to take place every 16 to 20 weeks. Recovery of equipment could be done from a RIB, as the use of AR systems eliminates the need for a larger boat with a winch to haul gear.

9.5. Data Handling

A strict routine should be adhered to when setting and downloading PODs, and note taking of any difficulties is greatly advised. When setting units, the time and date must be recorded as this information is required when downloading the data from the SD card after retrieval. Upon retrieval, all units are opened to retrieve an SD card. This Secure Digital card stores all files in a specific format which requires the dedicated software C-POD.exe. When the data is extracted from the SD card, a CP.1 file is then stored on the computer (a typical file size for a three-month deployment is approximately 100MB). This CP.1 file must be processed using CPOD.exe in order to find click trains, and this reduces the file size and produces a CP.3 file.

9.6. Preliminary Analyses

The CP.1 and CP.3 files can be opened simultaneously and viewed in the same window using CPOD.exe. It is recommended that the data are viewed from the start to the end of each file to make sure it has read and processed okay. Furthermore, a brief analysis of the CP.3 file should be carried out to determine whether the data is as it should be. For example, extracting DPM/day per species, should give a good indication. If unexpected data are recorded, then this may highlight a problematic unit and it may need to be deployed on a field calibration for further assessment.

9.7. Data Storage

As mentioned previously, a typical file size (CP.1 file) of 100MB is normal for a three-month deployment. The size of this file can vary between sites due to the amount of cetacean activity, as well as background or ambient noise. Quieter areas will show smaller files sizes, while deeper deployments away from the surface will also reduce the amount of noise the unit detects. The software CPOD.exe processes these CP.1 files and a smaller CP.3 file is produced which extracts all cetacean click trains from all the other noise stored on the CP.1. It is recommended that a 2TB or greater external hard-drive be used to store all CP.1 and CP.3 files, while further back-ups are made on CD after every recovery.

9.8. Equipment Maintenance

Chelonia Ltd, recommends having double the number of acoustic units needed to carry out a survey. This eliminates the need for data downloading and battery changes in the field and protects the longevity of the equipment. By downloading the equipment in the field, the internal components of the units are exposed to more moisture than if done in a lab. We recommend having some spare units which can be deployed at sites when retrieving gear. This would cut down on the amount of time in the field, and would also alleviate problems associated with equipment loss or failure over the duration of a project.

The storage of C-PODs and acoustic release units in the lab should be given consideration. All units should be cleaned, removing any fouling and drying out external ropes before storing. When not in use, units should be stored without batteries, with their lids firmly secured, and a silica bag inside to absorb any moisture build up from when the unit was open.

9.9. Data Archiving

All data archiving should take place in raw format, with a copy of the software version used to analyse the data. C-POD data and all raw data, i.e. CP.1 files, should be stored on an external hard drive, with a backup copy made for safe keeping. A copy of the software version available at the time for analysis should also be stored with the raw files, as well meta-data, with details of deployment location, latitude and longitude, deployment technique, depth, and any other information that is associated with the deployment. With regard to PAM data, raw wav. files should be stored on external hard drives, with a backup copy for safe keeping. A meta-database should be setup in order to identify data files under each folder. Additionally, a Microsoft Access database should also accompany the raw wav files, with GPS coordinates of the track covered as well as any user information collected over the survey. A copy of the software version used to collect or analyse the data, such as PAMGUARD, should also be archived, or, at the least, details of the version should be recorded on the meta-database. To ensure secure data archiving and to contribute to the repository of cetacean data in Ireland, copies of all CP.1 files should be sent to the National Biodiversity Data Centre (NBDC), located at Waterford Institute of Technology. A copy of the software used to export and process files at that time should also be archived at this repository.

9.10. Assessment of the Performance of Three Devices for Use in Acoustic Monitoring Programmes

The initial field calibration in Galway Bay proved the most comprehensive dataset from which to compare SAM devices. Both C-PODs and T-PODs functioned throughout the calibration period, but the AQUAclick only worked for 14 days. The reason for incorporating SAM into the monitoring programmed is for the ease of acquiring long-term datasets while reducing number of hours in the field. The use of AQUAclicks would require servicing every 14 days, adding additional cost to a project and increasing the likelihood of gaps in a dataset due to adverse weather preventing servicing. It was for this reason that the units are not assessed in the detail that the C-PODs were.

The battery life of a C-POD is long at approximately five months, as determined over the duration of this study. T-PODs lasted, on average, three months, proving the C-PODs to be superior. The units are also robust, as incidents such as ship strikes have failed to destroy the transducers of C-POD. Over the duration of the spring and summer months, all units were prone to fouling by algae and other marine growth. However, as additional buoyancy was added to the units in the form of salmon floats, this did not have an impact during deployment. It did, however, put extra stress on

mooring lines, such as the light weight moorings used in Galway Bay, and probably attributed to the weakening of the line which resulted in the loss of the surface mooring in adverse weather conditions. The return of lost units through www.phonehome.org, a web-based reporting facility provided by the manufacturer, was successful on two occasions when units were found washed up on a beach. It is also recommended to write contact detail on the side of units and on mooring buoys with indelible marker to ensure their return if they become loose. On one occasion, a mooring buoy was washed up in Galway Bay and was reported due to legible contact details.
The biggest gap in long-term SAM due to equipment failure was recorded in the Shannon Estuary, where on two successive deployments, the data failed to read to the SD card and had, in fact, retained the data from a previous deployment. The setup instructions had been followed and the flashes of the LED light had indicated the successful setting of the unit. However, when retrieved and an attempt made to write data to the SD card, a problem was encountered. This was the main and only problem encountered with C-POD failure over the duration. However, T-PODs did malfunction on a number of occasions and due to "comms port" errors, data could not be successfully downloaded despite numerous attempts with altered setting of both the POD and the computer. All T-POD communication was carried out using USB boxes instead of the printer port cable which was more problematic.

C-POD and T-POD deployments were carried out simultaneously in the Moneypoint and Spiddal to assess differences between devices. Graphs are presented below to show that C-PODs are, by far, superior units for monitoring both species (Figure 9.3 and 9.4). Results during the present study showed that, on average, C-PODs detected seven times more DPM than T-PODs for harbour porpoises and four times more for dolphins. The results would suggest that previous datasets collected at these sites using T-PODs would need to be converted if they were to be compared with C-POD data. Therefore, we would recommend that Dolphin DPMs be multiplied by ratios when comparing T-POD with C-POD data. Where T-POD data has been collected at other sites, we would recommend that a trial simultaneous deployment of both devices be carried out to assess the differences between the two for specific sites and species.

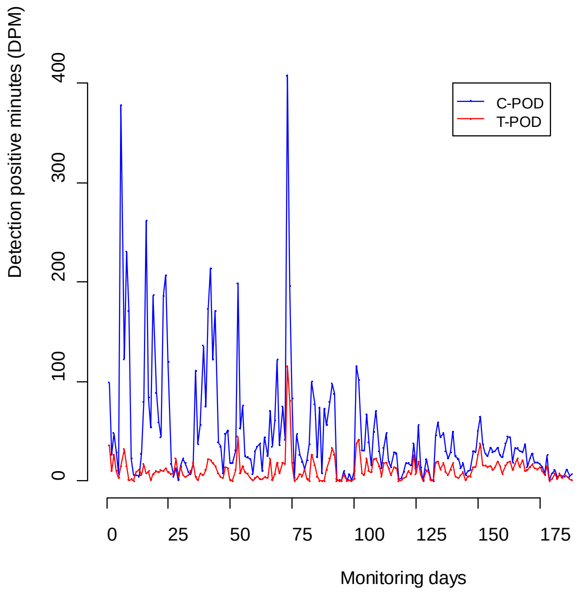


Figure 9.3: C-POD and T-POD comparison from Spiddal, Galway Bay. The red line represents T-POD data and the blue line represents C-POD data

