Appendix A9.2 Marine Mammal Survey Investigation

Greater Dublin Drainage Project, Co. Dublin

Report on Marine Mammal Surveys

Final Report

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EXECUTIVE SUMMARY

A marine mammal survey using visual and static acoustic monitoring methodology was conducted between March 2015 and September 2015 off Loughshinny and March 2015 and March 2017 off Portmarnock, North Co. Dublin as part of the Greater Dublin Drainage (GDD) project. The study aimed to assess the distribution, habitat use, seasonal occurrence and behaviour of marine mammals in the study area and if possible derive density and abundance estimates for harbour porpoise.

Three integrated methods were used in line with best practice, these were land-based vantage point surveys, boat-based transects and Static Acoustic Monitoring. Visual surveys were only carried out in favourable weather conditions (Beaufort sea-state <2 and visibility >6km). Monthly land-based surveys were conducted from sites at Loughshinny and Howth Head. Single platform line-transect boat surveys were conducted bi-monthly following a pre-determined route and standardised design. Static acoustic monitoring using C-PODs was conducted for six months at a single site off Loughshinny and for 24 months at three locations off Portmarnock.

The software programme DISTANCE was used for calculating detection functions, which is the probability of detecting an object a certain distance from the track-line and used to calculate the density of animals on the track-line of the vessel. A detection function was calculated from each boat survey, providing sufficient number of sightings were made to provide a robust estimate.

All C-POD data were analysed using only high probability clicks, which reduced the possibility of false positives (i.e. recorded as present when there were in fact no dolphins or porpoise present). Harbour porpoise detections were extracted as detection positive minutes per day and were analysed statistically for temporal and geographical trends. Porpoise detections were analysed with respect to season (spring, summer, autumn and winter), diel cycle (day and night-time), tidal state (ebb, flood, slack high, slack low) and tidal phase (spring, neap) at a resolution of one hour. A Generalised Linear Mixed Model (GLMM) was fitted to the binomial data using the glmer function in the *lme4 package* developed for the statistical program *R*. Details of individual harbour porpoise click trains were extracted and analysed.

Six monthly land-based surveys were conducted from the Martello Tower at Loughshinny. Twenty hours of land-based monitoring was conducted over six survey days. The weather was favourable throughout all surveys with no swell, sea state ≤2 and visibility of 6-20km. Precipitation was recorded on two days in July and September. Marine mammals were sighted on 86% of land-based survey days with harbour porpoise present on 67% and seal species present on 67% of days. Eleven (11) sightings of harbour porpoise (23 individuals) and 12 seal sightings (12 individuals) were recorded. Ten (10) of the seal sightings were identified as grey seals while two could not be identified to species level. Harbour porpoise numbers peaked in September, however there was no peak in seal numbers.

Land-based survey effort conducted from Howth Head amounted to around 144 hours (23 surveys) between 18 March 2015 and 11 March 2017. Environmental conditions were favourable with no swell, sea-state <2 for 99% and visibility >6km for 97% of survey effort. Marine mammals were sighted on 100% of survey days with grey seals present on 100% and harbour porpoise present on 83% of days. Two-hundred and sixty (260) sightings of grey seals totalling 325 individual animals, comprising 323 adults and two juveniles, were recorded with an average group size of one individual. Sighting rate for grey seals was greatest in April 2015 although high numbers were also recorded in September 2015, January 2016 and October 2016. One-hundred and sixty-seven (167) sightings of harbour porpoise totalling 293 individual animals were recorded comprising 237 adults, 41 juveniles and 15 calves. Mean group size for harbour porpoise from land-based watches was two individuals. Calves were present between September and November 2015 and in August 2016. Harbour porpoise sighting rate was greatest between August and January 2015 and August and October 2016 with mean group size also increasing during this period.

A total of 897km of track-line was surveyed during eleven independent surveys, carried out from April 2015 to January 2017. Environmental conditions were favourable with visibility of >6km for 91% and swell of <1m for 100% of survey effort. Sea-state <2 was recorded for all of eight of the eleven surveys however sea-state of >2 was recorded for 8% of the survey carried out in April 2015, 36% in June 2015 and 46% during the December 2016. Marine mammals were sighted on all survey days with a total of 192 sightings of 251 individual animals. Four marine mammal species were recorded; harbour porpoise, grey seal, harbour seal and minke whale. Seals were recorded on 91% of survey days with the highest numbers of individuals recorded in November 2015. Grey seal sightings were distributed evenly across the study area and all sightings recorded were of single adults. Two harbour seals were sighted, one each in April and August 2015, both of which were of single adults. Single minke whales were recorded in June 2015 and August 2016. Harbour porpoise were recorded on 100% of survey days with the greatest number of sightings recorded in November 2015 and August 2016. Group size also increased between August and November 2015 and in August 2016 with calves recorded during these three surveys. The lowest number of sightings were in June 2015, June 2016 and December 2016.

Density estimates for harbour porpoises were calculated for seven of the eleven boat survey days but not for surveys in June 2015, March 2016, June 2016 and December 2016 as the total number of sightings during each survey were less than 10, which is considered too few to derive a reliable density estimate. Mean group size was greater in August 2015 and August 2016 compared to other surveys, suggesting a peak occurred in late summer, which was consistent with land-based observations. Within the area surveyed, the density of harbour porpoise varied from 0.61 to 2.29 per km^2 per survey with a mean density of 1.32 harbour porpoise per km^2, which is high for coastal sites in Ireland and similar to previous surveys in the area. Density estimates increased during summer and early winter (August-November) in 2015 and in August 2016, with lowest densities recorded in April 2015 and February 2016.

A total of 189 days of Static Acoustic Monitoring data was collected off Loughshinny. Harbour porpoise detections were recorded on 100% of days. The number of Porpoise Positive Minutes (PPM) ranged from 8 to 475 per day with a mean of 139 PPM. Results showed that season had a significant effect on the presence of porpoises at the site with a peak in autumn. Most porpoise detections were recorded during early morning suggesting they were more active at the site during night-time and in the early morning. Tidal cycle was not found to be a significant factor but tidal phase was, with highest detections during spring cycles. A total of 100,421 porpoise click trains were recorded at Loughshinny over the six month deployment, with 95% (95,509 trains) consistent with foraging, highlighting Loughshinny as a very important feeding site.

Static Acoustic Monitoring was carried out at three sites simultaneously off Portmarnock for a total duration of 750 days, between March 2015 and March 2017. All three sites were along the proposed route of the discharge pipe ranging from 2.5km (GDD1) to 5km (GDD3) offshore. Detections were recorded on average between 96-99% of days at each site. The number of PPM ranged from 3690 to 25089 per year between sites, with the mean ranging between 41.3 to 94.3 per day. The highest detection rate was recorded across the autumn and winter months, during the hours of darkness (incl. at dawn and dusk), during high tide and at the furthest offshore station (GDD3) during the neap cycle of the tidal phase. The site in the middle of the SAM array (GDD2) had the highest overall detection rate.

This survey, carried out over two years, using a range of survey techniques, has clearly demonstrated that North County Dublin is a very important area for marine mammals. The waters off Loughshinny are an important feeding area for harbour porpoise, especially during the autumn months, and at night and during early morning and spring tides. The area off Portmarnock is important for both grey seals and harbour porpoise, both of which were recorded throughout the year. Grey seals were regularly present in small numbers and distributed throughout the survey area. Peaks in sightings from Howth Head occurred during spring and autumn, coinciding with pupping and post-moult periods at the local well-known breeding and haul out sites at Lambay Island, Skerries and Irelands Eye. Harbour porpoise were also distributed throughout the site, with numbers increasing during late summer and autumn in both 2015 and 2016, which may be due to seasonally abundant food sources such as sprat, herring, *Trisopterus spp.* and gadoid species. Lower numbers were recorded during late spring/early summer (March-June) which may be linked to an offshore movement of this species before calving. Density estimates of harbour porpoise were high compared to coastal sites elsewhere in Ireland, and emphasizes the importance of this site for this species as these were some of the highest densities for this species recorded in Ireland to date. Static Acoustic Monitoring provided a high resolution (hourly) insight into the use of this habitat across time and throughout the day and night. Harbour porpoise were present almost daily at Portmarnock but were strongly influenced by seasonal, diel and tidal factors.

Harbour porpoises and grey seals are both listed on Annex II of the Habitats Directive and are thus entitled to strict protection, including their habitats. Extreme care must be taken to ensure the proposed development does not degrade this habitat or cause undue disturbance to marine mammals.

INTRODUCTION

The Irish Whale and Dolphin Group (IWDG) were sub-contracted by Techworks Marine to establish the extent and nature of marine mammals in north County Dublin in connection with the Greater Dublin Drainage (GDD) project. The GDD project proposes a new marine outfall pipe discharging 1km north-east of Ireland's Eye in north Dublin and 6km out to sea. The discharge is within the recently designated Rockabill to Dalkey Island Special Area of Conservation which lists harbour porpoise as a qualifying interest. The study aimed to assess the distribution, habitat use, seasonal occurrence and behaviour of marine mammals in the study area and derive density and abundance estimates for harbour porpoise. The results of this survey will be used to inform the most appropriate construction methodology for the marine outfall pipe while minimising any impacts on marine mammals. The survey commenced in March 2015 for two years within two defined study areas; i) Portmarnock and ii) Loughshinny. The Portmarnock site was monitored for two years while Loughshinny for six months from March 2015.

The survey used three independent methods: land-based, boat-based and Static Acoustic Monitoring (SAM) to ensure a robust assessment was carried out. This is in line with best practice which recommends a combination of visual and acoustic techniques especially if harbour porpoise (*Phocoena phocoena*) are known to occur in the area, as they can be very difficult to observe in even moderate sea conditions. Land-based observations were conducted from vantage points with a good field of view over the core study area, which avoided the possibility of disturbance and potential displacement during boat-based surveys (David, 2002). Boat-based line transect surveys were conducted to describe the broader -scale distribution and to derive density and abundance estimates. Boat-based surveys can cover a large area including sites which are difficult to observe from land even with good optics. However, all visual monitoring techniques can be influenced by variables such as sea-state (Evans and Hammond, 2004; Teilmann, 2003; Palka, 1996; Clarke, 1982), observer variability (Young and Peace, 1999), optics and height above sea level. Evans and Hammond (2004) recommended that visual surveys should generally not be carried out in sea-states above Beaufort 2, as the probability of detecting animals is markedly reduced above this. Static Acoustic Monitoring (SAM) is a very useful tool for monitoring small cetaceans since it can be carried out without these visual constraints, and does not influence their behaviour. SAM involves the detection and recording of odontocete vocalisations or echolocation clicks and is especially useful for defining fine-scale habitat use. Additionally, SAM can be used to study behaviour, such as foraging, approach behaviour and communication. SAM however is spatially constrained as the detection distance for harbour porpoise can be as little as 200-300m and it cannot provide information on density or abundance but can provide robust information on spatial and temporal trends. This report provides a detailed exploration of marine mammal activity off Loughshinny Co. Dublin over a 6-month period and Portmarnock Co. Dublin over a 24-month period.

METHODS

2.1 Study Area

The study area in north County Dublin, where the proposed outfall pipe will be constructed and operated is adjacent to a number of high nature conservation sites for marine mammals, protected under EU legislation. One of the three Special Areas of Conservation (SACs) which include harbour porpoise as a qualifying interest; occurs within the study area. Rockabill to Dalkey Island SAC (Site Code: 003000) was designated in 2012 while Lambay Island SAC (Site Code: 000204) with both grey and harbour seal as qualifying interests also lies within the study area (Figure 1). The boundaries of the current survey included both these protected sites and adjacent waters including the route of the proposed outfall pipe.

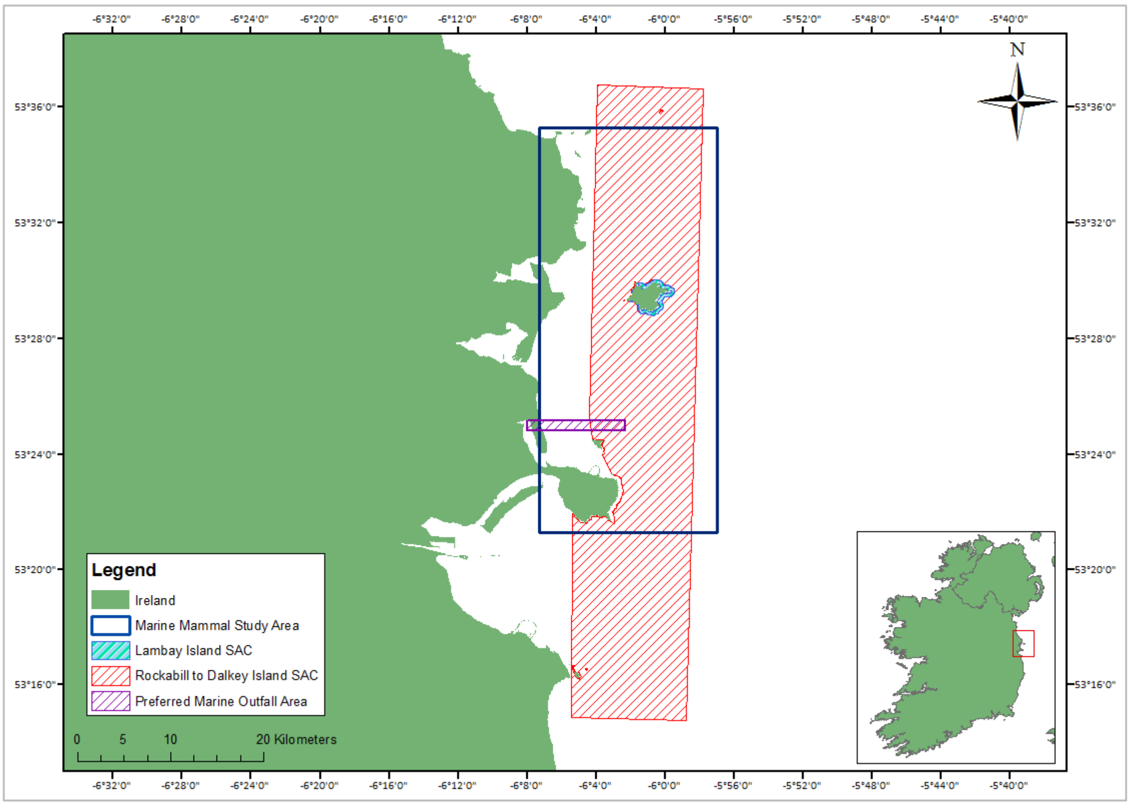


Figure 1. Study area for GDD Marine Mammal Surveys showing the GDD Preferred Marine Outfall Area and SACs within the Study Area ©National Parks and Wildlife Services SAC

2.2 Land-based Surveys

2.2.1 Land-based Observation Site

Land based observations were carried out from the Martello Tower at Loughshinny and from the north-eastern cliffs of Howth Head. Both sites were selected as a suitable vantage points for land-based observations based on their height above sea level and the field of view over the survey area (Figure 2).

Figure 2. Location of Loughshinny and Howth Head land-based survey sites

2.2.2 Land-based Methodology

Land based observations were carried out for a duration of six months from Loughshinny and 24 months from Howth Head. Quantified effort watches, where time spent watching and weather conditions are recorded, were carried out once a month during suitable weather conditions defined as Beaufort sea-state <2 and in visibility of >6km. Each watch lasted for 420-560 minutes (7-8 hours) and were carried out in 100 minute samples in accordance with IWDG standardised methodology for their Inshore Cetacean Monitoring Programme (Berrow et al. 2010). Two observers were present at the observation site to maximise search effort and assist in tracking as well as compliance with health and safety.

Visual observations were made using a tripod-mounted scope (Opticron) equipped with a 20-60x wide-angle eyepiece and handheld binoculars (7 x 50; Opticron). Environmental conditions (sea-state, wind and weather variables) were recorded at the start of each observation and every 30 minutes throughout the watch or when weather conditions changed. During watches, two types of visual observations were conducted: scan sampling and focal follow observations (Mann, 1999).

2.2.2.1 Scan Sampling

During scan sampling, the study area (up to 5km from the observation site) was systematically scanned using the telescope (observer 1) and binoculars (observer 2). For each sighting species, group size, group composition, location, direction of travel and behaviour were recorded. The geographical location of each sightings was recorded using a T107 Leica theodolite or, when the use of the theodolite was restricted, by estimating distance (km) and bearing (degrees) from the observation site using reticule binoculars.

2.2.2.2 Focal Follow Observations

Harbour porpoise were tracked using a T107 Leica theodolite to determine their habitat use. During each surfacing the group size, composition, location and direction of travel were recorded along with the behaviours described by Mann (1999). Focal follow observations or tracks began at the first sighting of harbour porpoise and continued for as long as possible. Tracks ended when individuals either moved out of sight, weather conditions deteriorated or when darkness fell. If the use of the theodolite was restricted, location was determined by estimating distance (km) and bearing (degrees) from the observation site using reticule binoculars.

2.3 Boat-based Surveys

Conventional single line-transect marine mammal surveys were carried out aboard MV *Beluga* along a predetermined route. Four different routes were used; surveys 1-4 included coverage of the waters off Loughshinny while surveys 5-11 targeted the Portmarnock area after surveys had been completed off Loughshinny (Figure 3).

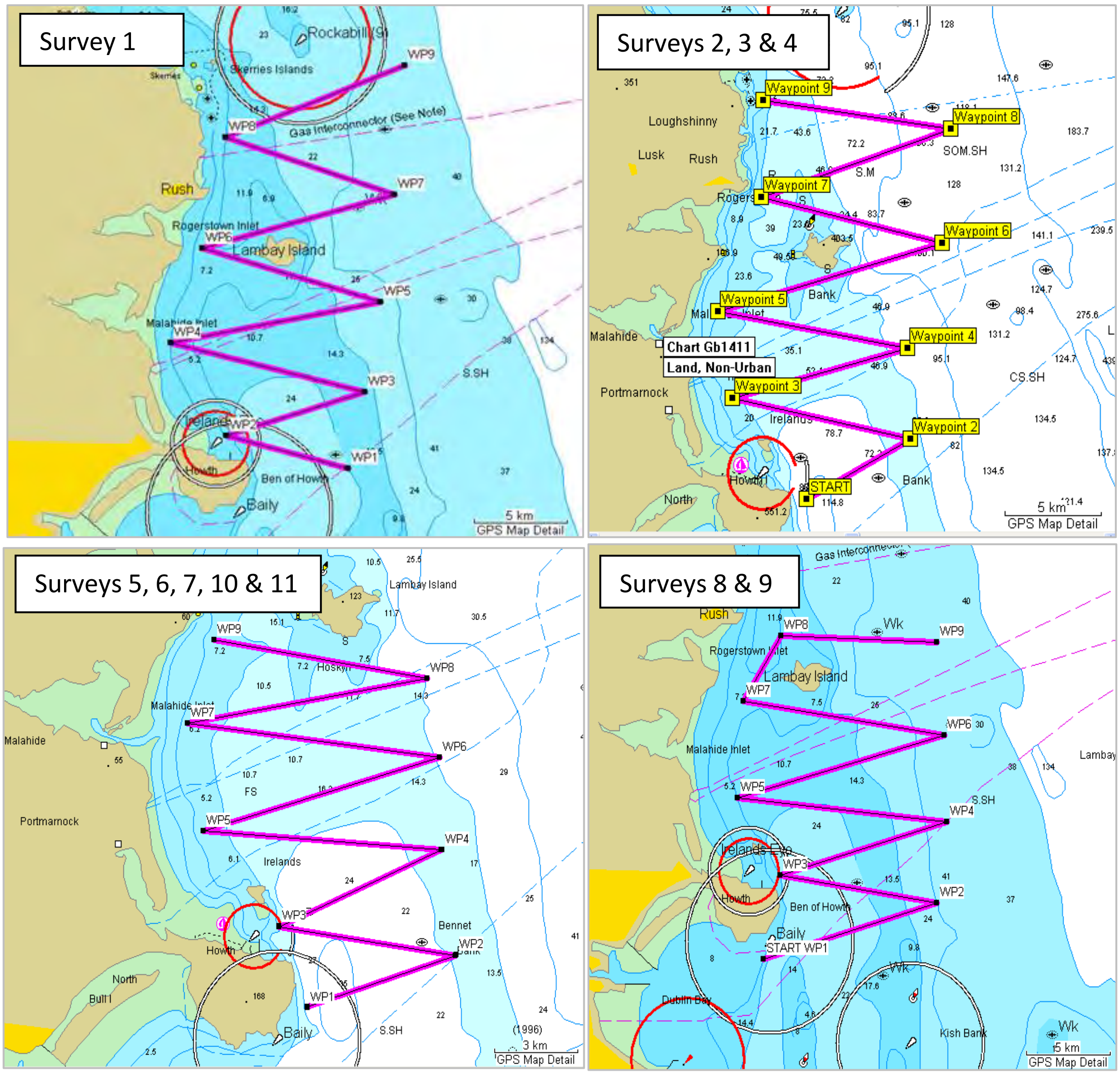


Figure 3. Line Transect Route for boat-based marine mammal surveys

2.3.1 Line Transect Methodology

Single platform line transect surveys were conducted every two months onboard a 13m cruiser with flying bridge, MV *Beluga* which has a platform height of 3.1m. Surveys were carried out in sea-state ≤2 and in visibility ≥6km. The vessel travelled at a speed of 9-10 knots, which was 2-3 times the typical average speed of the target species as recommended by Dawson et al. (2008). This helped minimise any potential missed sightings due to avoidance behaviour.

Three people were required on each survey; two primary observers and one operating the software programme LOGGER (©IFAW). The primary observers were positioned on the flying bridge, which provided an eye-height above sea-level of between 4-5m depending on the height of the observer. Primary observers scanned with the naked eye from dead ahead to 90º to port or starboard depending on which side of the vessel they were positioned. During all transects, the position of the survey vessel was tracked continuously through a GPS receiver fed directly into LOGGER software via a laptop. Survey effort, including environmental conditions (sea-state, wind strength and direction, glare etc.) were recorded directly onto LOGGER every 15 minutes.

When a sighting of a marine mammal was made, the position of the vessel and the angle and distance of the sighting from the track of the vessel were recorded. The angle to the sighting from the vessels course was recorded via an angle board attached to the vessel immediately in front of each observer. Binoculars (Opticron 10x50 Marine, with graduated reticle) or a range-finder stick (JNCC approved) were used to estimate distance to sighting, while the binoculars were used to confirm species identification, group numbers, composition and behaviour. This data was communicated to the LOGGER operator in the wheelhouse via a VHF radio. The team of three observers rotated positions between each side of the vessel and LOGGER every hour to avoid bias on one side of the track line or a decline in sighting detections due to fatigue.

2.4 Static Acoustic Monitoring

2.4.1 Study Area

Two CPODs were moored in one site (one as a control) around 3km east of Loughshinny, Co. Dublin and approximately 6km north of Lambay Island (Figure 4). Additional deployments took place off Portmarnock, Co. Dublin just north of Ireland's Eye. Three locations, (GDD1, GDD2 and GDD3) were monitored here with GDD1 closest to land at 2.5km offshore, GDD2 was 1km to the east of GDD2, while GDD3 was a further 1.5 km from GDD2 and thus 5km offshore (Figure 4).

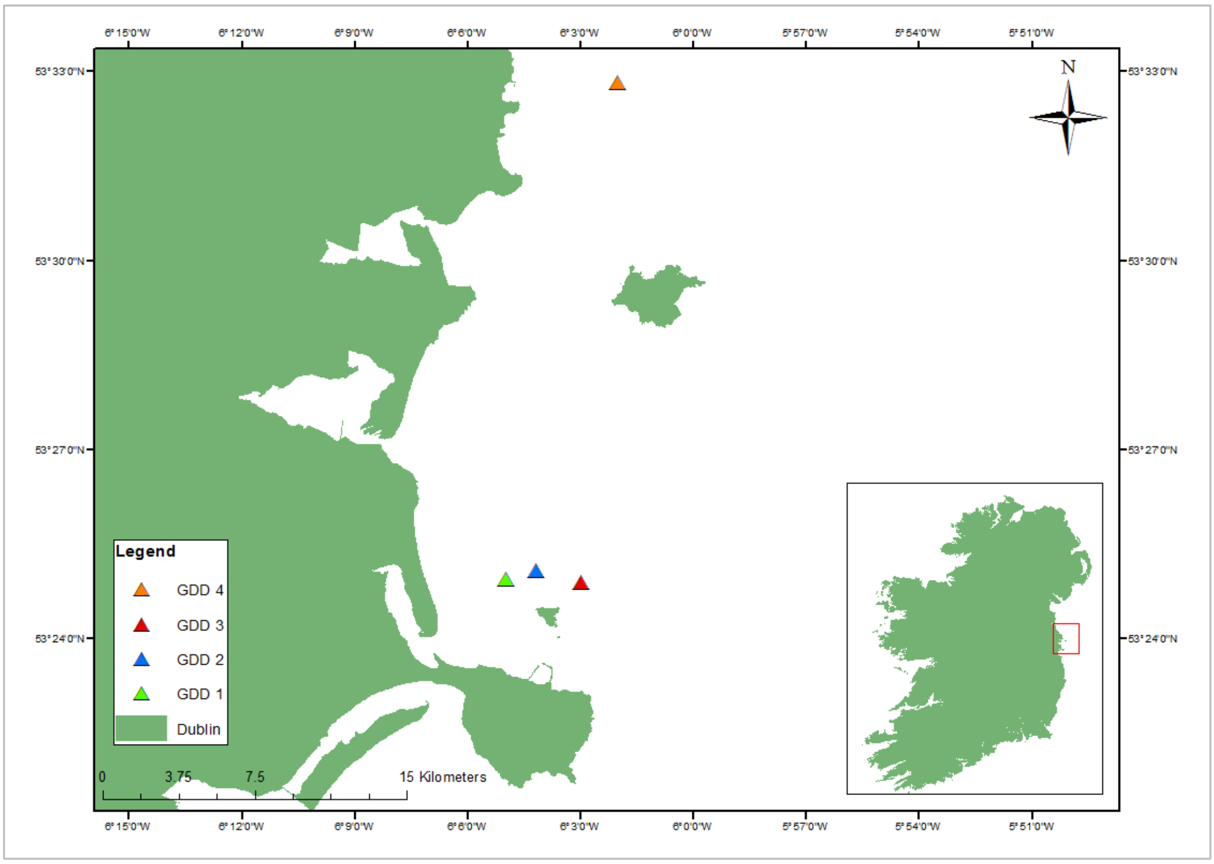


Figure 4. Map of deployment locations of C-PODs off Portmarnock (GDD1, GDD2 and GDD3) and Loughshinny (GDD4)

2.4.2 Static Acoustic Monitoring (SAM) Equipment

2.4.2.1 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 (Figure 5). 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 extraction of data files under pre-determined parameters, as set by the user. C-PODs also record temperature at its deployment depth. It should be noted that the C-POD does not record actual sound files, only information about the tonal clicks it detects. The C-POD is a sound pressure level detector with a threshold of 1Pa peak to peak at 130 kHz, with the frequency response shown below (Figure 6, www.chelonian.co.uk). An estimated detection distance of 797.6m ±61m (75% of groups recorded<400m) for C-PODs and bottlenose dolphins was generated in the Shannon Estuary, while distances estimates of 441m ±42m (92% <400m) were calculated for harbour porpoise in Galway Bay (O'Brien et al., 2013).

Figure 5. C-POD unit by Chelonia Ltd

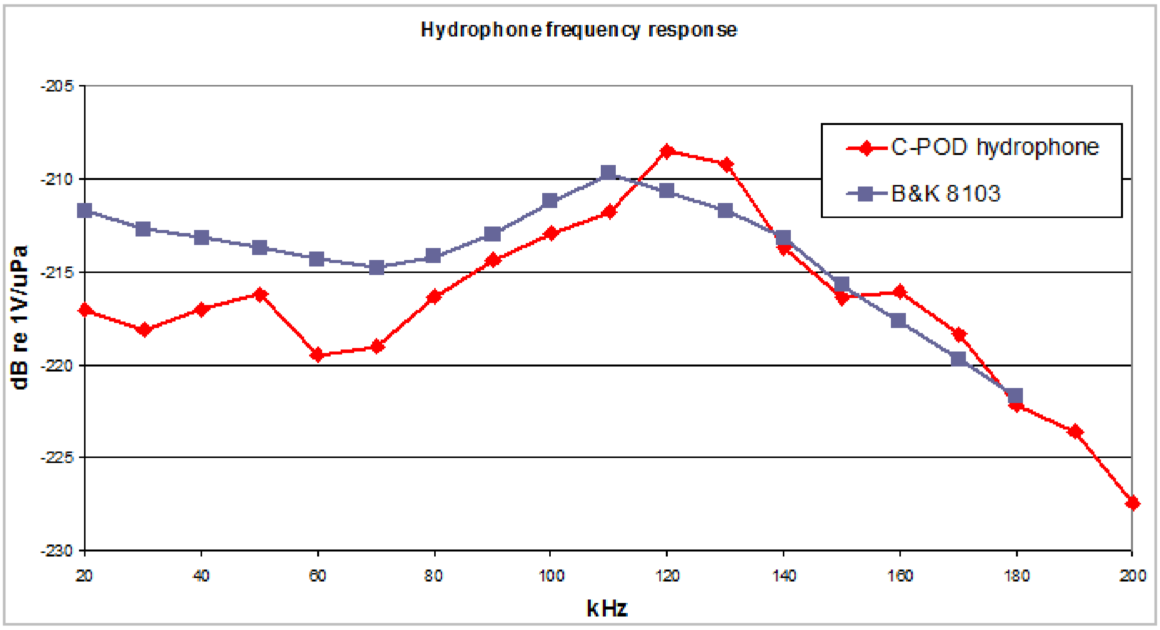


Figure 6. Threshold for detection across various frequency bands between 20 and 200 kHz for the C-POD (note 1Pa p-p is the SI unit for pressure and correctly represents the threshold) © Chelonia Ltd.

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 C-POD.exe software includes automatic click train detection, which is continually evolving as Chelonia Ltd receives more feedback from their clients. 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 2.044 (October, 2014) was used for all analyses. C-POD.exe software allows the user to extract click trains under five classification parameters but only the porpoise like category was used for this analyses of the long-term dataset (Figure 7).

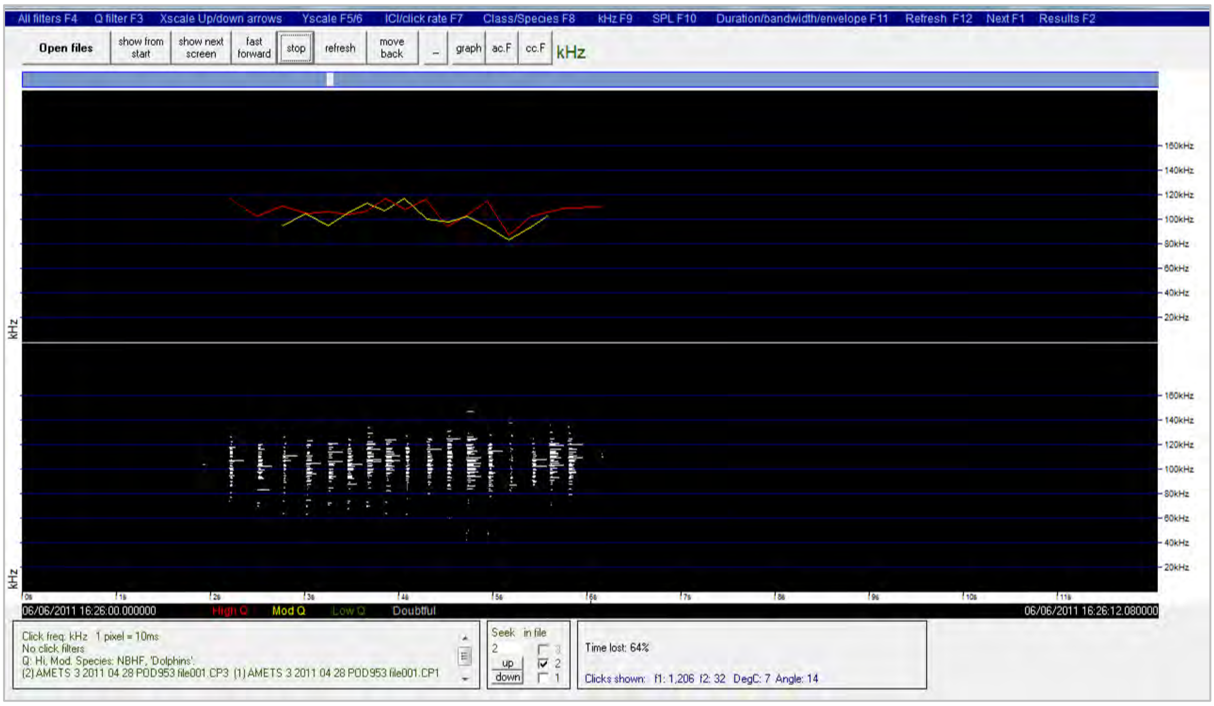


Figure 7. Screen grab of C-POD.exe, showing a harbour porpoise click train

2.4.3 C-POD Calibration

Calibration of C-PODs is important in order to facilitate a comparison of acoustic detection results collected by different units across various locations. 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, Chelonia Ltd., *pers. comm.*). Field calibrations are especially important where projects use 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 C-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, to allow for the generation of correction factors which can be applied to the resulting data. Field trials should be carried out in high density areas in order to determine the detection function (O'Brien et al. 2013). The field calibration of new units should be carried out in conjunction with a reference C-POD, where a single unit is used solely for calibrations and is deemed a reference. This allows for the incidence where new units are acquired over the course of a project to be calibrated with the reference.

All units used to carry out SAM during the present project were deployed together in the Shannon Estuary prior to monitoring. C-PODs 549, 795, 796,950 and 1524 were deployed for a total of 13 days (Figure 33), and a second deployment consisting of C-PODs 169, 172, 173, 487 and 1147 for a total of 23 days (Figure 34). This allowed enough time to establish if sensitivity would be a confounding factor between units before been deployed as part of the present study.

Upon recovery of the units during monitoring, data were extracted under two categories, 1) NBHF (porpoise band) and 2) Other (dolphin band) using the C-POD.exe software (Version 2.044, October, 2014). These data were in the form of Excel.xlsx files using C.POD.exe software and analysed as Detection Positive Minutes (DPM) across hourly segments. Statistical analyses were carried out using the program *R* (R Development Core Team, 2011). All combinations of C-POD pairs were modelled using an orthogonal regression of DPM across hourly segments. This was compared to a null model, assuming no variation in C-POD detections, a = 0 and b = 1, and used to assess C-POD performance. An error margin of ±20% DPM per hour was plotted along the null model to distinguish between an acceptable level of variation in C-POD performance and problematic variation due to faulty or highly sensitive units (Tregenza *pers comm.).* From these graphs it is possible to determine successful or unsuccessful C-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 0 on the horizontal axis, of mean intercept values and deviation from 1 on the horizontal axis, of mean gradient values indicated deviations from the null model. This was also used to identify if only one or two POD combinations were unsuccessful and also the extent of variability within the intercept and gradient values. Results were then used to highlight poor performing units or very sensitive units, if they existed and a correction factor can be generated and applied to the data.

2.4.4 Moorings

C-PODs were deployed as part of Techworks Marine's heavy weight mooring systems deployed to monitor current and turbidity over the same duration (Figure 8).

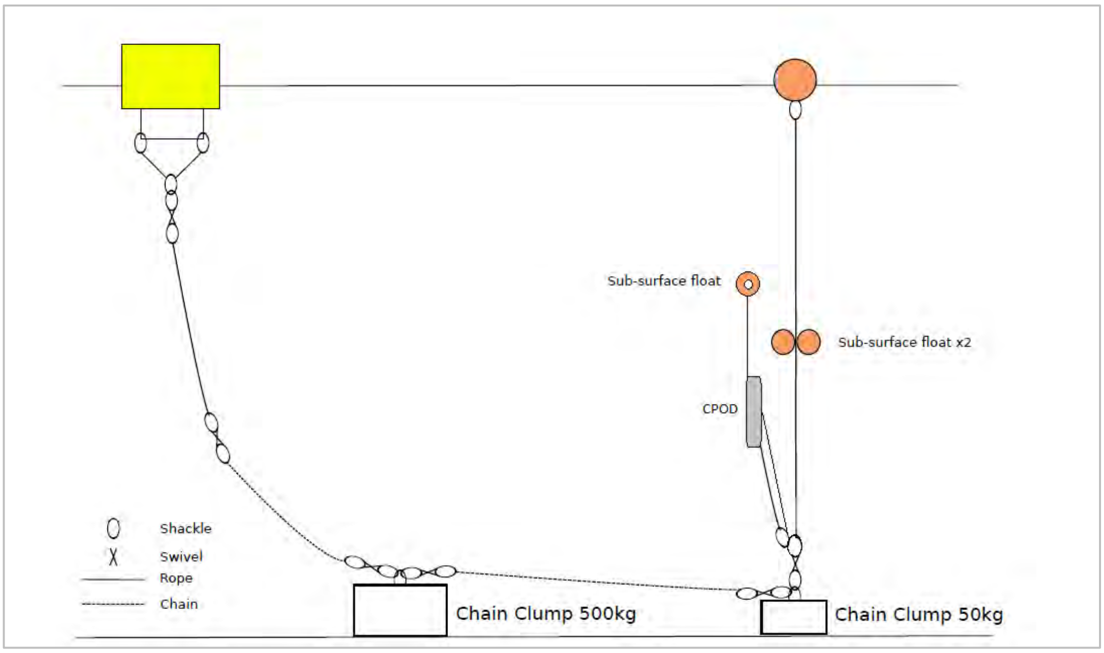


Figure 8. Heavy weight mooring deployed with C-POD attached (image updated from TechWorks Marine mooring diagram)

2.5 Data Analysis

2.5.1 Visual Observations

Visual survey data for land and boat-based surveys (i.e. sighting, effort and weather information) was compiled into a *Microsoft Access* database and *Microsoft Excel*. Maps of study areas and marine mammal sightings were created with ArcMap 10.2.

2.5.1.1 Density and abundance estimation

Distance sampling was used to derive a density estimate and to calculate a corresponding abundance estimate for the study area where possible. The software programme DISTANCE (Version 5, University of St Andrews, Scotland) was used for calculating the detection function, which is the probability of detecting an object a certain distance from the track-line. The detection function was used to calculate the density of animals on the track-line of the vessel. During this survey, we assume that all animals on the track-line were observed, i.e., that g(0) = 1, which is not correct but testing this would require a double platform survey which is not practical at small coastal sites. This assumption is consistent with previous small scale coastal sites in Ireland (see Berrow et al. 2014), to enable comparisons across sites. The DISTANCE software allows the user to select a number of models in order to identify the most appropriate for the data. It also allows truncation of sighting outliers when estimating variance in group size and testing for evasive movement prior to detection.