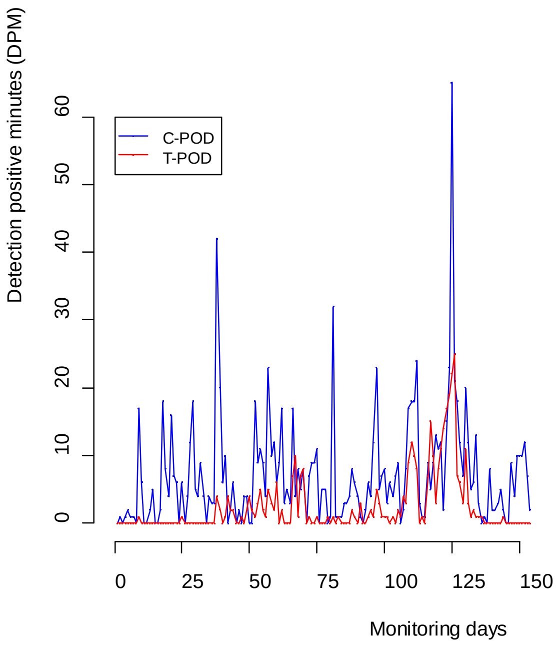


Figure 9.4: C-POD and T-POD comparison from Moneypoint. The red line represents T-POD data and the blue line represents C-POD data

9.11. Analysis Tools

9.11.1. *T-POD.exe, C-POD.exe and Aquaview.exe*

Although not extensively used during the present study, Aquaview.exe was required to set and download AQUAclicks after retrieval. This software had limited application in comparison with C-POD.exe. The AQUAview does not run a train detection algorithm and therefore an observer was required to run through the raw data to highlight trains. A large volume of work is required with the AQUAclick data in order to transform it into a comparable format with POD data. As T-PODs are now obsolete, C-POD.exe is the main software used for data analyses. If analyses are to take place on T-POD data, then a version of T-POD.exe is required, as C-POD.exe uses completely different file formats. Therefore, we recommend that T-POD.exe is archived in order to be able to extract or analyse T-POD data in later years. Additionally, C-POD.exe is under constant revision, and, therefore, we recommend that an annual list of changes to the software is stored with the metadata in order to facilitate data reviews in the future. All problems should be reported to the manufacturer as they will incorporate all comments and feedback where possible. It also serves to inform the manufacturers of potential problems they might not yet have encountered.

9.11.2. *Statistical software R (R Development Core Team, 2011)*

R provides a wide variety of linear and nonlinear modelling, classical statistical tests, time-series analysis, classification, clustering and graphical techniques. R is one of the main statistical packages in use on an international scale for cetacean research. It has the ability to facilitate complex analysis using multiple factors, which cannot be achieved using some of the other statistical packages available. R is constantly updated and, therefore, its capabilities are constantly expanding. It is recommended that when using this software, package versions used, via the CRAN website, are archived along with extensive R scripts which can be repeated at a later date.

9.11.3. *Cyclops*

Cyclops tracker is a marine mammal positioning system that can be easily run in real time in the field. A complete re-write of Cyclops tracker was conducted and VADAR (Visual Detection and Ranging at sea) will be released in late 2011 (http://cyclops-tracker.com/). VADAR has a completely different data file structure to those of previous versions of Cyclops tracker. This software also allows for input from research vessels' GPS position coordinates. Raw data and calculated positions can be exported in a text format for input into a Geographic Information System (GIS). If land based theodolite tracking is to be carried out, it is advised that Cyclops tracker or VADAR is used for a proportion of the tracking at the start of the day. This serves to check for any observation or observer errors and reduces personnel time when analysing data.

9.12. **Monitoring Index for Favorable Conservation Status**

The results of the present study supported the selection of %DPMs as a monitoring index over various temporal scales, taking into account total deployment time. This index can therefore be used to compare data between sites even when the number of samples (hours monitored) from different areas are unbalanced. It also serves as a comparison with other short-term studies where time scales do not extend beyond a few months, but an index can be generated for, for example, a month and compared accordingly. This index will also allow for comparison with past data where T-PODs were used. It will simply require the multiplication by a percentage to account for inter-device differences after a simultaneous deployment has been carried out at this site. The monitoring index will serve as an effective monitoring indicator of changes in the presence of odontocetes in an area over time and will serve to inform management if a population is changing. A concise background dataset will have to be established for an area, probably in the region of two years, before this monitoring index can be used to its full potential or used to evaluate a site on an annual basis.

9.13. **Cost Analyses of SAM**

The following is a cost analysis for the provision of long-term SAM. These costings take into account all aspects of deployment and recovery, and, depending on the number of units required for an area, the price can be multiplied accordingly. As a final evaluation of SAM compared to visual monitoring for an area, a cost analysis compares the financial commitment required to carry out each method as a means to monitor an area for a duration of 12 months.

9.13.1. *Acquisition of Equipment*

The units included in this cost estimation include C-PODs and AQUAclicks. T-PODs were excluded as they are no longer in production. C-PODS are the recommended SAM equipment due to their cost, battery life, ease of setting, downloading and analyses of data. The cost of C-POD and AQUAclick units are presented. All prices exclude VAT and are converted from a sterling exchange rate (Nov, 2011).

C-PODs- Chelonia Ltd (www.chelonia.co.uk)

All costs ex VAT

C-POD V1	**€3,428.00**
Delivery	**€30**

Approx. €3,460.00 per unit (as of Nov, 2011)

AQUAclick- Aquatec Ltd (www.aquatecgroup.com)

All costs ex VAT

AQUAclick (incl. starter kit)	**£2,170**
Ex starter kit	**£1,830**
Delivery	**£50**

Approx. €2,600.00 per unit incl. starter kit, €2,200 thereafter

9.13.2. *Moorings*

The costs of moorings are often greater than the cost of the SAM units themselves. However, choice of moorings is one of the most important decisions to be made over a project duration and will ensure whether robust datasets are collected or not. If equipment cannot be securely moored in the marine environment then there is no assurance that it will be there upon return. As SAM equipment can be deployed for long durations (four to five months), large gaps will exist in a dataset if units go missing over the duration. A number of mooring designs were tried and tested over the project duration, and it is recommended that AR systems be prioritised if possible. Although this mooring mechanism can add a substantial cost to a project at the outset, it will provide savings over its duration. AR arrays will allow for ease of retrieval and deployment of equipment without the need for larger vessels with lifting apparatus. AR arrays can be retrieved and deployed from RIBs, and their use avoids the need for maintenance of moorings. It is recommended that the location of AR arrays be recorded and, through the use of a diver, that the sacrificial mooring blocks be retrieved at least every 12 months to avoid littering the deployment sites.

Robust/durable moorings (suppliers JFC Marine, SwanNet Grundry)

All costs ex VAT

JFC Marine

1.2m Navigational Buoy	**€1,325.00**
2 nautical mile light	**€345.00**

SwanNet Grundry

16mm open link chain	**(20m)**	**€300**
Dyneema rope	**(30m)**	**€200**
6.6 ton shackles	**(4)**	**€50**
Flex Swivel		**€30**
Bruce holding anchor	**(100kg)**	**€700**

Approx. €2,950 for a robust inshore mooring. Additional costs include boat hire (approx. €1,000 per day due to weight of mooring). Additional costs after initial deployment include servicing of mooring (at least every 12 months) or if a problem is encountered. A pulley system is required for this mooring type in order to avoid the requirement for a larger boat with lifting apparatus for retrieving units.

Marine Electronics (www.marine-electronics.co.uk)

All costs ex VAT

Model 3480W Acoustic Release Unit	**£3,950**
Transponder command unit	**£2,950**
Command unit battery charger	**£250**

Approximately €8,370 for a single unit and command unit. Batteries need to be replaced every three months and require six 9V lithium batteries, costing approx. €20.

Sonardyne (www.sonardyne.com)

<u>All costs ex VAT</u>

Light Weight Transponder (LRT)	**£1,748**
Rope canister system	**£882**
Command unit-System kit	**£4,637**
Re-battering every 12-18 months	**£39.00**

Approximately €8,500 for a single release unit and command system. Also included is a roped canister. If, in the event, the release fails to trigger, the roped canister will fire and return to the surface to allow for the sub-bottom array to be retrieved. Sonardyne's units have an internal battery which needs to be changed by the manufacturer every 12 to 18 months. This cost is in the region of €46.00 plus P&P per unit but the turnaround time required for this service can be in the region of six to eight weeks, which could be critical to a project looking at seasonal effects.

Regardless of AR array type, a sacrificial bottom weight is required in order to moor the arrays in place. A company would be contracted to develop concrete moulds and construct concrete mooring blocks that can be used as sacrificial anchors. This method of mooring is a cheap alternative to metal, which is very expensive at present. These mooring blocks can be constructed in bulk and stored until required. Mooring blocks should be retrieved using a commercial diver at least every 12 to 18 months, where the depth allows it, to avoid littering the marine environment but also to recycle materials and reduce the overall cost of the project.

Sacrificial mooring blocks (20 X 20kg blocks). For each additional 20 blocks, cost is increased by concrete, shackles and daily rate (approx. €400). This is a small cost when compared with that for a heavy duty mooring, where a bruce holding anchor (100kg) costs €700.

<u>All costs ex VAT</u>

Construction of moulds (timber): €100
Labour to construct mooring blocks: €400
Concrete: €100
Shackle (6 tonne green pins marine) X20: €200

9.13.3. *Field calibrations*

All equipment is calibrated to a standard prior to dispatch by Chelonia Ltd. Additional field calibrations are required to evaluate the performance of an individual unit in the marine environment and, additionally, to compare the performance of individual units against each other. This evaluation allows for the identification of very sensitive or less sensitive units and allows for the comparison of data between sites. The cost of calibration varies and would comprise personnel time, batteries and boat hire for deployment and retrieval (Figure 9.5).

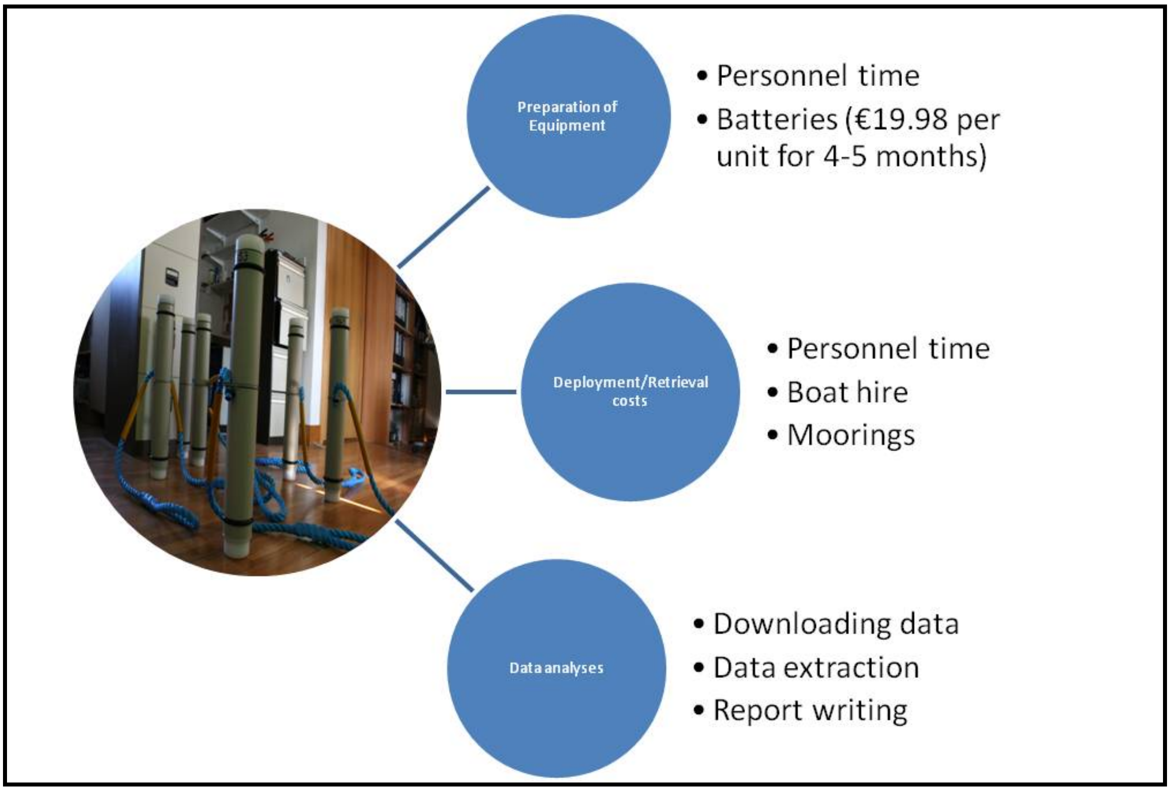


Figure 9.5 Costs associated with field calibration, recommended prior to the incorporation of any equipment into long-term monitoring programmes, and to be carried out at least every 18 months.

9.13.4. *Long-term SAM*

There are a number of areas to address and to cost for when planning a long-term SAM programme (Figure 9.6). The cost of monitoring will have slight increases associated with it when an area requires multiple units. Therefore, during the planning stage, the number of units required for an area should be established using the recommended calculations above.

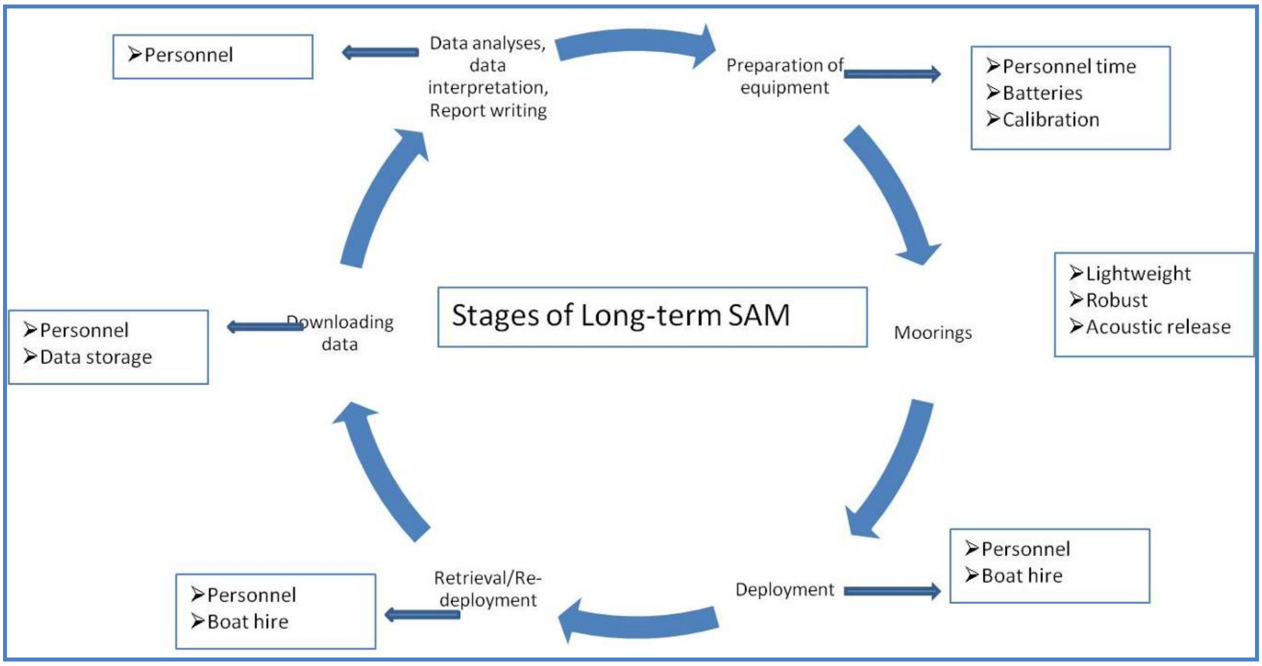


Figure 9.6: Costs associated with long-term SAM programmes

9.13.5. *Cost Analyses*

For a statistically robust dataset to be gathered from visual monitoring, a minimum of two dedicated surveys would need to be carried out per month. This would ensure that the temporal factors such as months had a minimum number of replicates. However, the possibility of achieving a 12-month dataset with bi-monthly surveys on the west coast of Ireland is highly unlikely. The cost of gathering such a dataset includes the following:

The following are the estimated cost associated with boat-based surveys	**€**
• **Boat hire will cost a minimum of €1200 per day incl. VAT and fuel cost**	**1,200**
• **Observer daily rate (X4 people @€300 per day per person)**	**1,200**
• **Travel (approx. 300 per survey depending on mileage)**	**300**
• **Overnight stays (4 people at €100 per night)**	**400**
• **Equipment hire and survey prep. (1 person at €300 per day)**	**300**
• **Data entry and input after each survey, report prep. (1 person at €300 per day, 2 days)**	**600**
• **Final report prep (5 days, 2 personnel)**	**3,000**
Total cost for a single survey	**4,000**
Total cost for 12 months at 2 surveys per month	**€99,000**

If SAM was to be carried out at a single site for a 12-month duration, the following would be the estimated cost:

The following are the estimated costs associated with SAM	
C-POD Units X4, Chelonia Ltd	**13,800**
AR systems X 4 and control unit (Sonardyne)	**17,500**
Mooring blocks (prep of 20 moulds)	**800**
Calibration (incl. boat hire, personnel and analyses)	**3,000**
Equipment servicing (incl. boat hire, personnel, equipment prep data anal and travel)	**11,800**
Final report prep (5 days, 2 personnel)	**3,000**
Total cost for 12 Months SAM	**€49,900**
If buying double, the amount required for ease of servicing, protection of equipment and provision for losses:	**€**
AR releases (X 4)	**7,400**
C-PODs (X4)	**13,712**
Therefore, an additional €21,112 would be required	
	€71,012

The initial start-up costs for SAM are significant but are reduced each consecutive year after the equipment has been acquired. Additionally, the first costing only takes into account the fees associated with the purchase of four units. It would be recommended to purchase double the amount of equipment required for monitoring a site at the onset of a project. This will ensure that equipment does not have to be serviced in the field and, additionally, if losses are encountered, gaps in monitoring would not be experienced due to delays associated with equipment purchase and calibration. Equipment value will depreciate over time, but it assumed that this investment will cover at least three years monitoring, with additional annual costs for personnel and those associated with deployment.

SAM can be a cost effective means for monitoring and maintaining FCS, thereby conforming with the requirements under the Habitats Directive. A SWOT analysis of the weaknesses and strengths of each technique was carried out and presented in Table 9.1.

Table 9.1: SWOT analyses of SAM versus visual boat-based surveying

Type	Strength/Opportunities	Weakness/Threats
SAM	• Continuous data acquisition at four sites • Independent of weather • Independent of darkness • Not influenced by observer variability • Cheap in comparison to visual vessel based surveying • Data to assess temporal trends can be obtained rapidly • Behaviour and thus habitat usage can be explored • Cost per detection is low	• No information on density or absolute abundance • Can't be interfered with, resulting in loss of units • Exposed to adverse weather conditions • Losses can result in large gaps in dataset • Limited detection range • Inability to differentiate between dolphin species
Visual boat based surveys	• Abundance and density estimates can be generated • Can identify to species level • Can estimate seasonal patterns in abundance • Can measure adult to calf ratios	• Cost per detection is high • No temporal datasets will exist for night time hours • Limited to days of excellent sea conditions • Can't assess habitat use during night time hours

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APPENDIX

```
## choose .csv file for analysis
file.choose()
gb1=read.csv(file="F:\\PReCAST\\Calibration data_files\\calibration\\GB_Cal_001.csv")
##gb1 is hardcoded in the script and needs to be changed for each trial
##packages needed to run analysis
library(gtools)
library(gdata)
library(MethComp)
library(plotrix)
##create matrix/grid of all pod to pod combinations analysed
pod.names<-names(gb1)[1:9]
##[1:9] is hardcoded, number of units in trial
combinations.pods<-expand.grid(pod.names,pod.names, stringsAsFactors = FALSE)
combinations.pods$int<-NA
combinations.pods$int.upr<-NA
combinations.pods$int.lwr<-NA
combinations.pods$slope<-NA
combinations.pods$slope.upr<-NA
combinations.pods$slope.lwr<-NA
combinations.pods
## create a function for orthogonal regression with 20% error
calib.func<-function(pod1, pod2){
dat.pod1<-gb1[,pod1]
dat.pod2<-gb1[,pod2]
lm.null<-lm(dat.pod1~-1+offset(dat.pod2), data=gb1)
lm.orth<-Deming(dat.pod2, dat.pod1, vr=1)
plot(dat.pod2,dat.pod1, xaxt="n", yaxt="n", type="n", xlim=c(0,60), ylim=c(0,60))
for(i in 1:60){
draw.circle(x=i,y=i,radius=(0.2*i),nv=100,border=NA,col="lightgrey",lty=NULL,lwd=1)}
points(dat.pod2,dat.pod1)
abline(c(0,1))
abline(lm.orth[1:2], col="blue")
 legend("bottomright", paste(pod1, " vs ", pod2, sep=""), bty="n")
  box()}
## the dimensions of the graph lattice, (9,9) is hardcoded
par(mfrow=c(9,9), mar=c(0,0,0,0), oma=c(2,2,1,1))
##run the function above for the gb1 dataset
##1:81 is hardcoded, the number of pod combinations
for(i in 1:81){
print(i)
calib.func(pod1=combinations.pods[i,1], pod2=combinations.pods[i,2])
dat.pod1<-gb1[,combinations.pods[i,1]]
dat.pod2<-gb1[,combinations.pods[i,2]]
lm.orth<-Deming(dat.pod2, dat.pod1, vr=1, boot=TRUE)
combinations.pods$int[i]<-lm.orth[1,1]
combinations.pods$int.upr[i]<-lm.orth[1,5]
combinations.pods$int.lwr[i]<-lm.orth[1,4]
combinations.pods$slope[i]<-lm.orth[2,1]
combinations.pods$slope.upr[i]<-lm.orth[2,5]
combinations.pods$slope.lwr[i]<-lm.orth[2,4]}
##create centipede plots of slope and intercept values
##1:81 is hardcoded, the number of pod combinations
par(mfrow=c(1,2))
with(combinations.pods, plot(int,1:81, pch=19, xlim=c(-2.5,2.5), xlab="Intercept",
sub="(mins)", cex.sub=0.75, ylab="Pod Combination", main="GB1", cex.main=1, cex=0.75))
with(combinations.pods,arrows(int.lwr, 1:81, int.upr, 1:81, code=3, angle=90, length=0.04))
abline(v=0, lty=2, col="red")
with(combinations.pods, plot(slope,1:81, pch=19, xlim=c(-1,3), xlab="Gradient",
ylab="Pod Combination", main="GB1", cex.main=1, cex=0.75))
with(combinations.pods,arrows(slope.lwr, 1:81, slope.upr, 1:81, code=3, angle=90, length=0.04))
abline(v=1, lty=2, col="red")
##create boxplots of mean slope(gradient) values
##use slope for this as slope centipede plot showed up greatest variation
##use Var1 and Var2 i.e C-167&C-177 and C-177&C-167
par(mfrow=c(1,2))
boxplot(slope~Var1, ylim=c(0,2),data=combinations.pods, main="GB1")
abline(h=1, lty=2, col="red")
boxplot(slope~Var2, ylim=c(0,2),data=combinations.pods, main="GB1")
abline(h=1, lty=2, col="red")
```