To calculate density, “day” was used as the sample regime with sightings used as sampling observations. Estimates of abundance and density obtained via the DISTANCE modelling process are presented for each survey day. The overall pooled abundance/density estimate was derived from data from both survey days combined. This was necessary in order to obtain sufficient sightings for a robust estimate using the DISTANCE model (the minimum required is 40—60; Buckland *et al.* 2001). In conducting this pooled analysis, we assumed that there were no significant changes in distribution within each site between sample days or any immigration into or emigration out of the site.

The data were fitted to a number of models available in the DISTANCE software. The Half-Normal model with cosine adjustments was found to best fit according to the Akaike Information Criterion delivered by the model. The recorded data were grouped into equal distance intervals of 0-25m, 25-50m up to 200m for the first survey and 0-30m, 30-60m up to 300m for the second survey and both surveys combined. The DISTANCE model determines the influence of cluster size on variability by using a size-bias regression method with the log(n) of cluster size plotted against the corresponding estimated detection function g(x).

A Chi-squared test associated with the estimation of each detection function is delivered by the DISTANCE model. If found to be statistically significant it indicated that the detection function was a good fit and that the corresponding estimates were robust. The proportions of the variability accounted for by the encounter rates, detection probability and group size (cluster size) are presented with each detection function. Variability associated with the encounter rate reflects the number of sightings on each track-line. The detection probability reflects how far the sightings were from the track-line and cluster size reflects the range of estimated group sizes recorded on each survey.

2.5.2 Static Acoustic Monitoring

All C-POD data were analysed using only high probability clicks. Both dolphin and porpoise detections were extracted as detection positive minutes per day (DPM), but only porpoise detections were analysed statistically. Dolphin detections were present but upon visual validation were found to be false positives. False positives are very short click trains, similar to a dolphin echolocation click train and can occur due to background sounds in the marine environment. As recommended by the manufacturers, a validation overview was carried out on the data, where 10% of all detected trains were visually inspected on cpod.exe to verify they were rightly assigned to harbour porpoise. Of this 10%, 1% of trains were classified as false positives, and therefore analysis of the porpoise detections proceeded with the classification of hourly variables into the following categories; season (spring, summer, autumn and winter), diel cycle (day and night-time), tidal state (ebb, flood, slack high, slack low) and tidal phase (spring, neap). The term PPM represents the number of minutes in a day or an hour that harbour porpoises were acoustically detected. Seasonal categorisations were assigned according to the seasons spring (February, March, April), summer (May, June, July), autumn (August, September, October) and winter (November, December, January). Data files in the format porpoise minutes per hour (PPM/h) were classified into day and night-time categories using local times of sunrise and sunset times, obtained from the U.S. Naval Observatory, who provide the sun rise and sunset data in a readily available format (www.aa.usno.navy.mil/data/docs/RS). Hourly data segments were further categorised into each of the four tidal states, where three hours were assigned to each state (one hour either side of the hour). Files were further split to correspond with tidal phase (spring and neap cycles) using admiralty data (WXTide 32) where two days either side of the highest tidal height was deemed spring, and two days either side of the least difference in tidal height between high and low tide was deemed neap, all other days were classified as transitional.

All data were analysed using the program *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. The effective programming language includes conditionals, loops, user-defined recursive functions and input and output facilities. A Generalized Linear Mixed-effect Model (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 further 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 Porpoise Positive Hours (PPH) were extracted across all levels and displayed as box plots using the HH package developed for *R*.

RESULTS

3.1 Land-based observations

Land-based monitoring was carried out monthly from 18 March 2015 until 11 March 2017. Just under 144 hours of monitoring was conducted over 23 independent surveys. Half day surveys were carried out from March to 07 September 2015 when Loughshinny was also surveyed in the same day. Full days surveys off Howth Head commenced on 19 September 2015.

3.1.1 Environmental Conditions

Environmental conditions were favourable during nearly all of the land-based surveys. Swell of less than 1m was recorded on 100% of survey days. Sea-state 0 was recorded for 23% of total survey effort, sea-state 1 for 54%, sea-state 2 for 21% and sea-state 3 for 1% (Figure 9). Visibility of 1-5km was recorded for 3% of total survey effort, 6-10km for 21%, 11-15km for 7%, 16-20km for 36% and greater than 20km for 32% (Figure 10).

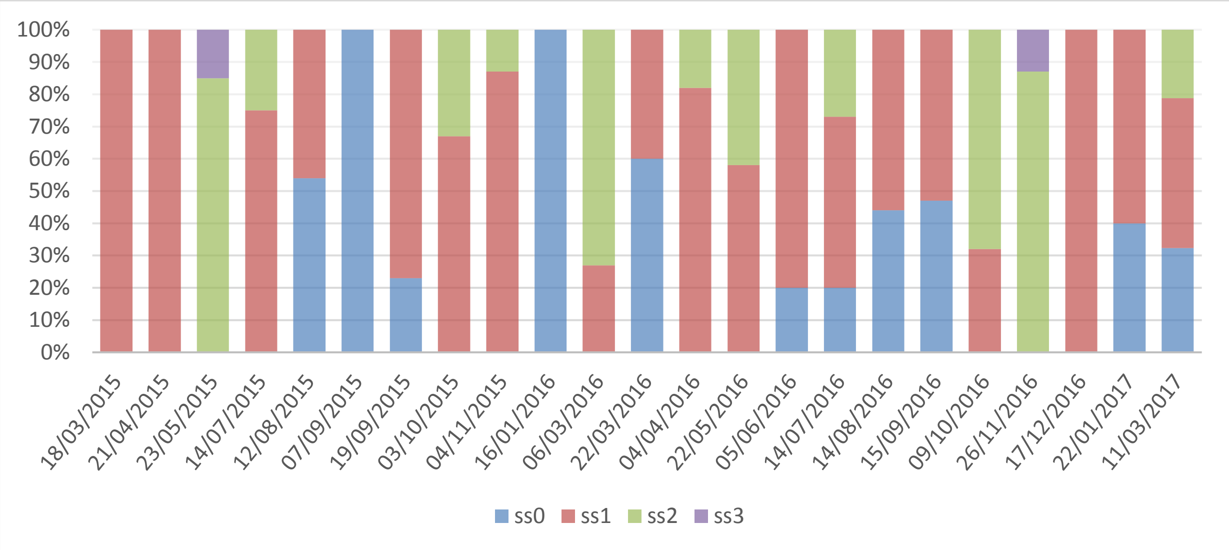


Figure 9. Beaufort Sea-state (%) recorded during land-based surveys from Howth Head

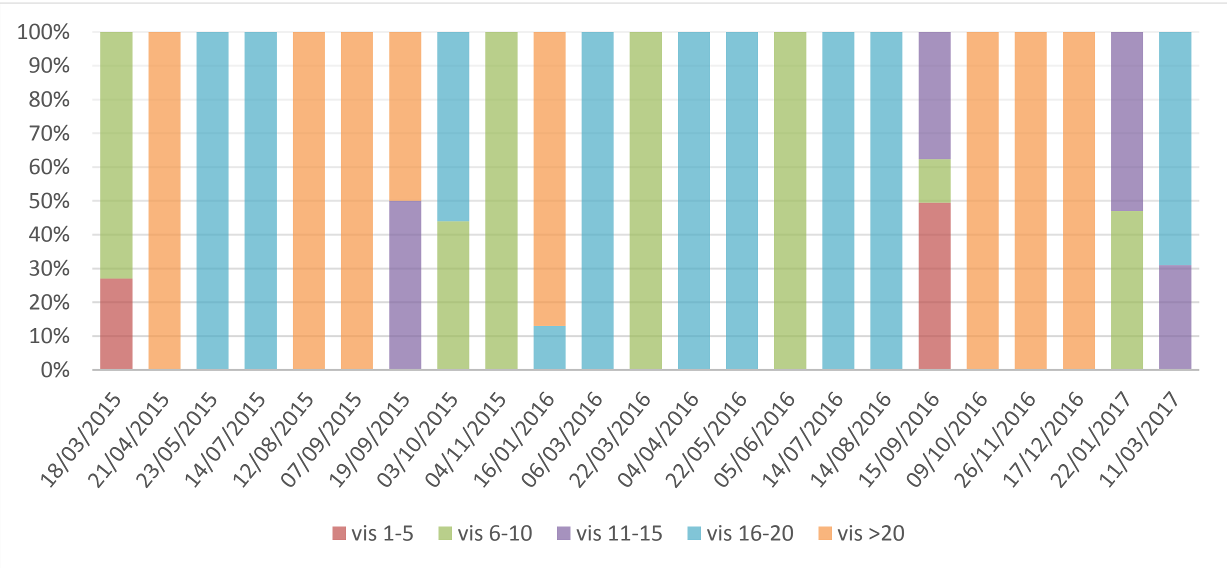


Figure 10. Percentage visibility (km) recorded during land-based surveys from Howth Head

3.1.2 Scan sampling marine mammal sightings

Marine mammals were sighted on 100% of survey days with harbour porpoise present on 83% and seals present on 100% of days. A total of two marine mammal species were recorded during the survey period; harbour porpoise and grey seal.

3.1.2.1 Harbour Porpoise

One hundred and sixty-seven (167) sightings of harbour porpoise were recorded totalling 293 animals (Table 1). A total of 237 adults, 41 juveniles and 15 calves were recorded and sightings had an average group size of two animals. Calves were only recorded between September and November 2015 and in August 2016.

Table 1. Summary of harbour porpoise sightings recorded during Howth Head land-based observations. Grey shaded rows show half-day surveys.

Date	No. sightings	No. animals	Adults	Juveniles	Calves	Range of group size
18/03/2015	0	0	-	-	-	-
21/04/2015	2	3	3	-	-	1-2
23/05/2015	0	0	-	-	-	-
14/07/2015	0	0	-	-	-	-
12/08/2015	1	4	3	1	-	-
07/09/2015	6	18	11	2	5	2-4
19/09/2015	15	28	22	1	5	1-5
03/10/2015	3	6	4	1	1	1-3
04/11/2015	11	19	14	3	2	1-5
16/01/2016	11	29	23	6	-	1-12
06/03/2016	2	2	2	-	-	1
22/03/2016	6	7	6	1	-	1-2
04/04/2016	0	0	-	-	-	-
22/05/2016	4	5	5	-	-	1-2
05/06/2016	1	2	2	-	-	-
14/07/2016	7	13	13	-	-	1-3
14/08/2016	43	66	59	5	2	1-3
15/09/2016	8	14	12	2	-	1-3
09/10/2016	31	60	43	17	-	1-4
26/11/2016	1	1	1	-	-	-
17/12/2016	5	5	5	-	-	1
22/01/2017	4	5	3	2	-	1-2
11/03/2017	6	6	6	-	-	1
TOTAL	**167**	**293**	**237**	**41**	**15**	

Sighting rate was calculated as the number of sightings and number of animals per hour of effort in order to compare the half day and full day surveys. Harbour porpoise sighting rate was consistently higher during late summer and autumn, between August and January 2015 and August and October 2016 (Figure 11). Group size also increased during this period (Table 1).

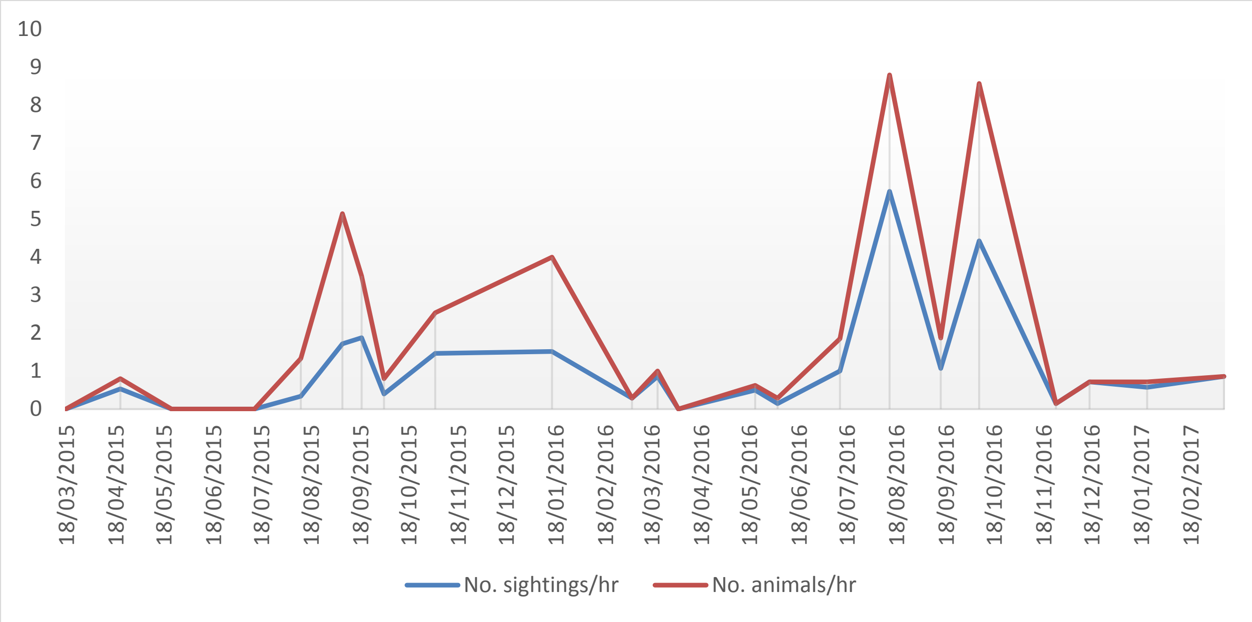


Figure 11. Harbour porpoise sighting rate for Howth Head land-based surveys

The greatest number of the harbour porpoise sightings were recorded to the northeast of the observation site, where animals were often recorded swimming in a tidal current close to the cliffs (Figure 12).

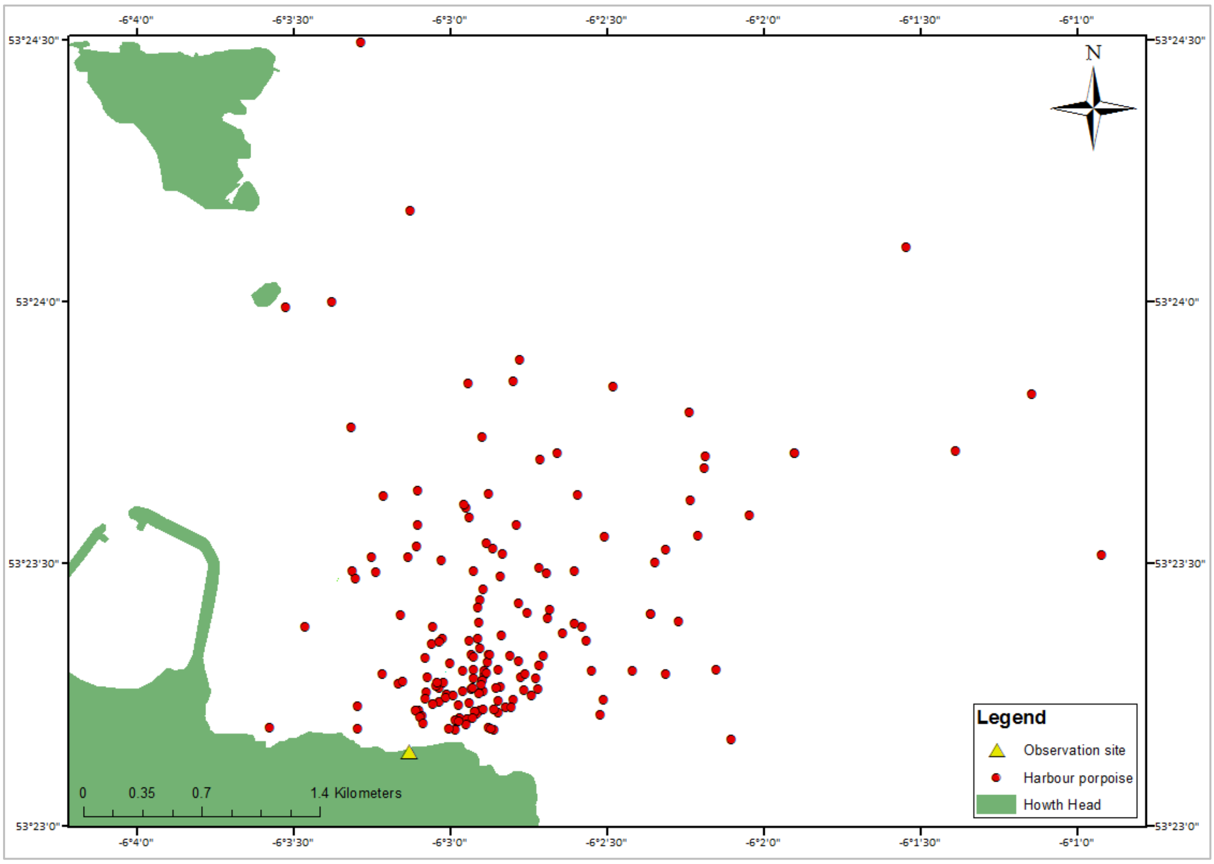


Figure 12. Distribution of harbour porpoise sightings off Howth Head

3.1.2.2 Grey seals

Two hundred and sixty (260) sightings of grey seals were recorded totalling 325 animals. A total of 323 adults and two juveniles were recorded and sightings had an average group size of one animal.

Sighting rate for grey seals was more consistent over the survey period with less consistent peaks. Rate was greatest in April 2015 although high numbers were also recorded in September 2015, January 2016 and October 2016. Group size also increased during this time (Figure 13).

Grey seal distribution was more westerly than harbour porpoise and individuals were often recorded feeding within close proximity to the northern cliffs of Howth Head (Figure 14).