Figure 1: R-script for calibration analysis

Table 1: Results of T-POD deployments in Galway Bay (Spiddal Wave Platform) between January 2009 and July 2010. Total days monitored =189, Total Detection Positive Minutes (Total DPM) =2207, Percentage Detection Positive Minutes (%DPM) = 0.829 for Narrow Band High Frequency (NBHF) detections. Total DPM=10, %DPM=0.004 for dolphin detections

Galway Bay - Spiddal													
				NBHF	NBHF	NBHF	NBHF	NBHF	Dolphin	Dolphin	Dolphin	Dolphin	Dolphin
Month	Total Days	Total Hours	Total Min	Total DPH	Total DPM	% DPD	% DPH	% DPM	Total DPH	Total DPM	% DPD	% DPH	% DPM
Jan-09	5	101	6060	29	86	100.000	28.713	1.419	0	0	0.000	0.000	0.000
May-09	13	302	18120	53	135	92.308	17.550	0.745	0	0	0.000	0.000	0.000
Jun-09	19	444	26640	84	174	100.000	18.919	0.653	0	0	0.000	0.000	0.000
Aug-09	25	587	35220	125	253	96.000	21.295	0.718	1	1	4.000	0.170	0.003
Sep-09	27	637	38220	127	396	81.481	19.937	1.036	1	1	3.704	0.157	0.003
Jan-10	15	355	21300	51	192	66.667	14.366	0.901	0	0	0.000	0.000	0.000
Apr-10	15	349	20940	94	196	93.333	26.934	0.936	6	7	20.000	1.719	0.033
May-10	31	744	44640	141	282	96.774	18.952	0.632	1	1	3.226	0.134	0.002
Jun-10	30	720	43200	232	456	96.667	32.222	1.056	0	0	0.000	0.000	0.000
Jul-10	9	200	12000	25	37	100.000	12.500	0.308	0	0	0.000	0.000	0.000
Total Monitoring Period	189	4439	266340	961	2207	92.063	21.649	0.829	9	10	3.175	0.203	0.004

Table 2: Results of C-POD deployments in Galway Bay (Spiddal Wave Platform) between January 2009 and September 2010. Total days monitored =569, Total Detection Positive Minutes (Total DPM) =27902, Percentage Detection Positive Minutes (%DPM) = 3.320 for Narrow Band High Frequency (NBHF) detections. Total DPM=125, %DPM = 0.015 for dolphin detections

Galway Bay - Spiddal													
				NBHF	NBHF	NBHF	NBHF	NBHF	Dolphin	Dolphin	Dolphin	Dolphin	Dolphin
Month	Total Days	Total Hours	Total Min	Total DPH	Total DPM	% DPD	% DPH	% DPM	Total DPH	Total DPM	% DPD	% DPH	% DPM
Jan-09	19	456	27360	156	730	100	34.211	2.668	1	3	5.263	0.219	0.011
Feb-09	28	672	40320	98	465	89.286	14.583	1.153	1	4	3.571	0.149	0.01
Mar-09	31	744	44640	153	630	100	20.565	1.411	2	12	6.452	0.269	0.027
Apr-09	30	720	43200	186	614	100	25.833	1.421	1	4	3.333	0.139	0.009
May-09	20	476	28560	185	1504	100	38.866	5.266	3	4	15	0.63	0.014
Jun-09	30	720	43200	267	1834	100	37.083	4.2454	0	0	0	0	0
Jul-09	9	197	11820	54	249	77.778	27.411	2.107	4	4	33.333	2.03	0.034
Aug-09	25	600	36000	277	1702	100	46.167	4.728	7	48	16	1.167	0.133
Sep-09	30	720	43200	275	1959	100	38.194	4.535	2	5	3.333	0.278	0.012
Oct-09	31	744	44640	533	5606	100	71.64	12.558	3	19	6.452	0.403	0.043
Nov-09	30	720	43200	420	4442	100	58.333	10.282	0	0	0	0	0
Dec-09	30	720	43200	204	1240	80	18.182	1.842	0	0	0	0	0
Jan-10	31	744	44640	256	2012	90.323	34.409	4.507	1	1	3.226	0.134	0.002
Feb-10	28	672	40320	72	293	71.429	10.714	0.727	0	0	0	0	0
Mar-10	31	744	44640	267	1155	100	35.887	2.587	0	0	0	0	0
Apr-10	34	804	48240	232	869	88.235	28.856	1.801	0	0	0	0	0

May-10	31	744	44640	221	714	96.774	29.704	1.599	0	0	0	0	0
Jun-10	30	720	43200	295	859	100	40.972	1.988	0	0	0	0	0
Jul-10	31	744	44640	189	560	100	25.403	1.254	1	2	3.226	0.134	0.004
Aug-10	31	744	44640	140	332	96.774	18.817	0.744	2	15	12.903	0.269	0.034
Sep-10	12	259	15540	35	133	77.778	17.327	1.097	3	4	0	1.485	0.033
Total Monitoring	572	13664	819840	4515	27902	94.728	32.229	3.4	31	125	4.218	0.221	0.015

Table 3: Results of T-POD deployments at Moneypoint (Shannon Estuary cSAC) between January 2009 and May 2010. Total days monitored =245, Total Detection Positive Minutes (Total DPM) = 375, Percentage Detection Positive Minutes (%DPM) = 0.110 for Narrow Band High Frequency (NBHF) detections. Total DPM=446, %DPM = 0.131 for dolphin detections

Moneypoint - Shannon Estuary cSAC													
				NBHF	NBHF	NBHF	NBHF	NBHF	Dolphin	Dolphin	Dolphin	Dolphin	Dolphin
Month	Total Days	Total Hours	Total Min	Total DPH	Total DPM	% DPD	% DPH	% DPM	Total DPH	Total DPM	% DPD	% DPH	% DPM
Jan-09	23	536	32160	0	0	0.000	0.000	0.000	1	1	4.348	0.187	0.003
Feb-09	14	314	18840	2	6	7.143	0.637	0.032	1	1	7.143	0.318	0.005
Mar-09	31	744	44640	55	94	74.194	7.392	0.211	41	58	64.516	5.511	0.130
Apr-09	14	329	19740	9	12	50.000	2.736	0.061	8	10	28.571	2.432	0.051
May-09	14	322	19320	8	9	35.714	2.484	0.047	7	7	42.857	2.174	0.036
Jun-09	31	717	43020	10	10	29.032	1.395	0.023	30	38	51.613	4.184	0.088
Jul-09	20	440	26400	19	21	75.000	4.318	0.08	44	65	80.000	10.000	0.246
Sep-09	2	35	2100	0	0	0.000	0.000	0.000	0	0	0.000	0.000	0.000
Oct-09	31	723	43380	4	4	12.903	0.553	0.009	9	9	25.806	1.245	0.021
Nov-09	7	147	8820	2	3	28.571	1.361	0.034	5	7	57.143	3.401	0.079
Dec-09	28	658	39480	32	50	64.286	4.863	0.127	90	166	85.714	13.678	0.420
Jan-10	12	291	17460	20	31	66.667	6.873	0.178	44	83	100.000	15.120	0.475
Apr-10	15	349	20940	54	127	93.333	15.473	0.606	1	1	6.667	0.287	0.005
May-10	3	67	4020	6	8	66.667	8.955	0.199	0	0	0.000	0.000	0.000
Total Monitoring Period	245	5672	340320	221	375	44.082	3.896	0.110	281	446	46.122	4.954	0.131