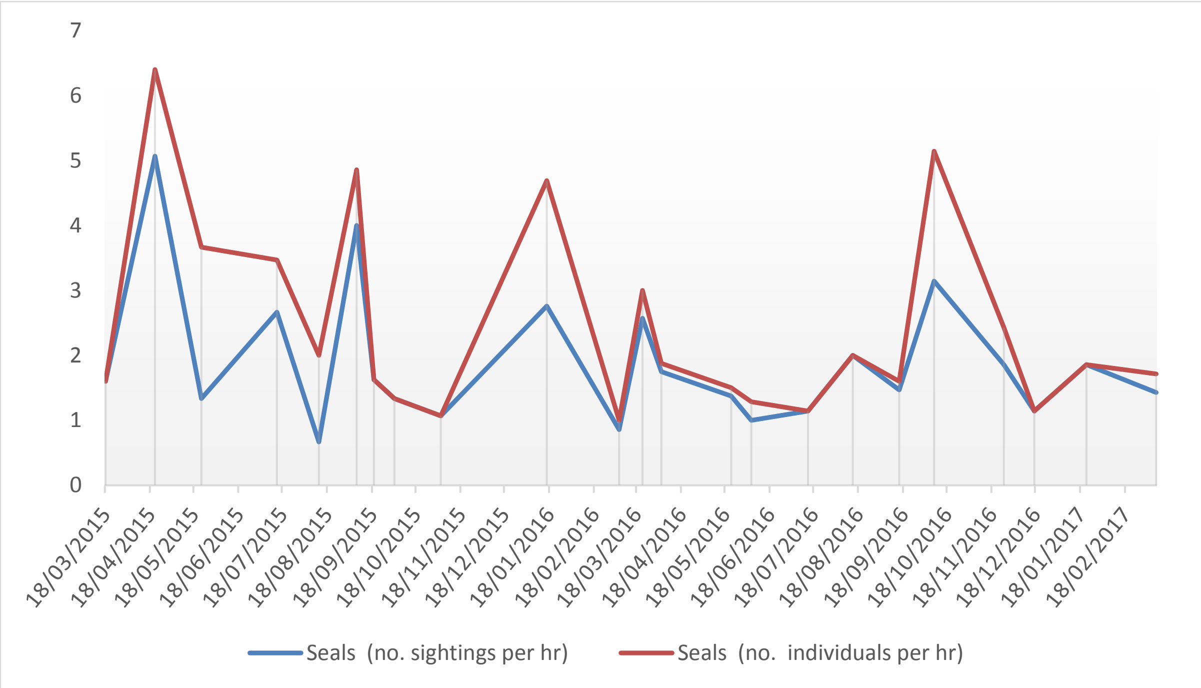


Figure 13. Grey seal sighting rate for Howth Head land-based surveys

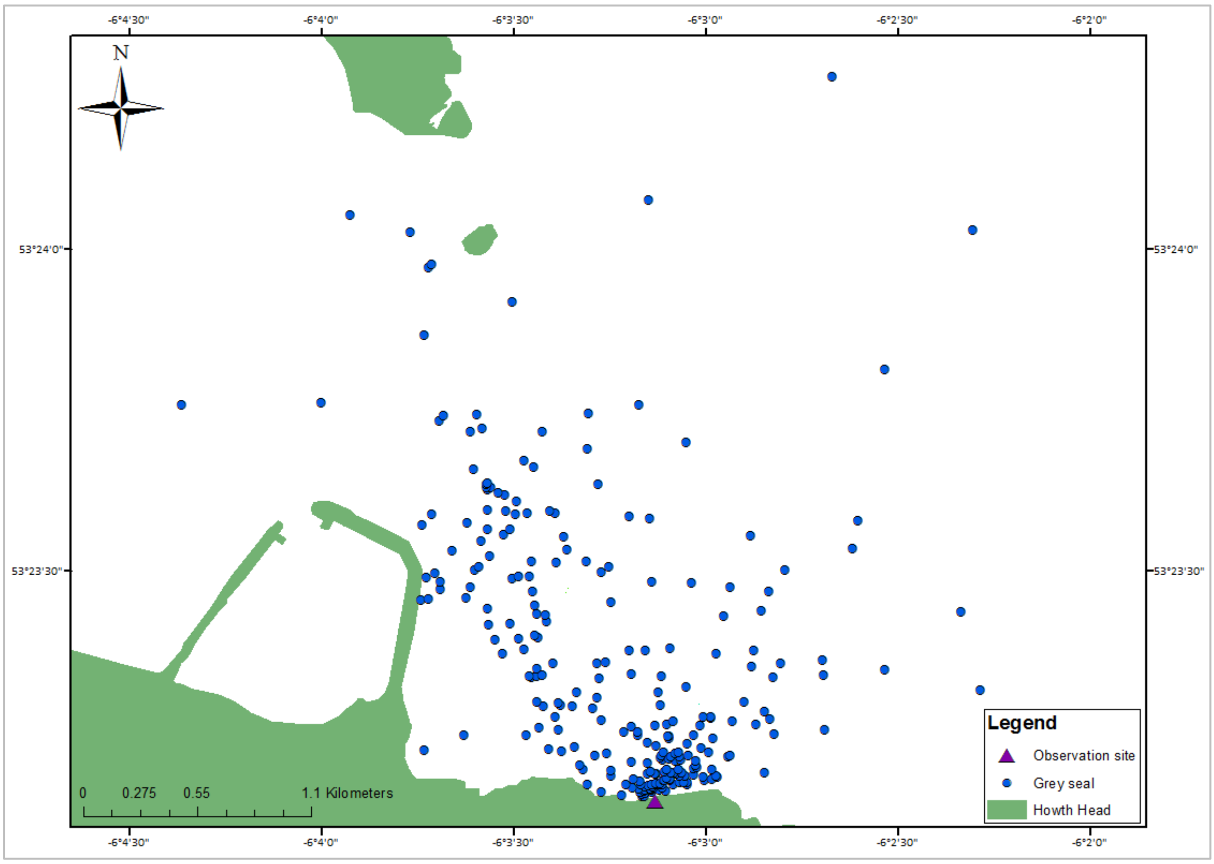


Figure 14. Distribution of grey seal sightings off Howth Head

3.1.2.3 Focal Follow Observations

When possible, harbour porpoise were tracked during each surfacing event to gain an understanding of their behaviour. Four focal follows were obtained over four days in September 2015, March 2016 and January and March 2017. In September 2015, a group of harbour porpoise comprising of two adults and one calf was tracked for 20 minutes. Single adult harbour porpoise were tracked for 59 minutes in March 2016, 24 minutes in January 2017 and 53 minutes in March 2017. With the exception of March 2016, all focal follows tracked harbour porpoise in a visible tidal current on the northwest coast of Howth Head (Figure 15).

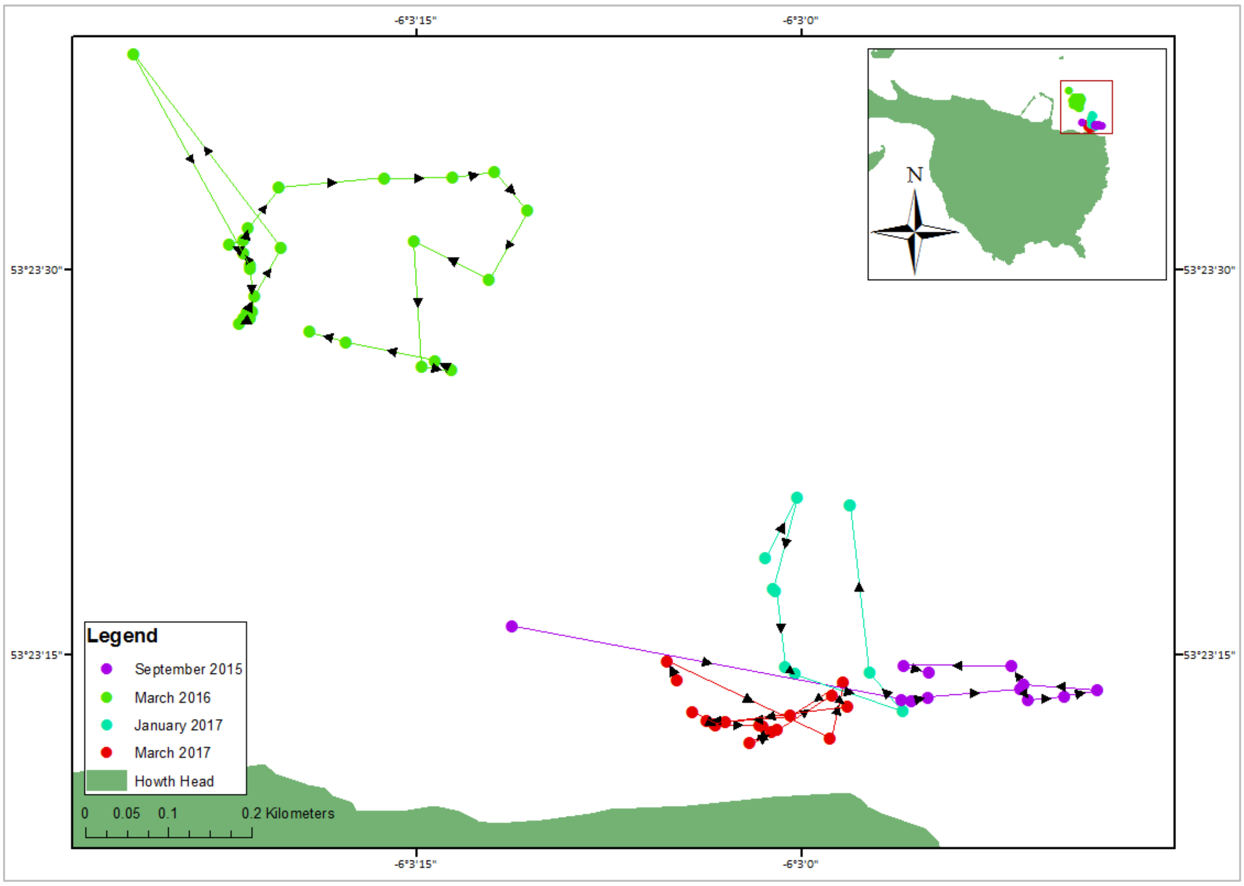


Figure 15. Focal follow tracking of harbour porpoise from the Howth Head site during 2015, 2016 and 2017

3.2 Boat-based surveys

Eleven boat-based marine mammal surveys were conducted onboard MV *Beluga* from April 2015 to January 2017 (Table 2). Track-lines were staggered to provide good coverage of the site and to ensure all habitats were surveyed (see Figure 3).

3.2.1 Environment

Environmental conditions were generally favourable throughout the boat-based surveys. Swell of less than 1m was recorded for 100% of survey effort. Visibility was greater >6km with the exception of the November 2015 where visibility was reduced to >3km due to sea fog. Sea-state of >2 was recorded for 8% during April 2015, 36% during the June 2015 survey and 46% during the December 2016 where sea-state was greater than forecast (Figure 16).

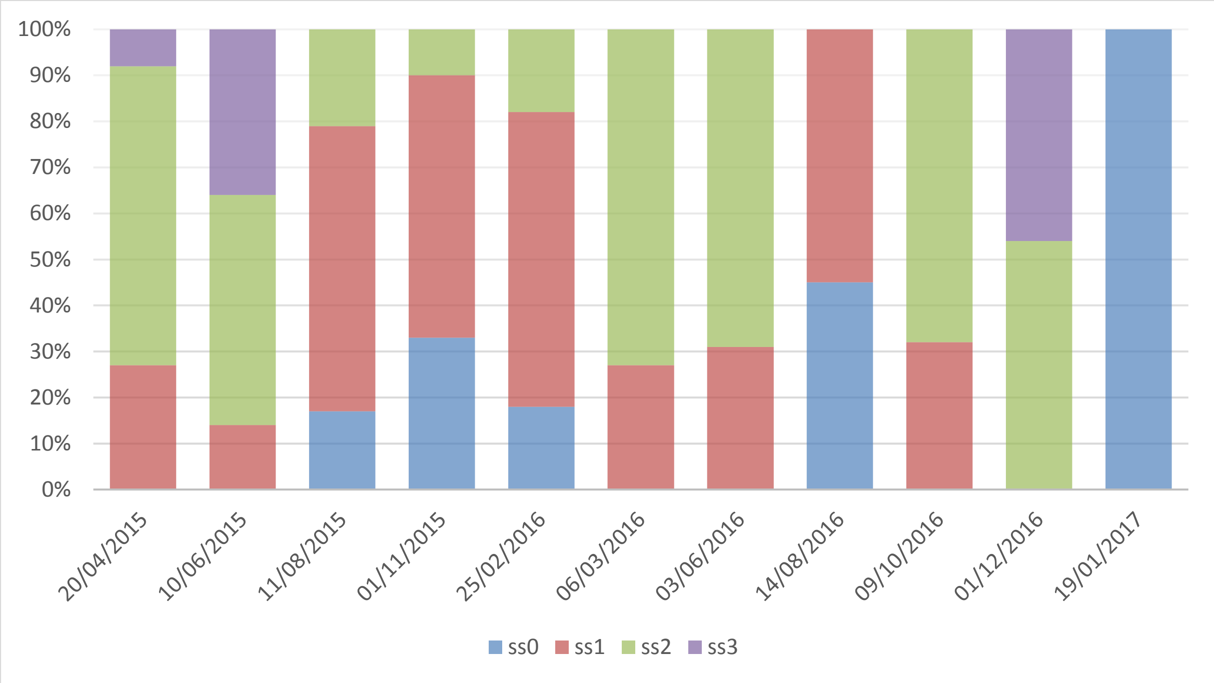


Figure 16. Beaufort Sea-state (%) recorded during boat-based surveys

3.2.2 Boat-based Marine Mammal Sightings

Marine mammals were recorded on 100% of boat-based surveys (Table 2, Figures 17-27). Species recorded comprised of harbour porpoise, grey seal, harbour seal and minke whale.

Table 2. Summary of marine mammal sightings and predominant sea-state from boat-based surveys

Date	No. harbour porpoise sightings	No. seal sightings	No. harbour porpoise individuals	No. seal individuals	No. other marine mammals	Predominant sea-state (0-2)
20/04/2015	11	2	15	2	0	2
10/06/2015	3	1	3	1	1 Minke whale	2-3
11/08/2015	20	2	37	2	0	1
01/11/2015	30	8	35	8	0	1
25/02/2016	16	4	17	4	0	1
06/03/2016	8	2	9	2	0	2
03/06/2016	2	1	2	1	0	2
14/08/2016	39	0	58	0	1 Minke whale	1
09/10/2016	12	2	16	2	0	2
01/12/2016	3	1	3	1	0	2
19/01/2017	23	2	31	2	0	0
Total	**167**	**25**	**226**	**25**	**2**	

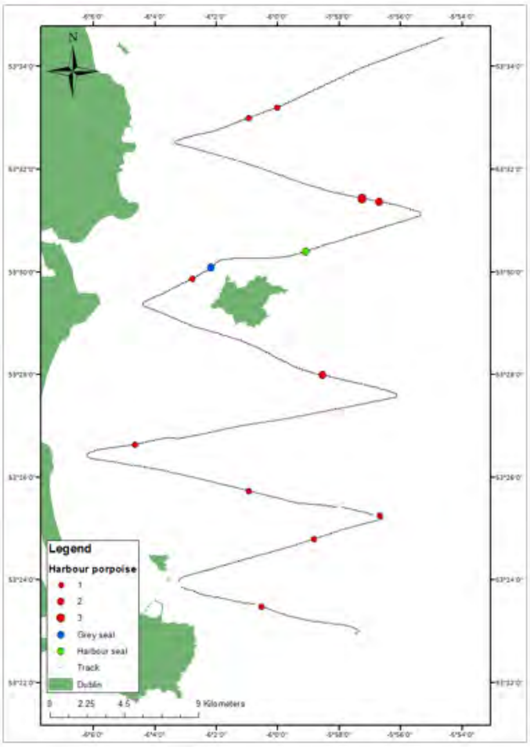


Figure 17. Trackline and sightings recorded during boat survey 1 (April 2015)

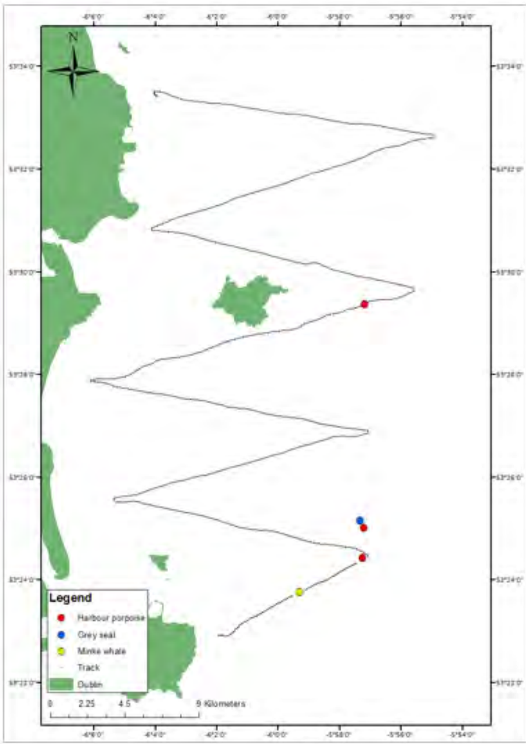


Figure 18. Trackline and sightings recorded during boat survey 2 (June 2015)

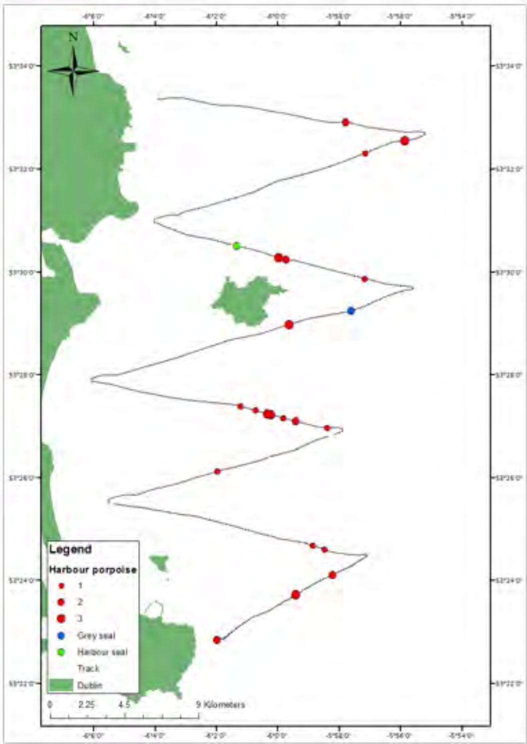


Figure 19. Trackline and sightings recorded during boat survey 3 (August 2015)

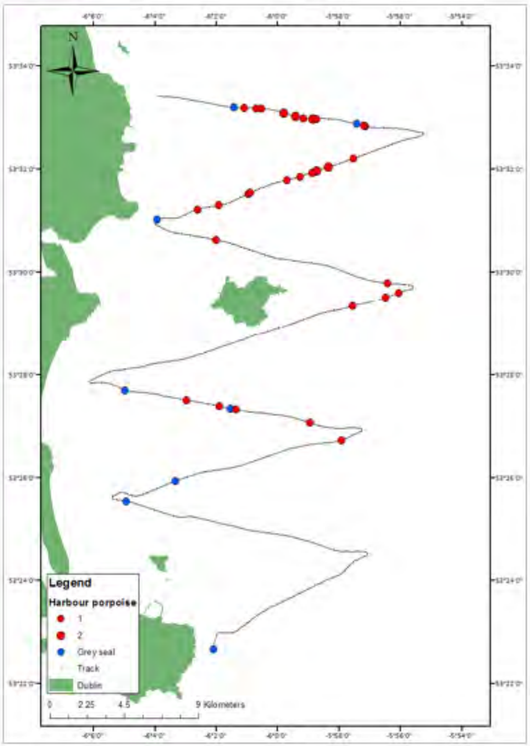
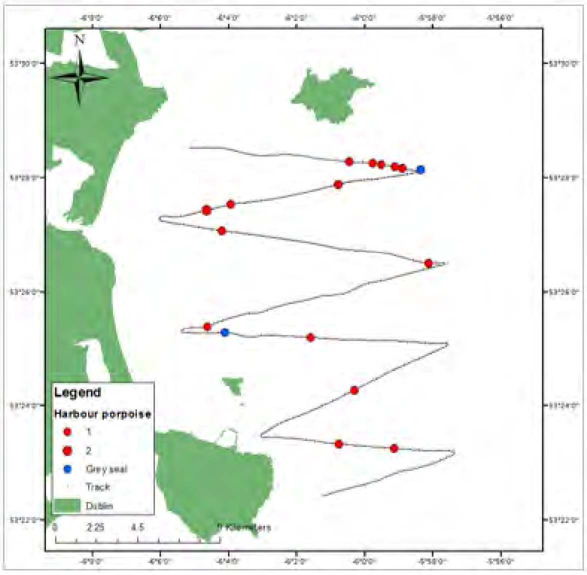


Figure 20. Trackline and sightings recorded during boat survey 4 (November 2015)



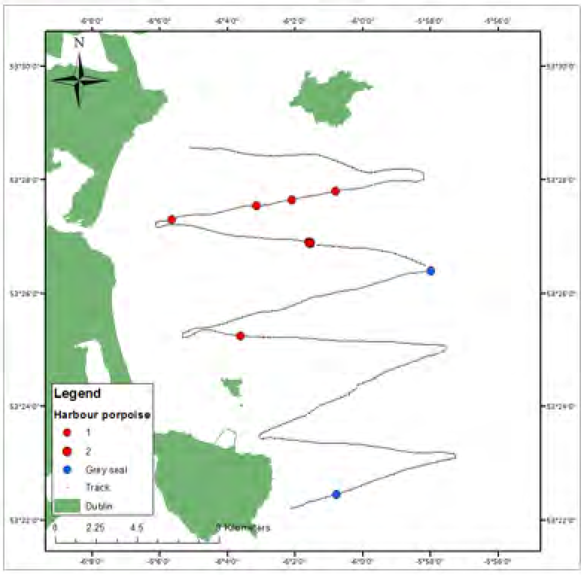
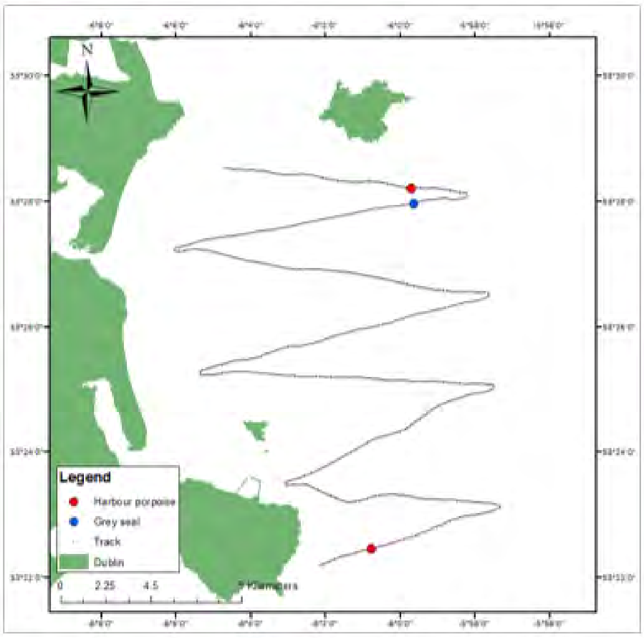


Figure 21. Trackline and sightings recorded during boat survey 5 (February 2016)

Figure 22. Trackline and sightings recorded during boat survey 6 (March 2016)



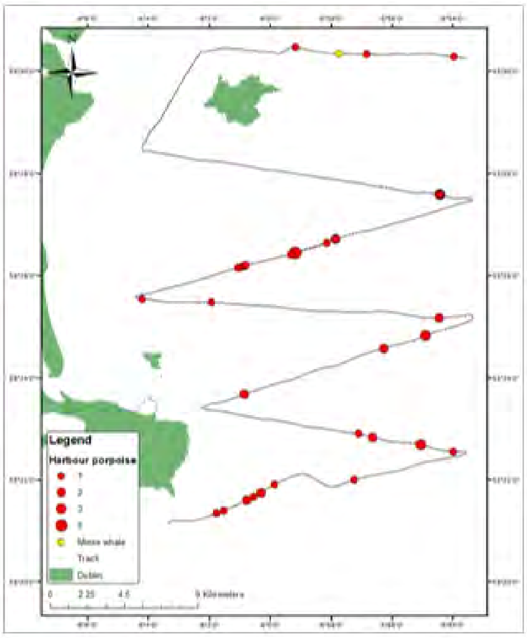


Figure 23. Trackline and sightings recorded during boat survey 7 (June 2016)

Figure 24. Trackline and sightings recorded during boat survey 8 (August 2016)

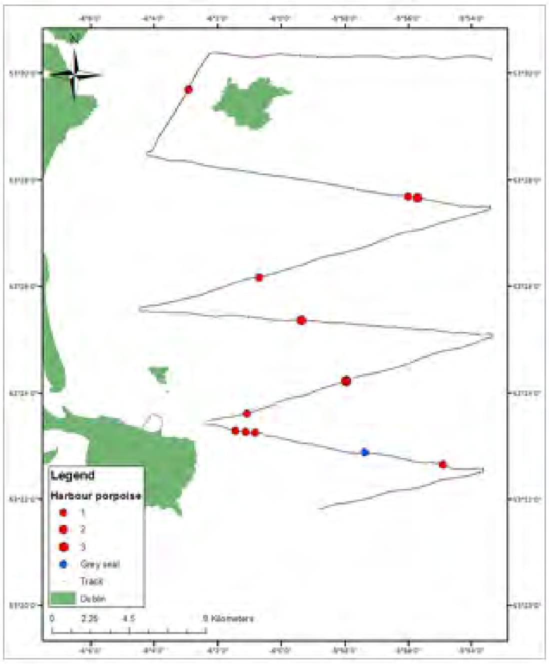


Figure 25. Trackline and sightings recorded during boat survey 9 (October 2016)

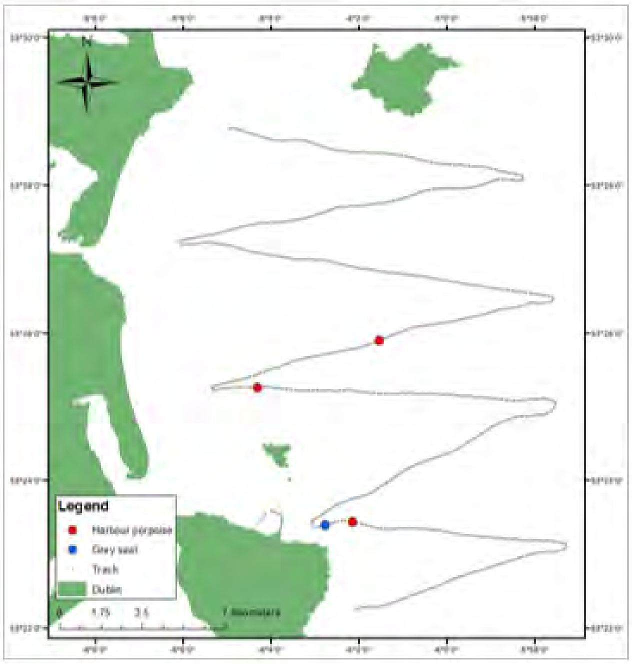


Figure 26. Trackline and sightings recorded during boat survey 10 (December 2016)

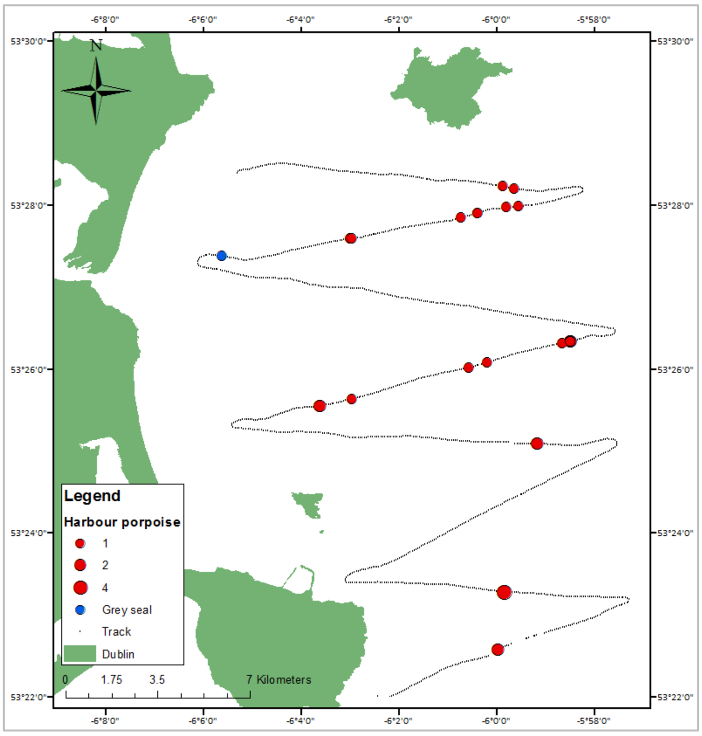


Figure 27. Trackline and sightings recorded during boat survey11 (January 2017)

3.2.2.1 *Seal species and minke whale*

Seals were recorded on 91% of survey days with the highest numbers of individuals recorded during November 2015 (Table 3, Figure 28). Grey seal sightings were distributed evenly across the study area and all sightings were of single adult individuals. Only two harbour seals were sighted, one during the April and one in August 2015 surveys, both of which were single adults. Single minke whales were recorded during two surveys, one in June 2015 and one in August 2016 (Table 3, Figure 29).

Table 3. Summary of seal sightings recorded during boat-based surveys

Date	No. seal sightings	No. seal individuals	Other marine mammals
20/04/2015	2	2	0
10/06/2015	1	1	1 Minke whale
11/08/2015	2	2	0
01/11/2015	8	8	0
25/02/2016	4	4	0
06/03/2016	2	2	0
03/06/2016	1	1	0
14/08/2016	0	0	1 Minke whale
09/10/2016	2	2	0
01/12/2016	1	1	0
19/01/2017	2	2	0

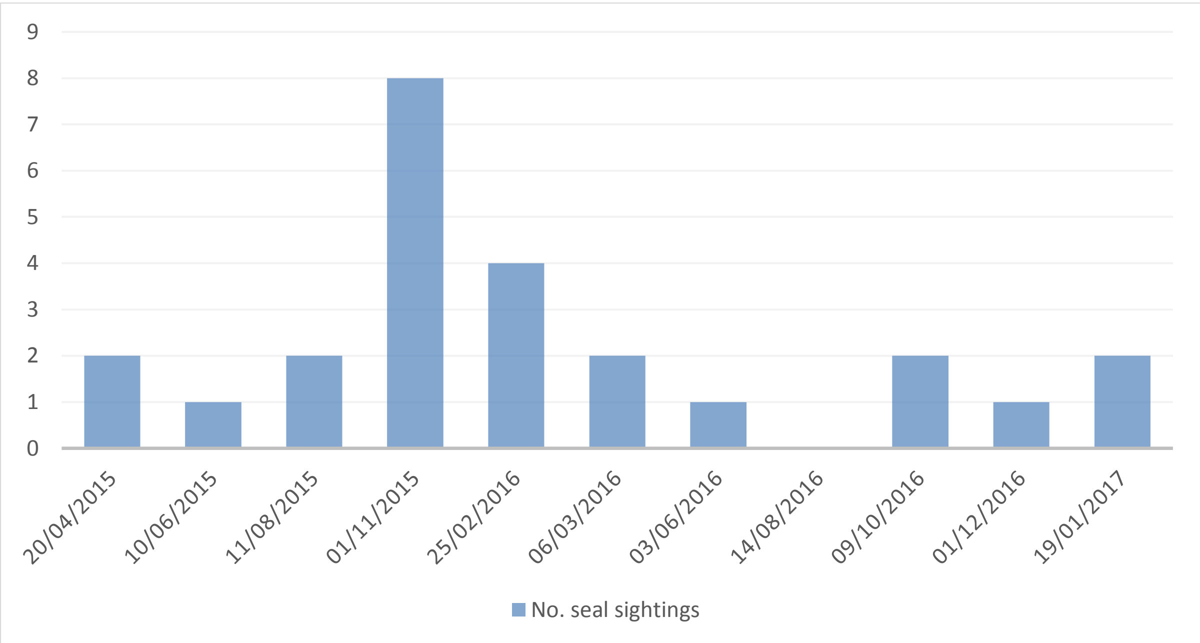


Figure 28. Number of seal sightings recorded during boat-based surveys

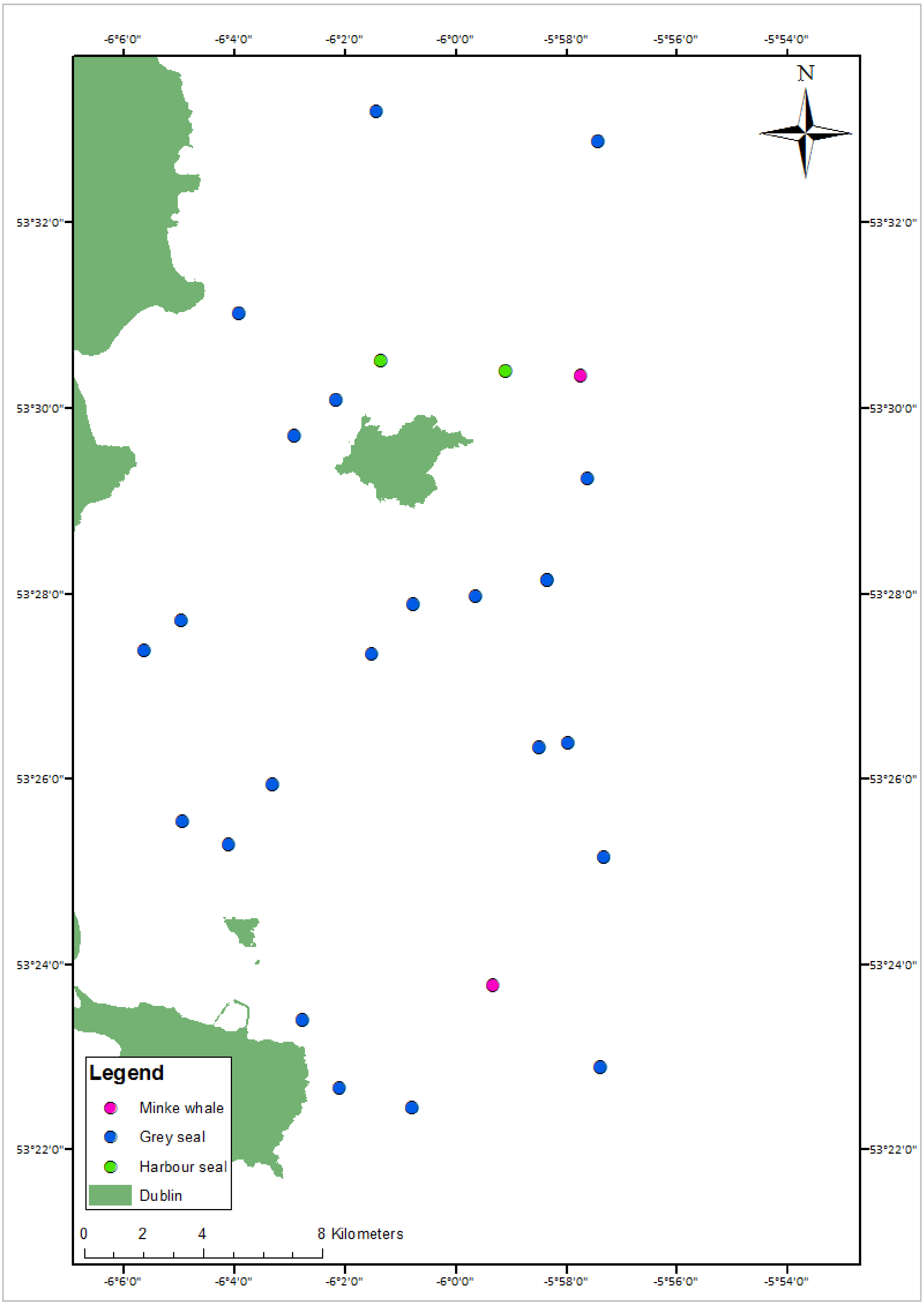


Figure 29. Geographic distribution of seal sightings and minke whales recorded during boat-based surveys

3.2.2.2 *Harbour porpoise*

Harbour porpoise were recorded on 100% of survey days with the greatest number of sightings recorded in November 2015 and August 2016 (Table 4, Figure 30). Group sizes also increased between August and November in 2015 and in August 2016. The lowest number of sightings were recorded in June 2015, June 2016 and December 2016 however sea-state was higher during these surveys which would increase the likelihood of missed sightings, therefore these results must be treated with caution. Calves were only recorded in August 2015, November 2015 and August 2016. Harbour porpoise sightings were regularly distributed across the study area (Figure 31).

Table 4. Summary of harbour porpoise sightings recorded during boat-based surveys

Date	No. HP sightings	No. HP individuals	Adults	Juveniles	Calves	Range in group size
20/04/2015	11	15	15	-	-	1-3
10/06/2015	3	3	3	-	-	-
11/08/2015	20	37	32	4	1	1-3
01/11/2015	30	35	32	2	1	1-2
25/02/2016	16	17	17	-	-	1-2
06/03/2016	8	9	8	1	-	1-2
03/06/2016	2	2	2	-	-	-
14/08/2016	39	58	47	6	5	1-5
09/10/2016	12	16	15	1	-	1-3
01/12/2016	3	3	3	-	-	-
19/01/2017	23	31	28	3	-	1-4
			202	**17**	**7**	**Average: 1.35**

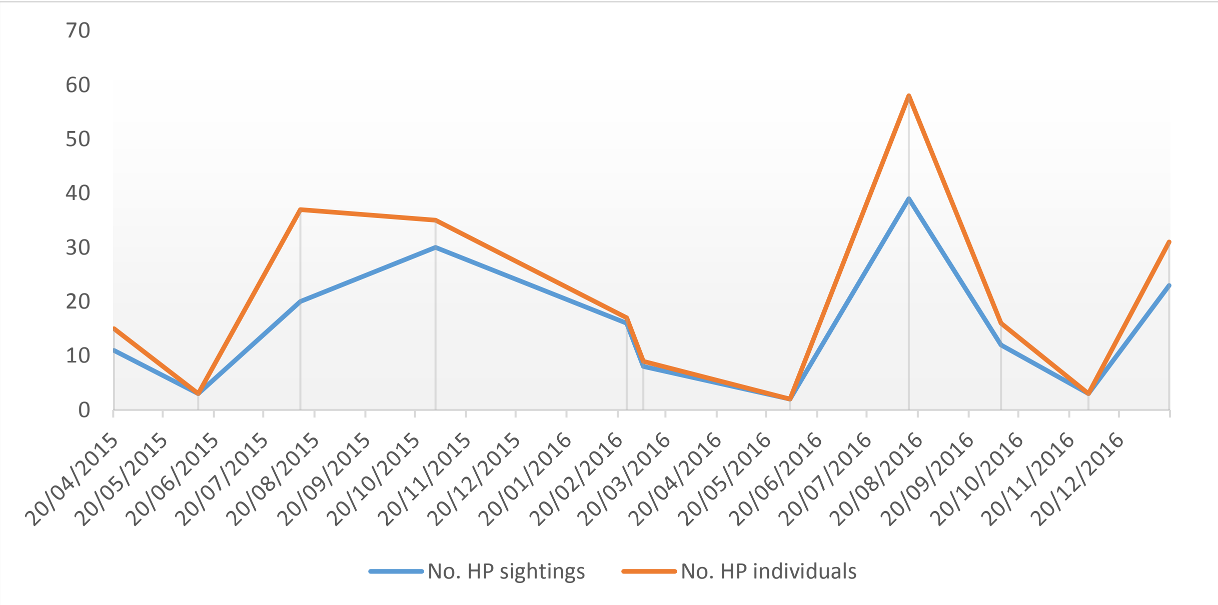


Figure 30. Number of harbour porpoise sightings and individuals recorded during boat-based surveys