Table 4: Results of C-POD deployments at Moneypoint, Co. Clare (Shannon Estuary cSAC), between January 2009 and February 2011. Total days monitored = 641, Total Detection Positive Minutes (Total DPM) = 235, Percentage Detection Positive Minutes (%DPM)= 0.026 for Narrow Band High Frequency (NBHF) detections. Total DPM=4010, %DPM = 0.437 for dolphin detections

Moneypoint - Shannon Estuary cSAC													
				NBHF	NBHF	NBHF	NBHF	NBHF	Dolphin	Dolphin	Dolphin	Dolphin	Dolphin
Month	Total Days	Total Hours	Total Min	Total DPH	Total DPM	% DPD	% DPH	% DPM	Total DPH	Total DPM	% DPD	% DPH	% DPM
Jan-09	22	528	31680	35	45	72.727	6.629	0.142	32	91	68.182	6.061	0.287
Feb-09	27	646	38760	17	30	48.148	2.632	0.077	52	132	70.370	8.050	0.341
Jun-09	15	351	21060	4	6	20.000	1.140	0.028	22	102	73.333	6.268	0.484
Jul-09	31	723	43380	8	12	25.806	1.107	0.028	94	267	96.774	13.001	0.615
Aug-09	31	744	44640	6	6	100.000	0.806	0.013	53	144	74.194	7.124	0.323
Sep-09	29	689	41340	5	5	17.241	0.726	0.012	17	51	34.483	2.467	0.123
Oct-09	18	421	25260	2	2	11.111	0.475	0.008	37	106	105.556	8.789	0.420
Nov-09	30	720	43200	2	2	6.667	0.278	0.005	68	553	86.667	9.444	1.280
Dec-09	31	745	44700	9	9	25.806	1.208	0.020	108	405	100.000	14.497	0.906
Jan-10	31	744	44640	9	20	29.032	1.210	0.045	87	261	77.419	11.694	0.585
Feb-10	28	672	40320	9	11	28.571	1.339	0.027	33	70	71.429	4.911	0.174
Mar-10	31	744	44640	7	12	19.355	0.941	0.027	55	190	77.419	7.392	0.426
Apr-10	32	743	44580	14	14	31.250	1.884	0.031	73	179	84.375	9.825	0.402
May-10	31	744	44640	5	5	12.903	0.672	0.011	55	101	87.097	7.392	0.226
Jun-10	30	720	43200	3	4	10.000	0.417	0.009	66	161	83.333	9.167	0.373
Jul-10	31	744	44640	11	13	35.484	1.478	0.029	8	510	96.774	17.204	1.142

Aug-10	31	744	44640	6	8	19.355	0.806	0.018	79	240	90.323	10.618	0.538
Sep-10	31	726	43560	4	10	12.903	0.551	0.023	19	42	45.161	2.617	0.096
Oct-10	31	744	44640	5	9	12.903	0.672	0.020	14	36	32.258	1.882	0.081
Nov-10	30	720	43200	4	4	13.333	0.556	0.009	62	173	83.333	8.611	0.400
Dec-10	31	744	44640	5	5	16.129	0.672	0.011	53	139	58.065	7.124	0.311
Jan-11	31	744	44640	3	3	9.677	0.403	0.007	26	57	32.258	3.495	0.128
Feb-11	8	191	11460	0	0	0.000	0.000	0.000	0	0	0.000	0.000	0.000
Total Monitoring Period	641	15291	917460	173	235	25.741	1.131	0.026	1233	4010	72.699	8.064	0.437

Table 5: Results of C-POD deployments at Foynes, Co. Limerick (Shannon Estuary cSAC), between February 2009 and October 2010. Total days monitored =591, Total Detection Positive Minutes (Total DPM) = 69, Percentage Detection Positive Minutes (%DPM) = 0.008 for Narrow Band High Frequency (NBHF) detections. Total DPM=1158, %DPM= 0.137 for dolphin detections

Foynes - Shannon Estuary cSAC													
				NBHF	NBHF	NBHF	NBHF	NBHF	Dolphin	Dolphin	Dolphin	Dolphin	Dolphin
Month	Total Days	Total Hours	Total Min	Total DPH	Total DPM	% DPD	% DPH	% DPM	Total DPH	Total DPM	% DPD	% DPH	% DPM
Feb-09	10	229	13740	3	4	10.000	1.310	0.029	6	16	50.000	2.620	0.116
Mar-09	31	744	44640	8	10	22.600	1.075	0.022	26	64	48.387	3.495	0.143
Apr-09	30	720	43200	5	5	16.667	0.694	0.012	28	65	73.333	3.889	0.150
May-09	18	423	25380	3	3	16.667	0.709	0.012	19	43	61.111	4.492	0.169
Jun-09	15	351	21060	6	6	26.667	1.709	0.028	5	10	33.333	1.425	0.047
Jul-09	31	744	44640	6	11	16.129	0.806	0.025	14	22	38.710	1.882	0.049
Aug-09	31	744	44640	7	7	16.129	0.941	0.016	18	38	51.613	2.419	0.085
Sep-09	31	721	43260	1	1	3.226	0.139	0.002	3	5	9.677	0.416	0.012
Oct-09	31	744	44640	2	3	6.452	0.269	0.007	13	26	32.258	1.747	0.058
Nov-09	30	720	43200	6	6	16.667	0.833	0.014	11	36	30.000	1.528	0.083
Dec-09	31	744	44640	0	0	0.000	0.000	0.000	12	39	22.581	1.613	0.087
Jan-10	33	768	46080	0	0	0.000	0.000	0.000	2	2	6.061	0.260	0.004
Feb-10	28	672	40320	0	0	0.000	0.000	0.000	33	120	57.143	4.911	0.298
Mar-10	31	744	44640	0	0	0.000	0.000	0.000	22	63	38.710	2.957	0.141
Apr-10	32	744	44640	0	0	0.000	0.000	0.000	31	176	59.375	4.167	0.394
May-10	31	744	44640	0	0	0.000	0.000	0.000	28	127	48.387	3.763	0.284

Jun-10	30	720	43200	2	5	6.667	0.278	0.012	33	110	76.667	4.583	0.255
Jul-10	31	744	44640	0	0	0.000	0.000	0.000	19	56	41.935	2.554	0.125
Aug-10	31	744	44640	0	0	0.000	0.000	0.000	21	85	45.161	2.823	0.190
Sep-10	31	727	43620	6	7	16.129	0.825	0.016	12	49	32.258	1.651	0.112
Oct-10	24	571	34260	1	1	4.167	0.175	0.003	6	6	20.833	1.051	0.018
Total Monitoring Period	591	14062	843720	56	69	7.797	0.398	0.008	362	1158	41.356	2.574	0.137

Table 6: Results of C-POD deployments at Wild Bank, Co. Kerry (Blasket Islands cSAC), between July 2009 and June 2010. Total days monitored =289, Total Detection Positive Minutes (Total DPM) =2097, Percentage Detection Positive Minutes (%DPM) =0.508 for Narrow Band High Frequency (NBHF) detections. Total DPM=252, %DPM=0.061 for dolphin detections