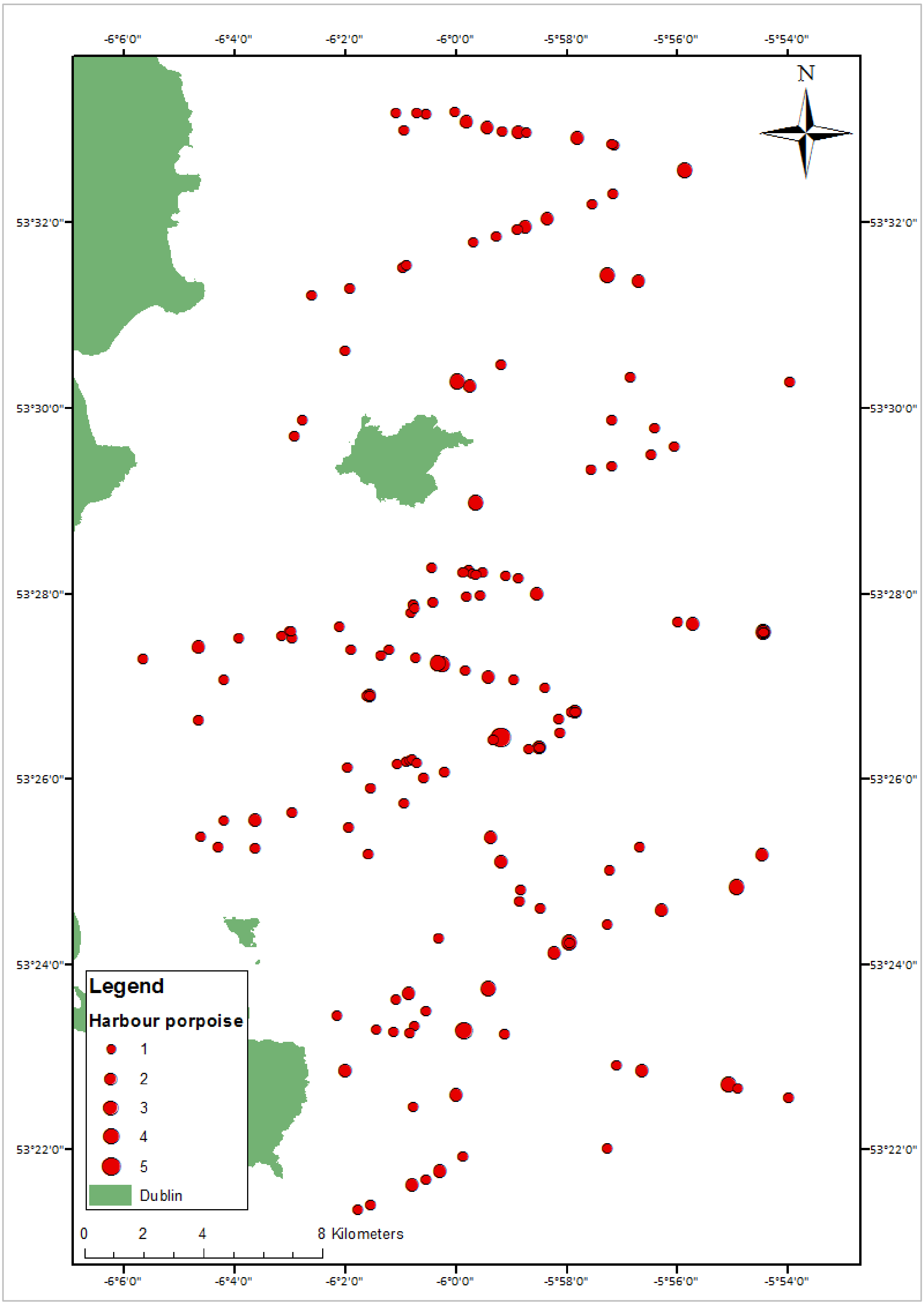


Figure 31. Geographic distribution of harbour porpoise recorded during boat-based surveys

3.2.2.2.1 Density and abundance estimation

Density estimates for harbour porpoises calculated for seven of the eleven survey days and not for surveys two (June 2015), six (March 2016), seven (June 2016) and ten (December 2016) as the number of sightings were less than 10 and too few to derive a reliable density estimate. The detection functions for all surveys combined could not be calculated as the area surveyed was reduced during the winter period and after Loughshinny was removed from survey obligations.

Evasive reactions of porpoises from the survey vessel were most evident on all surveys but especially on surveys 1, 5, 8 and 9 with a peak in sightings some 30-100m from the track-line (Figure 32), most likely resulting in an underestimate of animal density. Variation in cluster size was greater during the surveys 1 and 9 which contributed a greater proportion of the variability. Mean group (cluster) size was greater on surveys 3 (August 2015) and 8 (August 2016) compared to the other surveys, suggesting a peak occurred in late summer which is consistent with land-based observations. Adults will have calved before this period and calves were recorded during both the August 2015 and August 2016 surveys. Calves are unlikely to have weaned which may contribute to this elevated group size.

Density and abundance estimates for harbour porpoise for the Greater Dublin Drainage Marine Mammal Surveys are shown in Table 6. The density estimates increased during summer and early winter (August-November) in 2015 and during August 2016. Densities were lowest in April 2015 and February 2016. The total number of sightings used in the April 2015 (11), February 2016 (16) and October 2016 (12) surveys were low and results should be treated with caution. The track-line surveyed in February was around 25% less than in the previous surveys to account for shorter day length. Also the area surveyed was less than in previous surveys as Loughshinny had been dropped as an area of interest at the end of summer 2015. Areas of high densities of harbour porpoise to the north of the study site were therefore not surveyed which will reduce the reported density estimate. These changes to survey design should be taken into account however the trend to increased densities during late summer and early winter coincided with peak sighting rate from land-based watches.

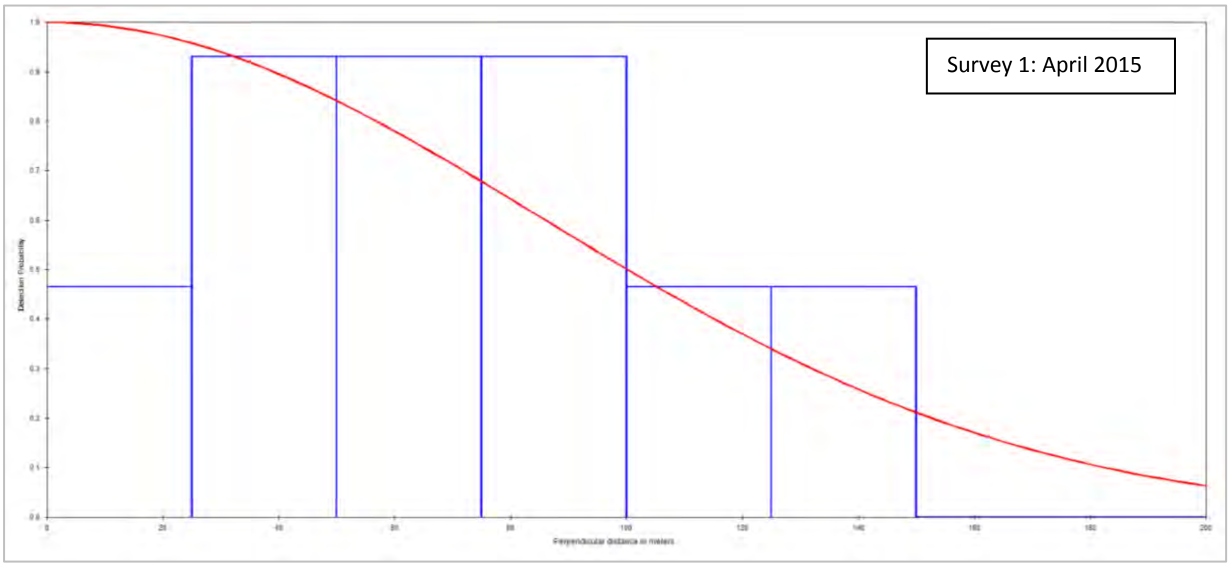
Table 5. Model data used in the harbour porpoise abundance and density estimation process for the Greater Dublin Drainage project (Note: A half-normal model with cosine series adjustments and sightings data truncated at 200m for surveys 1, 8 and 9 and 300m for surveys 3, 4, 5 and 11).

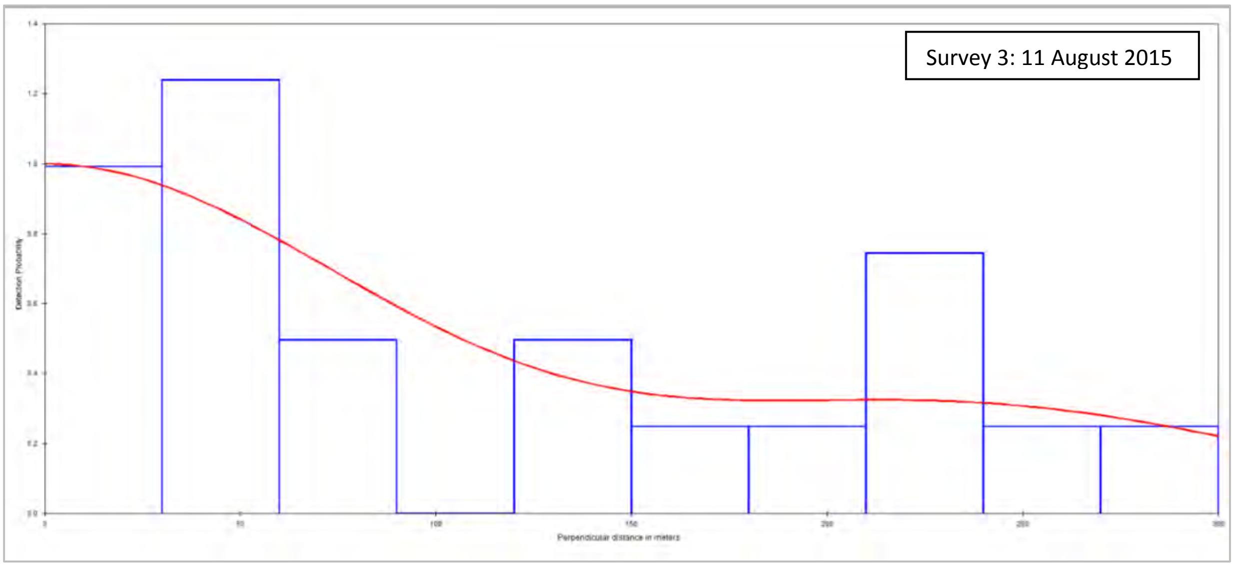
Sample Day	Track length (km)	Area surveyed (km^2)	Number of sightings	Chi^2 P value	Effective Strip Width (m)	Variability (D)	
						Detection	Cluster
1	78	197	11	0.924	104.65	67.6	32.4
3	75	189	20	0.602	148.78	84.1	15.9
4	75	189	30	0.542	141.8	89.0	11.0
5	60	85	16	0.193	190.42	100	00.0
8	89	201	39	0.093	105.1	77.9	22.1
9	89	201	12	0.464	97.35	73.1	26.9
11	89	201	23	0.930	206.9	82.5	17.5

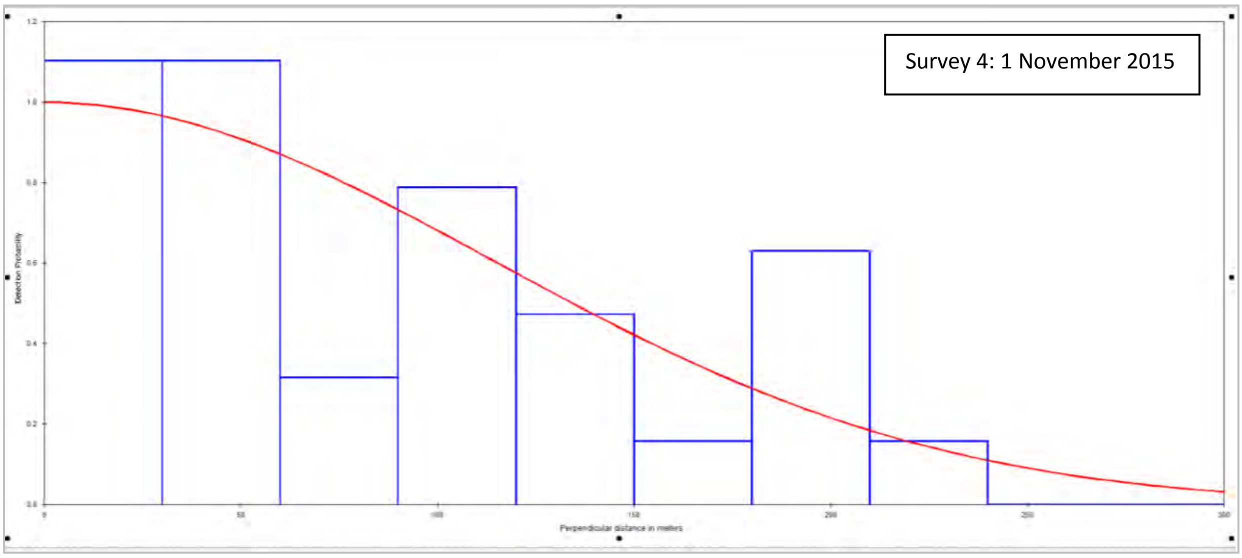
Table 6. Estimated density, abundance (N) and group sizes of harbour porpoise recorded for the Greater Dublin Drainage project.

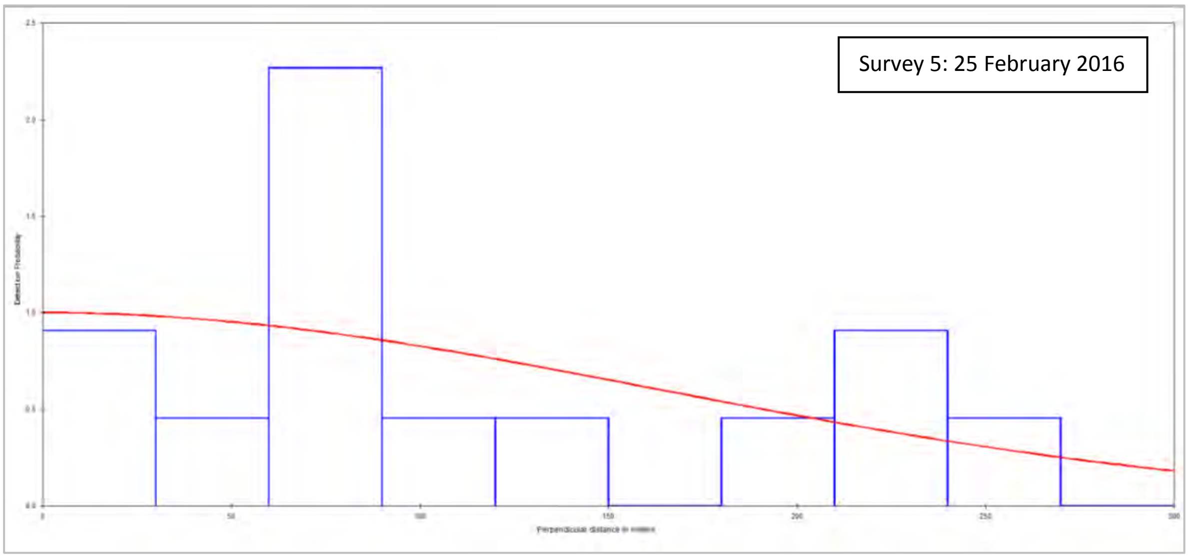
Sample Day	Date	N (95% CI)	SE	CV	Density (per km2)	Mean group size (95% CI)
1	Apr-15	154 (77-306)	54	0.33	0.78	1.44 (1.00-2.12)
3	Aug-15	361 (192-681)	114	0.32	1.91	1.85 (1.48-2.30)
4	Nov-15	332 (245-449)	50	0.36	1.76	1.17 (1.12-1.31)
5[1]	Feb-16	52 (31-86)	12	0.23	0.61	1.00
8	Aug-16	460 (339-625)	70	0.15	2.29	1.53 (1.25-1.85)
9	Oct-16	197 (111-349)	54	0.28	0.97	1.37 (1.00-1.89)
11	Jan-17	179 (117-275)	38	0.21	0.89	1.35 (1.07-1.69)

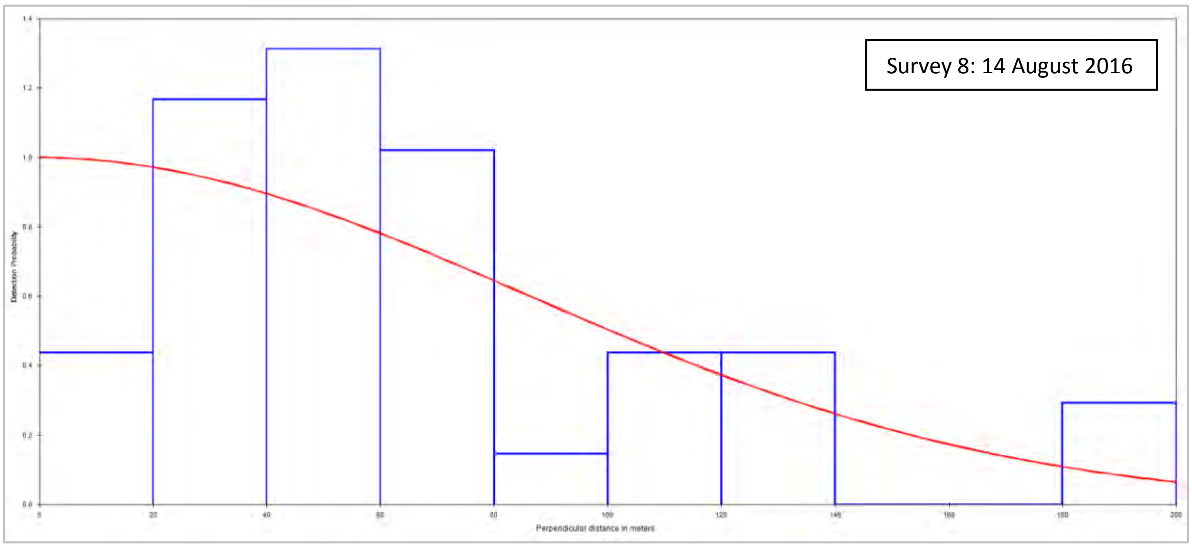
[1] – smaller area surveyed

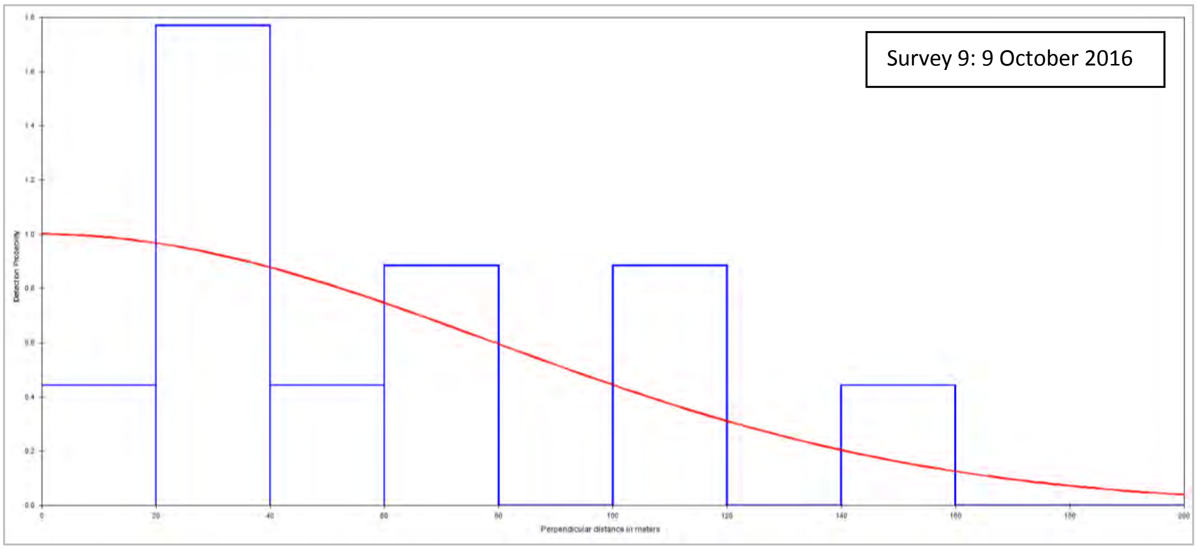

Survey 1: April 2015
Detection Probability
Perpendicular distance in meters


Survey 3: 11 August 2015
Detection Probability
Perpendicular distance in meters


Survey 4: 1 November 2015
Detection Probability
Perpendicular distance in meters


Survey 5: 25 February 2016


Survey 8: 14 August 2016


Survey 9: 9 October 2016

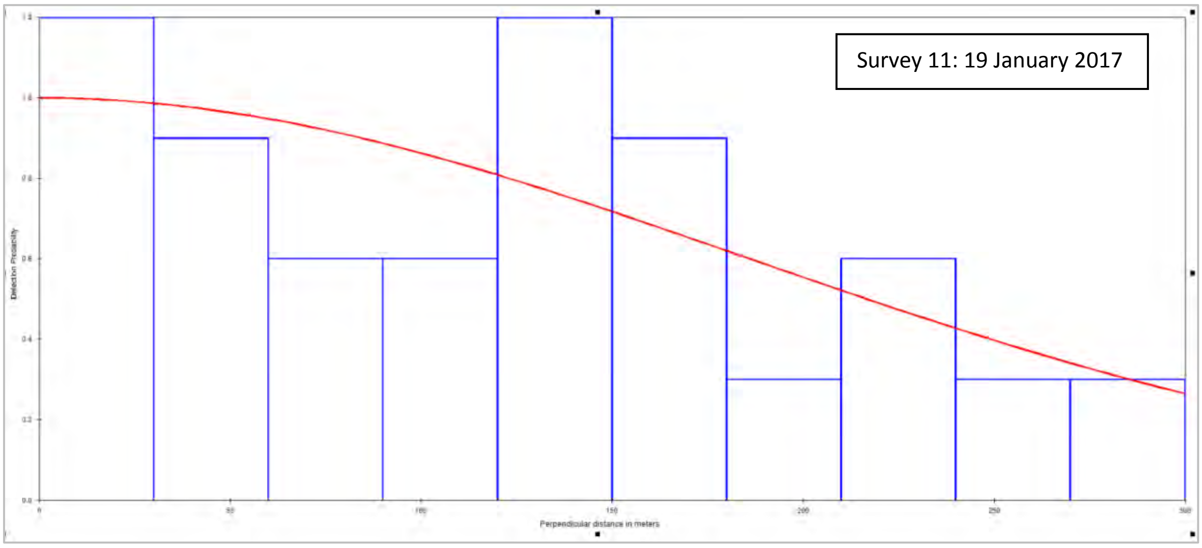


Figure 32. Detection functions for density estimates for boat-based surveys with sufficient number of sightings to analyse in DISTANCE.

3.3 Static Acoustic Monitoring

3.3.1 C-POD Calibrations

All units used over the duration of the present study were calibrated (Figure 33-Figure 38). From these trials, there were some differences in sensitivities between units but that individual unit performance was within the acceptable error margin of ±20% DPM per hour (Figure 35-Figure 38) and therefore no correction factor was applied to the data to make it comparable (O'Brien et al. 2013). During analysis of the long-term dataset, differences in sensitivities between units is accounted for by treating C-POD number as a random factor when running the GLMM and additionally C-PODs were deployed randomly between sites over the duration of the study.

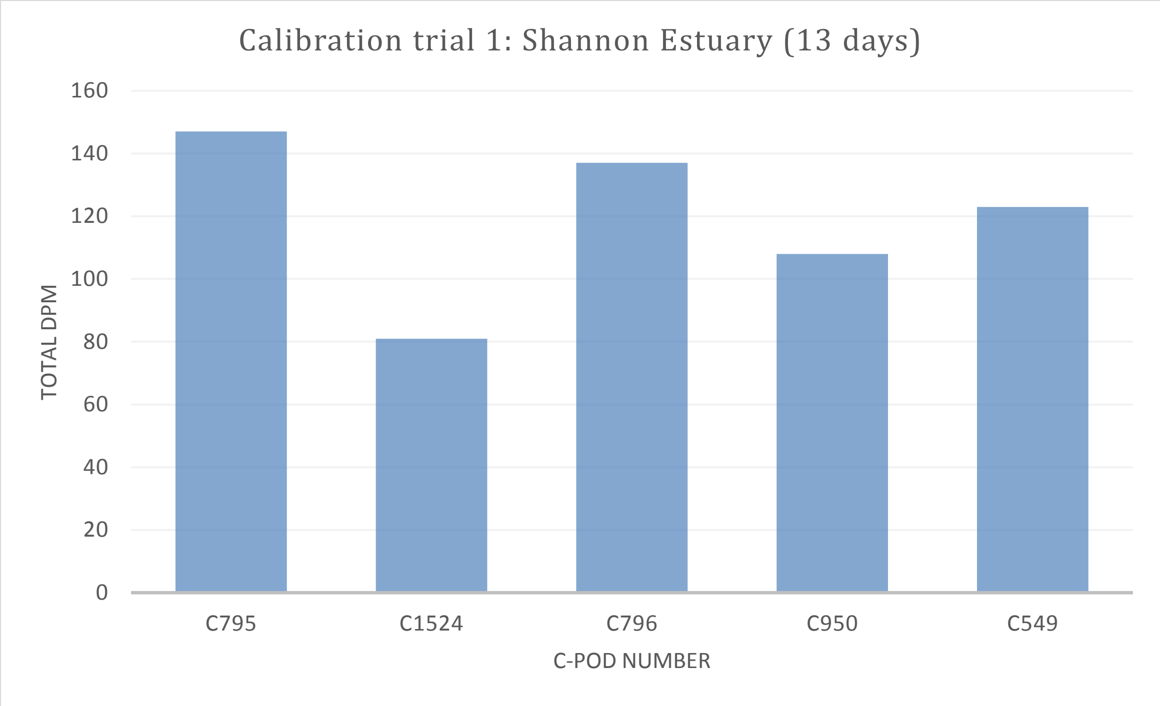


Figure 33. Detection Positive Minutes from all C-PODs deployed during calibration trial 1 in the Shannon Estuary.

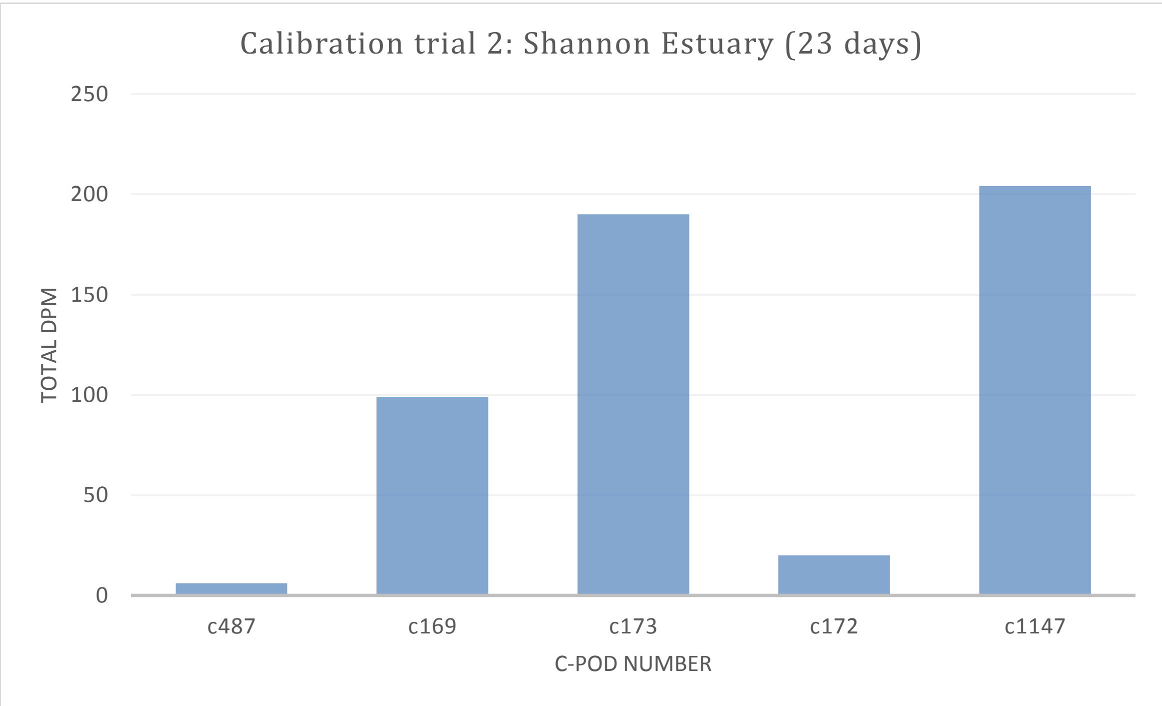


Figure 34. Detection Positive Minutes from all C-PODs deployed during calibration trial 2 in the Shannon Estuary.

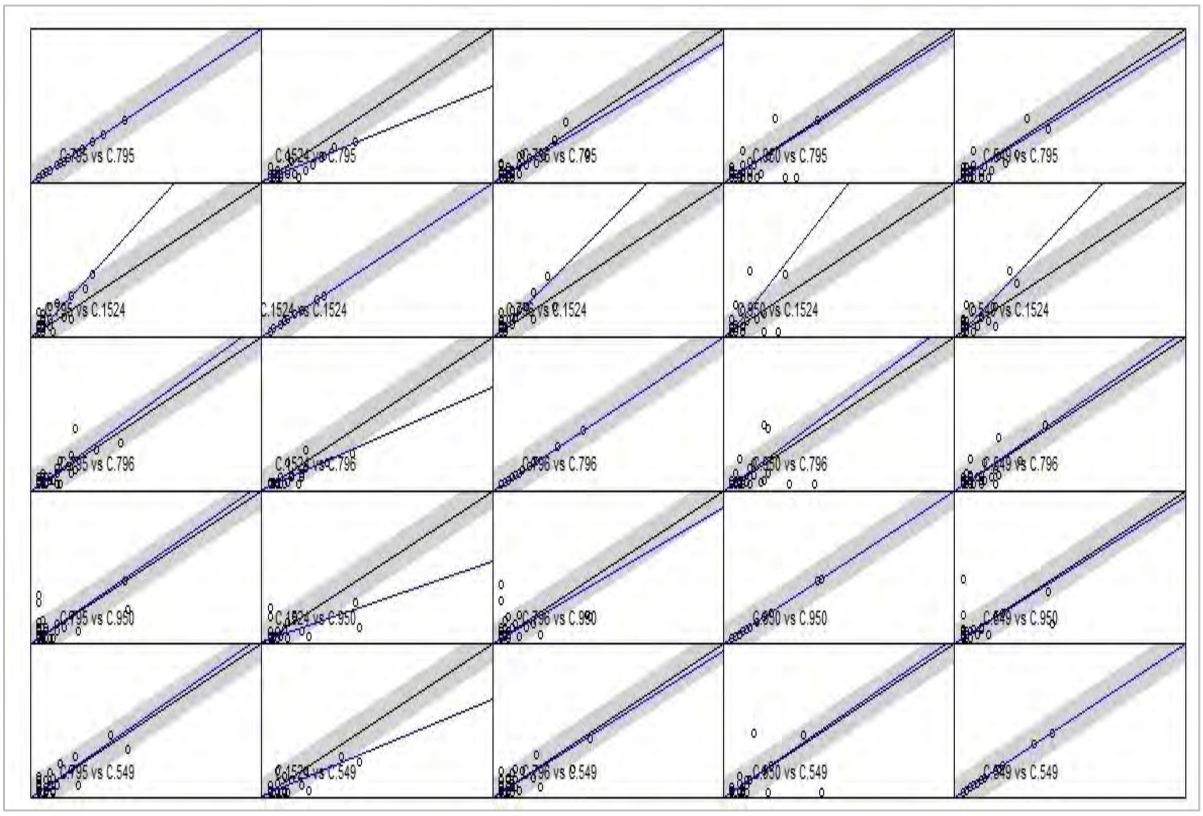


Figure 35. Orthogonal regression plot of C-POD comparisons in calibration trial, in blue, with a null model where each unit performs exactly the same, in black and an acceptable error margin of ±20%, in grey from Calibration 1, January 2015.

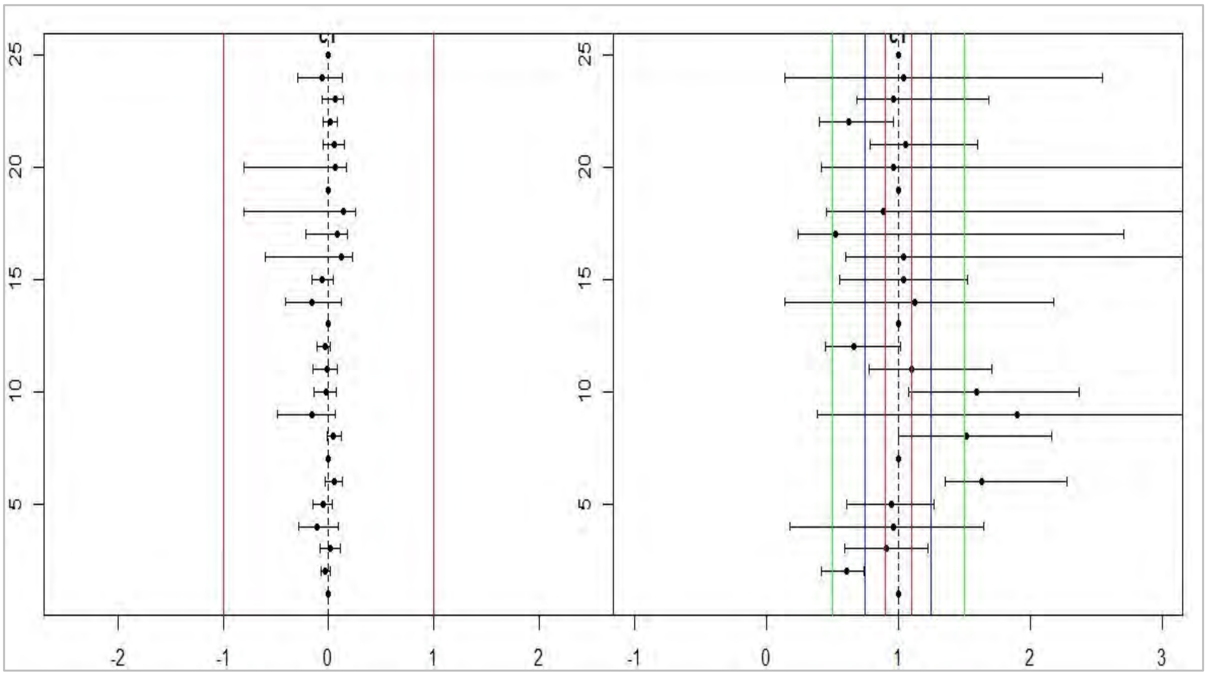


Figure 36. Centipede plot of the intercept and slope values (±std), of the orthogonal regression plots, for each pod performance comparison in calibration trail 1 at Money Point, January 2015. Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model assuming no variation. Plot indicates that a greater extent of variation is found within the gradient values.

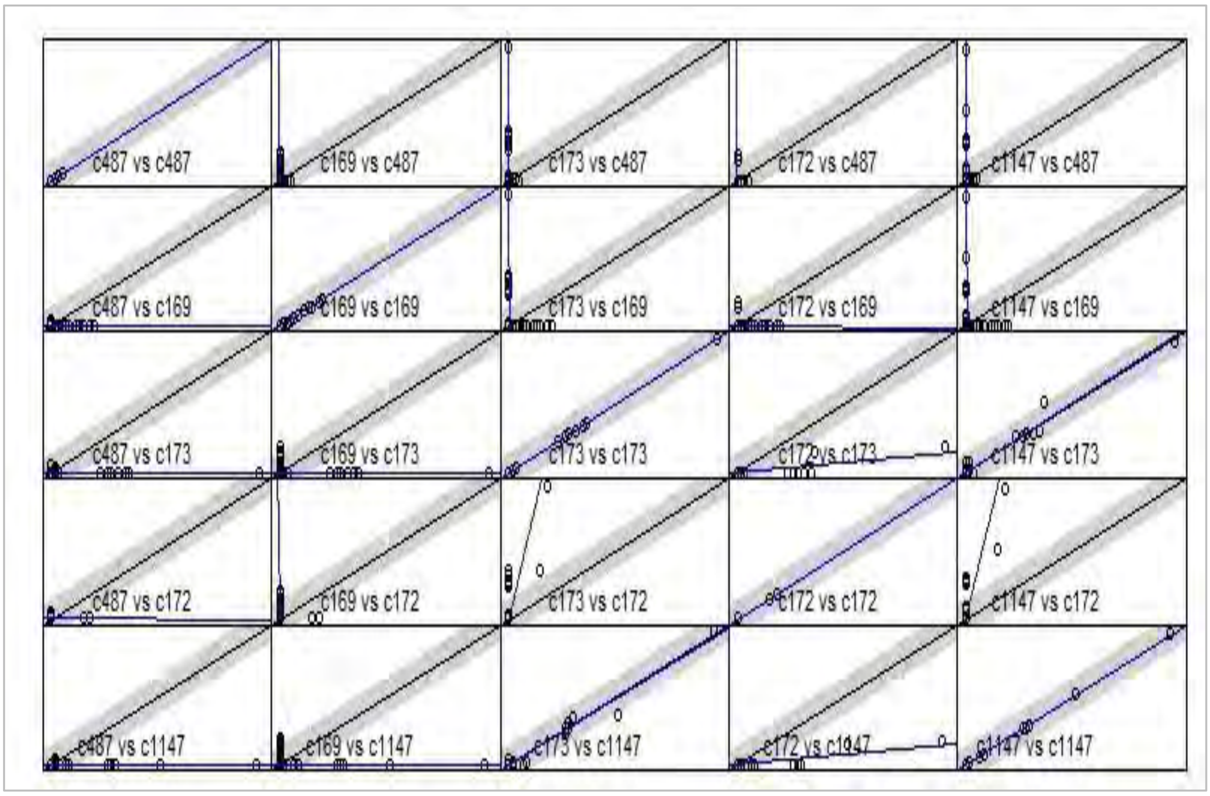


Figure 37. Orthogonal regression plot of C-POD comparisons in calibration trial, in blue, with a null model where each unit performs exactly the same, in black and an acceptable error margin of ±20%, in grey from Calibration 2, February 2015.