Wild Bank - Blasket Islands cSAC													
				NBHF	NBHF	NBHF	NBHF	NBHF	Dolphin	Dolphin	Dolphin	Dolphin	Dolphin
Month	Total Days	Total Hours	Total Min	Total DPH	Total DPM	% DPD	% DPH	% DPM	Total DPH	Total DPM	% DPD	% DPH	% DPM
Jul-09	3	60	3600	3	5	33.333	5.000	0.139	1	1	33.333	1.667	0.028
Aug-09	31	744	44640	54	87	61.290	7.258	0.195	4	10	12.903	0.538	0.022
Sep-09	31	726	43560	136	224	93.548	18.733	0.514	11	34	25.806	1.515	0.078
Oct-09	31	744	44640	147	312	96.774	19.758	0.699	6	7	19.355	0.000	0.016
Nov-09	30	720	43200	90	184	86.667	12.500	0.426	1	1	3.333	0.833	0.002
Dec-09	5	113	6780	8	13	60.000	7.080	0.192	0	0	0.000	0.000	0.000
Jan-10	25	577	34620	58	232	76.000	10.052	0.670	0	0	0.000	0.000	0.000
Feb-10	28	672	40320	166	756	100.000	24.702	1.875	5	16	14.286	0.744	0.040
Mar-10	31	744	44640	49	85	80.645	6.586	0.190	13	29	22.581	1.747	0.065
Apr-10	30	720	43200	36	54	63.333	5.000	0.125	29	137	36.667	4.028	0.317
May-10	31	744	44640	70	145	70.968	9.409	0.325	5	17	12.903	0.672	0.038
Jun-10	13	310	18600	0	0	0.000	0.000	0.000	0	0	0.000	0.000	0.000
Total Monitoring Period	289	6874	412440	817	2097	76.471	11.885	0.508	75	252	15.917	1.091	0.061

Table 7: Results of C-POD deployments at Inishtooskert, Co. Kerry (Blasket Islands cSAC), between July2009 and June 2010. Total days monitored =264, Total Detection Positive Minutes (Total DPM) =3930, % Detection Positive Minutes (%DPM) =1.040 for Narrow Band High Frequency (NBHF) detections. Total DPM=181, %DPM=0.048 for dolphin detections

Inishtooskert - Blasket Island cSAC													
				NBHF	NBHF	NBHF	NBHF	NBHF	Dolphin	Dolphin	Dolphin	Dolphin	Dolphin
Month	Total Days	Total Hours	Total Min	Total DPH	Total DPM	% DPD	% DPH	% DPM	Total DPH	Total DPM	% DPD	% DPH	% DPM
Jul-09	3	72	4320	7	7	66.667	9.722	0.162	0	0	0.000	0.000	0.000
Aug-09	31	744	44640	69	130	77.419	9.274	0.291	13	38	25.806	1.747	0.085
Sep-09	31	725	43500	62	123	80.000	8.552	0.283	21	63	40.000	2.897	0.145
Oct-09	31	744	44640	99	205	83.871	13.306	0.459	1	1	3.226	0.134	0.002
Nov-09	4	82	4920	14	37	75.000	17.073	0.752	0	0	0.000	0.000	0.000
Jan-10	24	563	33780	135	921	100.000	23.979	2.726	3	3	12.500	0.533	0.009
Feb-10	28	672	40320	139	922	100.000	20.685	2.287	10	13	25.000	1.488	0.032
Mar-10	31	744	44640	143	869	93.548	19.220	1.947	8	8	25.806	1.075	0.018
Apr-10	30	720	43200	74	150	86.667	10.278	0.347	8	10	23.333	1.111	0.023
May-10	31	744	44640	129	286	96.774	17.339	0.641	6	10	19.355	0.806	0.022
Jun-10	21	486	29160	87	280	95.238	17.901	0.960	22	35	57.143	4.527	0.120
Total Monitoring Period	264	6296	377760	958	3930	89.394	15.216	1.040	92	181	24.242	1.461	0.048

Table 8: Results of C-POD deployments at GOB, Co. Kerry (Blasket Islands cSAC), between February 2009 and March 2009. Total days monitored =52, Total Detection Positive Minutes (Total DPM) =3015, Percentage Detection Positive Minutes (%DPM) =4.143 for Narrow Band High Frequency detections (NBHF). Total DPM=2, %DPM=0.003 for dolphin detections

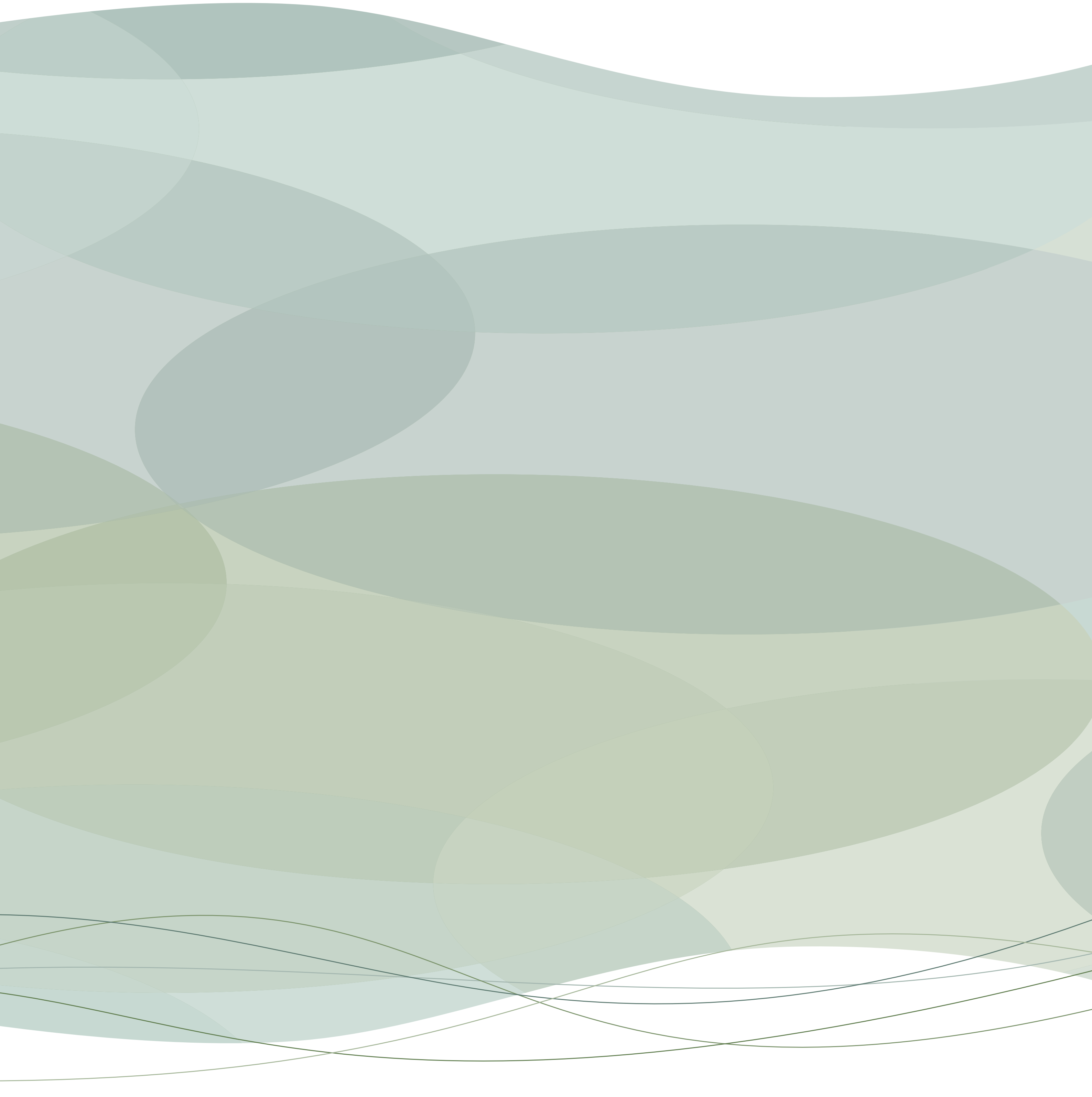
The Gob - Blasket Island cSAC													
				NBHF	NBHF	NBHF	NBHF	NBHF	Dolphin	Dolphin	Dolphin	Dolphin	Dolphin
Month	Total Days	Total Hours	Total Min	Total DPH	Total DPM	% DPD	% DPH	% DPM	Total DPH	Total DPM	% DPD	% DPH	% DPM
Feb-09	27	633	37980	319	2622	100	50.395	6.904	0	0	0.000	0.000	0.000
Mar-09	25	580	34800	94	393	88	16.207	1.129	2	2	8	0.345	0.006
Total Monitoring Period	52	1213	72780	413	3015	94.231	34.048	4.143	2	2	3.846	0.165	0.003

```
##choose .csv file for analysis
file.choose()
names(mpt)
##reorder levels in variables for box plot
gb$Season=factor(gb$Season, levels=c("Spring", "Summer", "Autumn", "Winter"))
gb$Diel=factor(gb$Diel, levels=c("D","E","N","M"))
gb$Tidal.phase=factor(gb$Tidal.phase, levels=c("Trans.", "NT", "ST"))
gb$Tidal.cycle=factor(gb$Tidal.cycle, levels=c("E","L","F","H"))
##subset by year
gb2009=gb[which(gb$Year=="2009"), 1:19]
gb2010=gb[which(gb$Year=="2010"), 1:19]
gb2011=gb[which(gb$Year=="2011"), 1:19]
##run generalized linear mixed model with pod as random factor using DPH
library(lme4)
m1=glmer(NBHF.hour~Season+Diel+Tidal.phase+Tidal.cycle+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
m2=glmer(NBHF.hour~Season+Diel+Tidal.phase+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
m3=glmer(NBHF.hour~Season+Diel+Tidal.cycle+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
m4=glmer(NBHF.hour~Season+Tidal.phase+Tidal.cycle+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
m5=glmer(NBHF.hour~Diel+Tidal.phase+Tidal.cycle+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
m6=glmer(NBHF.hour~Season+Diel+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
m7=glmer(NBHF.hour~Season+Tidal.phase+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
m8=glmer(NBHF.hour~Season+Tidal.cycle+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
m9=glmer(NBHF.hour~Diel+Tidal.phase+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
m10=glmer(NBHF.hour~Diel+Tidal.cycle+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
m11=glmer(NBHF.hour~Tidal.phase+Tidal.cycle+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
m12=glmer(NBHF.hour~Season+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
m13=glmer(NBHF.hour~Diel+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
m14=glmer(NBHF.hour~Tidal.phase+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
m15=glmer(NBHF.hour~Tidal.cycle+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
##obtain summary stats of all model combinations to determine best fit
summary(m1)
## get predictions of DPH and plot as boxplot
library(aod)
pred=(predict(m1, terms="response"))
summary(pred)
gb2009$predict=pred
summary(gb2009$predict)
library(HH)
gb2009$predict=antilogit(gb2009$predict)
par(mfrow=c(2,2))
plot(gb2009$Season, gb2009$predict,xlab="Season", ylab="Predicted DPH")
plot(gb2009$Diel, gb2009$predict, xlab="Diel", ylab="Predicted DPH")
plot(gb2009$Tidal.phase, gb2009$predict, xlab="Tidal phase", ylab="Predicted DPH")
plot(gb2009$Tidal.cycle, gb2009$predict, xlab="Tidal cycle", ylab="Predicted DPH")
##wald test
m1=glmer(NBHF.hour~-1+Season+Diel+Tidal.phase+Tidal.cycle+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
library(aod)
(season.test<-wald.test(vcov(m1),attributes(m1)$fixef,Terms=1:4))
m1.2=glmer(NBHF.hour~-1+Diel+Tidal.phase+Tidal.cycle+Season+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
library(aod)
(diel.test<-wald.test(vcov(m1.2),attributes(m1.2)$fixef,Terms=1:3))
m1.3=glmer(NBHF.hour~-1+Tidal.phase+Tidal.cycle+Season+Diel+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
library(aod)
(tp.test<-wald.test(vcov(m1.3),attributes(m1.3)$fixef,Terms=1:3))
m1.4=glmer(NBHF.hour~-1+Tidal.cycle+Season+Diel+Tidal.phase+(1|POD.ID),family=binomial,data=gb2009,control=list(msVerbose=TRUE))
library(aod)
(tc.test<-wald.test(vcov(m1.4),attributes(m1.4)$fixef,Terms=1:4))
```

Figure 2: R-script for generalised liner mixed-effects model of long-term SAM data for presence-absence analysis

```
##choose .csv file for analysis
file.choose()
names(gb)
##reorder levels in variables for box plot
gb$Season=factor(gb$Season, levels=c("Spring", "Summer", "Autumn", "Winter"))
gb$Diel=factor(gb$Diel, levels=c("D","E","N","M"))
gb$Tidal.phase=factor(gb$Tidal.phase, levels=c("Trans.", "NT", "ST"))
gb$Tidal.cycle=factor(gb$Tidal.cycle, levels=c("E","L","F","H"))
##run generalized linear mixed model with pod as random factor using MinICI<10ms
library(lme4)
m1=glmer(X.10ms~Season+Diel+Tidal.phase+Tidal.cycle+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
m2=glmer(X.10ms~Season+Diel+Tidal.phase+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
m3=glmer(X.10ms~Season+Diel+Tidal.cycle+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
m4=glmer(X.10ms~Season+Tidal.phase+Tidal.cycle+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
m5=glmer(X.10ms~Diel+Tidal.phase+Tidal.cycle+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
m6=glmer(X.10ms~Season+Diel+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
m7=glmer(X.10ms~Season+Tidal.phase+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
m8=glmer(X.10ms~Season+Tidal.cycle+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
m9=glmer(X.10ms~Diel+Tidal.phase+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
m10=glmer(X.10ms~Diel+Tidal.cycle+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
m11=glmer(X.10ms~Tidal.phase+Tidal.cycle+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
m12=glmer(X.10ms~Season+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
m13=glmer(X.10ms~Diel+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
m14=glmer(X.10ms~Tidal.phase+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
m15=glmer(X.10ms~Tidal.cycle+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
## get predictions of DPH
library(aod)
pred=(predict(m1, terms="response"))
summary(pred)
gb$predict=pred
summary(gb$predict)
library(HH)
gb$predict=antilogit(gb$predict)
par(mfrow=c(2,2))
plot(gb$Season, gb$predict,xlab="Season", ylab="Predicted Foraging")
plot(gb$Diel, gb$predict, xlab="Diel", ylab="Predicted Foraging")
plot(gb$Tidal.phase, gb$predict, xlab="Tidal phase", ylab="Predicted Foraging")
plot(gb$Tidal.cycle, gb$predict, xlab="Tidal cycle", ylab="Predicted Foraging")
##wald test
m1=glmer(X.10ms~-1+Season+Diel+Tidal.phase+Tidal.cycle+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
library(aod)
(season.test<-wald.test(vcov(m1),attributes(m1)$fixef,Terms=1:4))
m1.2=glmer(X.10ms~-1+Diel+Tidal.phase+Tidal.cycle+Season+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
library(aod)
(diel.test<-wald.test(vcov(m1.2),attributes(m1.2)$fixef,Terms=1:3))
m1.3=glmer(X.10ms~-1+Tidal.phase+Tidal.cycle+Season+Diel+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
library(aod)
(tp.test<-wald.test(vcov(m1.3),attributes(m1.3)$fixef,Terms=1:3))
m1.4=glmer(X.10ms~-1+Tidal.cycle+Season+Diel+Tidal.phase+(1|POD.ID),family=binomial,data=gb,control=list(msVerbose=TRUE))
library(aod)
(tc.test<-wald.test(vcov(m1.4),attributes(m1.4)$fixef,Terms=1:4))
```

Figure 3: R-script for generalised liner mixed-effects model of long-term SAM data for behaviour analysis



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