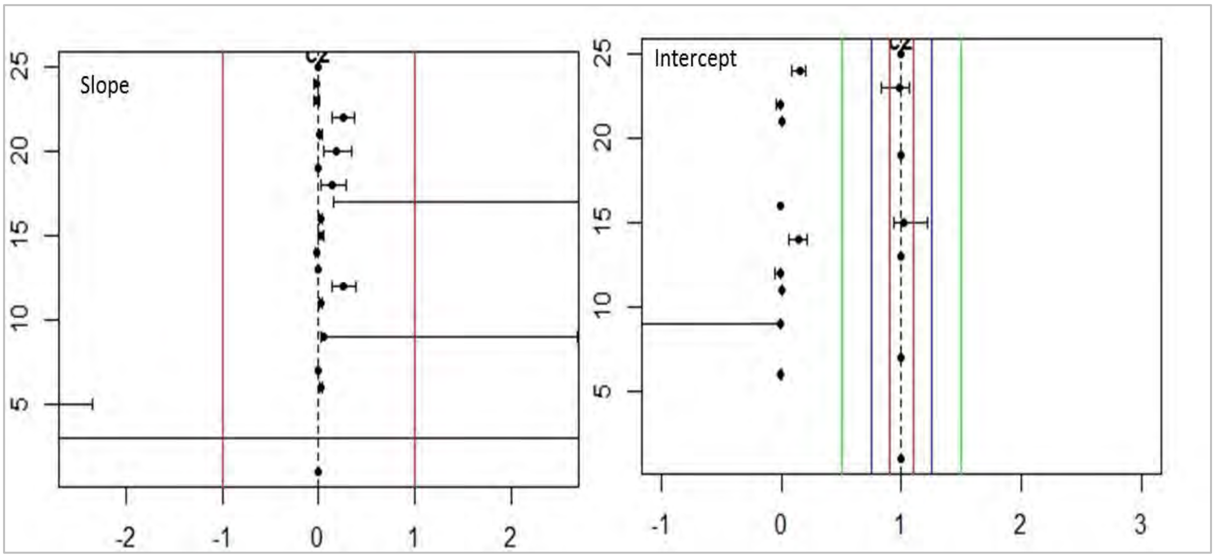


Figure 38. Centipede plot of the intercept and slope values (±std), of the orthogonal regression plots, for each pod performance comparison in calibration trail 1 at Money Point, January 2015. Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model assuming no variation. Plot indicates that a greater extent of variation is found within the gradient values.

3.3.2 Overview of SAM results

SAM using C-PODs was carried out at Portmarnock at three sites simultaneously for a duration of 750 days (between March 2015 and March 2017). The number of monitoring days at each site varied due to a number of reasons but mainly interference with moorings and gear missing upon retrieval (Table 7). This did not impact significantly on the dataset as monitoring over such a long-term period ensured enough replication was achieved across years and a range of factors which are thought to influence presence. Detections were recorded 96-99% of days on average at each site (Table 7). The number of Porpoise Positive Minutes (PPM) ranged from 3690 to 25089 per year, between sites, with mean DPM/day ranging between 41.3 to 94.3 (Table 7; Figure 39). Very few dolphin detections were recorded and most of those were determined to be false positives and therefore were not used for analyses. A monitoring index was calculated as the mean number of detection positive minutes per hour for porpoises (Table 7). This index can be compared across locations, or with results from previous studies in Ireland and was used to compare the present dataset with that recorded in 2015 from Loughshinny, Co. Dublin (approx. 14 km north of the Portmarnock site).

Table 7. Summary of all deployments across 3 GDD sites from 2015 to 2017 (N=750 days).

Location	Year	No. of days monitored	No. of data days	Total PPM	% PPDs	Mean DPM/Day	Mean DPM/hr	%DPM
GDD1	2015	294	294	24728	98	84.1	3.5	5.8
	2016	366	187	3680	94	20.6	0.81	1.4
	2017	90	75	1443	95	19.2	0.80	1.3
Total		**750**	**556 (74%)**	**29,851**	**x̄=96%**	**41.3**	**1.7**	**2.8**
GDD2	2015	294	211	11396	97	54.0	2.3	3.8
	2016	366	258	25089	99	97.2	4.1	6.7
	2017	90	75	9894	99	131.9	5.5	9.2
Total		**750**	**544 (72%)**	**46,379**	**x̄=98%**	**94.3**	**4.0**	**6.6**
GDD3	2015	294	228	14486	100	63.5	2.6	4.4
	2016	366	227	12820	99	56.5	2.4	3.9
	2017	90	75	3960	97	52.8	2.2	3.7
Total		**750**	**530 (71%)**	**31,266**	**x̄=99%**	**57.6**	**2.4**	**3.0**

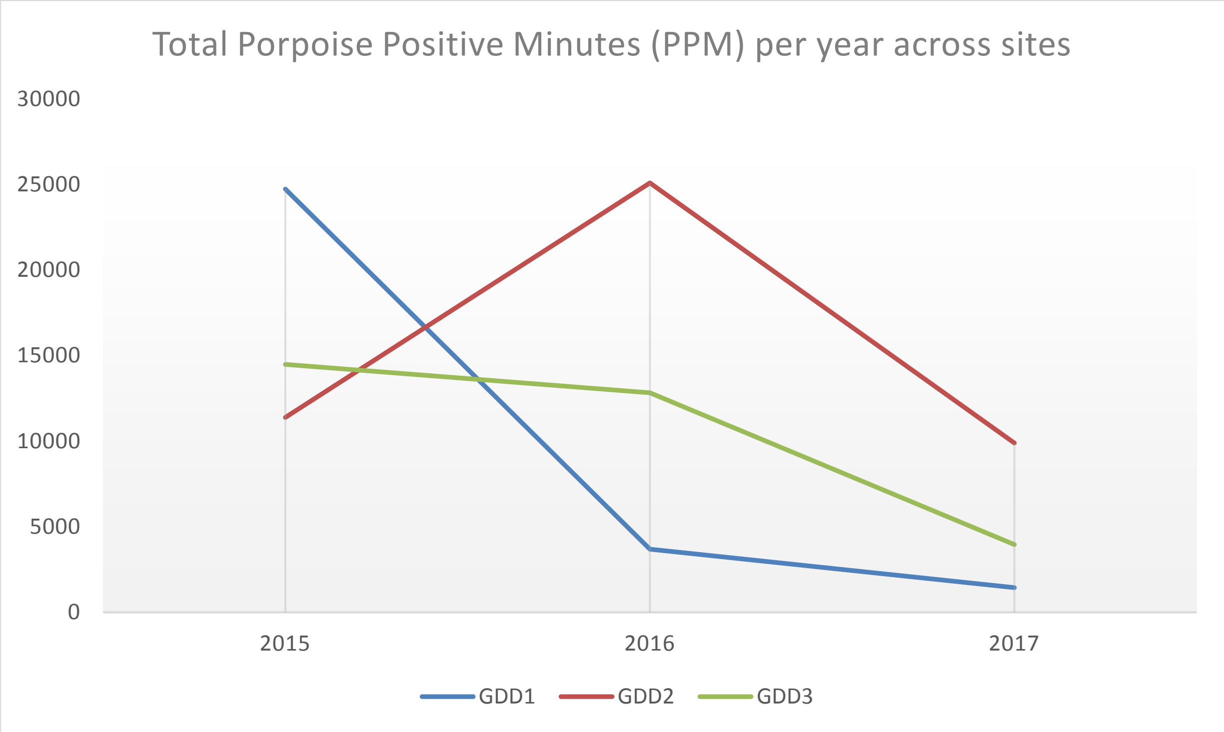


Figure 39. Porpoise Positive Minutes per day (PPMs) recorded each year across sites. The duration of sampling differed between years; days monitored in 2015 (294), days monitored in 2016 (366) and days monitored in 2017 (90).

3.3.2.1 Generalized linear mixed-effect model (GLMM) analyses

As this was a long-term study with monitoring taking place across three years and at three sites, analyses using GLMM were used to assess differences between years and then at the completion of the monitoring, data from all three years from each site were compiled and assessed as one long dataset, allowing for a detailed assessment of fine scale use of the area.

3.3.2.2 GDD 1

GDD1 was the closest site to shore, approx. 2.5 km, and was the shallowest location at a depth of 5.1m. Results across years showed that each of the four factors (season, diel, tidal cycle and tidal phase) were significant during 2015, while in 2016 only season and diel were found to be significant. When all data were compiled, all factors were found to be significant (Table 8).

Table 8. Results from GLMM's per year and all data combined from GDD1.

Location	Year	Variable	X^2	df	P-value
GDD1	2015	Season	212.2	4	0.000
		Diel	212.2	4	0.000
		T.P	192.3	3	0.000
		T.C	212.2	4	0.000
GDD1	2016	Season	140.1	4	0.000
		Diel	140.1	4	0.000
		T.P	53.7	3	0.1
		T.C	42.0	4	0.1
GDD1	2017	Season	167.5	4	0.000
		Diel	167.5	4	0.000
		T.P	128.7	3	0.000
		T.C	168.6	4	0.000
GDD	all years combined	Season	277.9	4	0.000
		Diel	204.2	4	0.000
		T.P	144.3	3	0.000
		T.C	204.2	4	0.000

Data are presented as box plots, which help to visualise the results. In 2015, there were significantly more detections at GDD1 during the autumn, winter and summer months when compared with spring ($\chi2= 212$, $p<0.000$). Significantly more detections were recorded during the hours of darkness and the intermittent hours between dawn and dusk ($\chi2= 212.2$, $p<0.000$), as well as during the tidal phase spring ($\chi2= 192.3$, $p<0.000$) and tidal cycle low ($\chi2= 212.2$, $p<0.000$), Figure 40)).

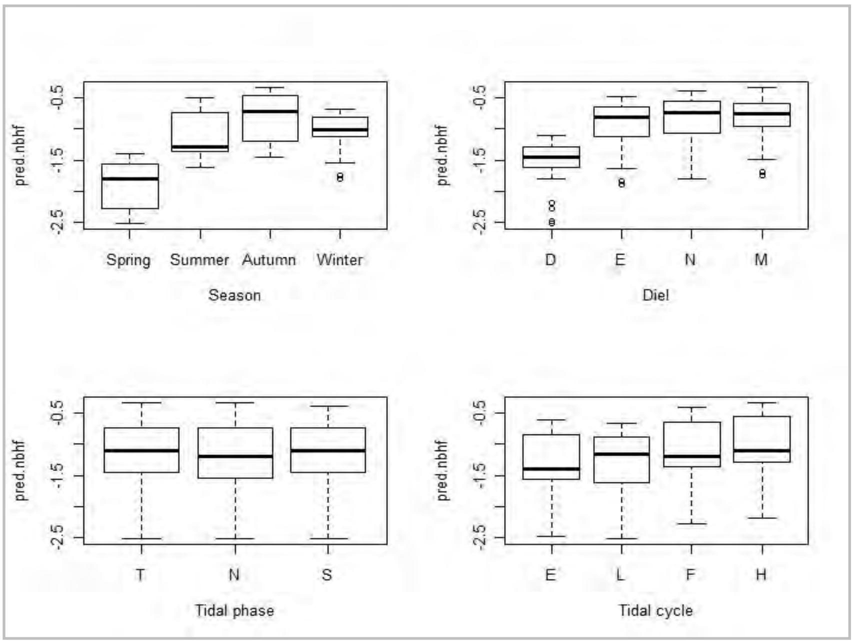


Figure 40. Predicted proportion of detection positive hours, in the narrow band high frequency channel at GDD1 (Co. Dublin) Mar 2015-Dec 2015 across the four variables of season; diel, where D =day, E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high.

In 2016, season was found to be a significant factor again but detections in spring was found to be significantly higher compared with 2015, where most detections were during the spring months (χ^2= 140.1, p<0.000). Similarly to 2015, more detections were recorded during the hours of darkness and the intermittent hours between dawn and dusk (χ^2= 140.1, p<0.000), but tidal phase (χ^2= 53.7, p=1.3) and tidal cycle (χ^2= 42.0, p=1.7) were not significant (Figure 41).

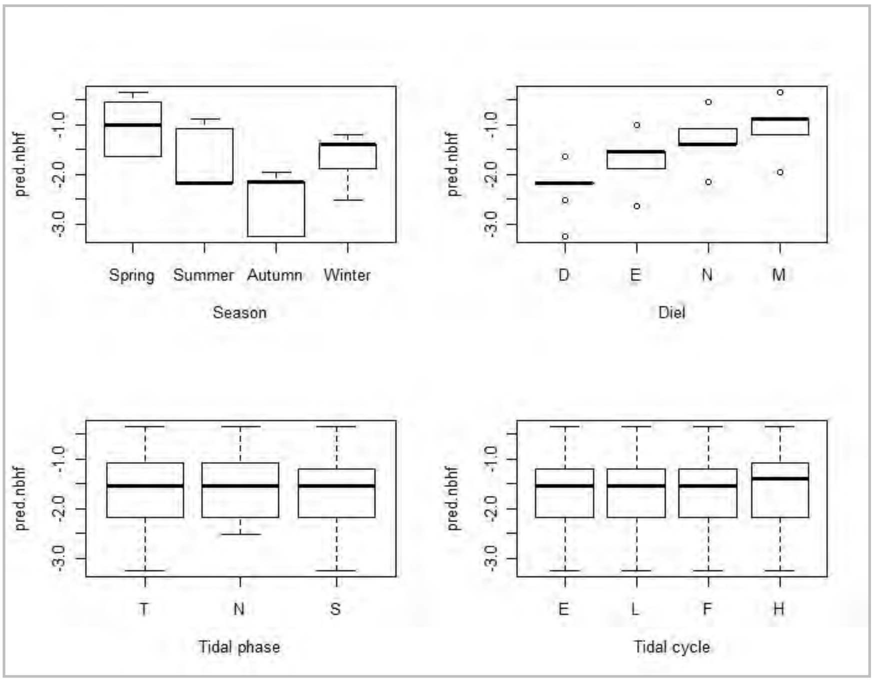


Figure 41. Predicted proportion of detection positive hours, in the narrow band high frequency channel at GDD1 (Co. Dublin) Jan - Dec 2016 across the four variables of season; diel, where D =day, E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high.

Monitoring only took place in 2017 between January and March but the data were still processed as before with just two seasons, winter and spring. All factors were found to be significant (Table 8, Figure 42).

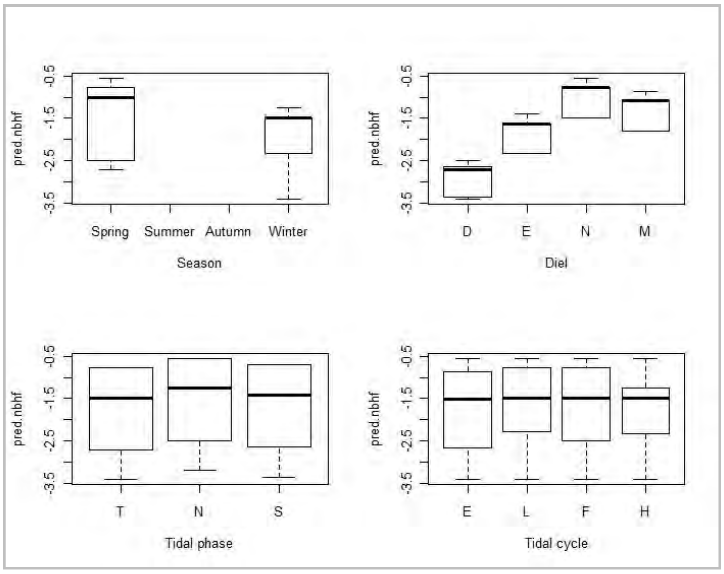


Figure 42. Predicted proportion of detection positive hours, in the narrow band high frequency channel at GDD1 (Co. Dublin) Jan - Mar 2017 across the four variables of season; diel, where D =day, E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high.

The last analyses on data from GDD1 was to combine all dataset collected across the 556 days, which showed that three of the four factors were significant. Significantly more detections occurred in Autumn (χ^2= 279.9, p<0.000), with most detections during the night and in morning hours (χ^2= 204.2, p<0.000), while significantly more detections were recorded at slack high tide (χ^2= 168.6, p<0.000), which is plausible given this site, is very shallow (Figure 43).

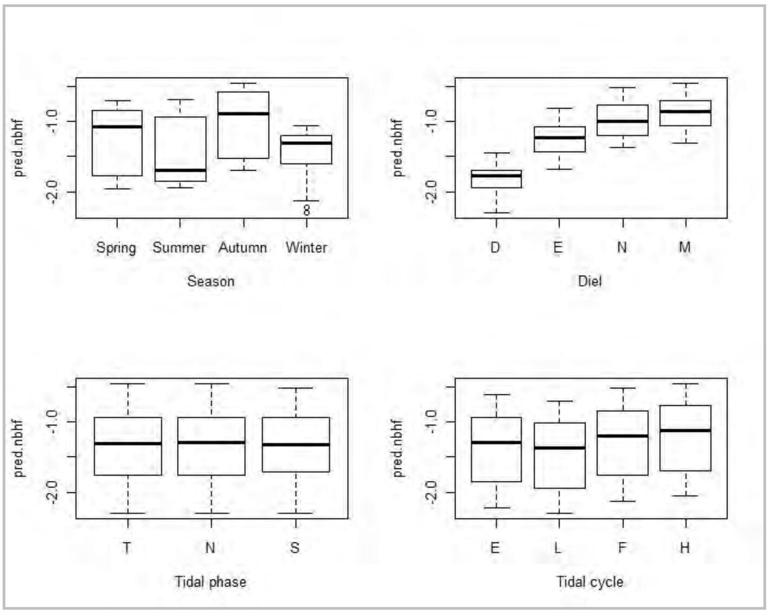


Figure 43. Predicted proportion of detection positive hours, in the narrow band high frequency channel at GDD1 (Co. Dublin), all days, Mar 2016 - Mar 2017 (556 days) across the four variables of season; diel, where D =day, E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high.

3.3.2.3 GDD 2

GDD2 was the middle site, approximately 1km from GDD1 and 1.5km from GDD3 and at a depth of approximately 14m. Results (Table 9) show a lot of variability between years and across factors, but when all years were combined it was evident that all factors except tidal phase were significant.

Table 9. Results from GLMM's per year and all data combined from GDD2.

Location	Year	Variable	X^2	df	P-value
GDD2	2015	Season	371.5	4	0.000
		Diel	371.5	4	0.000
		T.P	38.3	3	0.2
		T.C	458.4	4	0.000
GDD2	2016	Season	80.4	4	0.000
		Diel	80.4	4	0.000
		T.P	21.1	3	0.1
		T.C	29.2	4	0.000
GDD2	2017	Season	164.4	4	0.000
		Diel	164.4	4	0.000
		T.P	53.7	3	0.1
		T.C	170.6	4	0.000
GDD2	all years combined	Season	105.5	4	0.000
		Diel	760.5	4	0.000
		T.P	144.3	3	0.3
		T.C	59.9	4	0.000

Box plots below help visualise the results from GDD2 demonstrating there were significantly more detections during the winter, autumn and summer months when compared with spring ($\chi 2= 212$, $p<0.000$) in 2015, following similar trends to GDD1 but in the following year (2016). Significantly more detections were recorded during the hours of darkness and the intermittent hours between dawn and dusk ($\chi 2= 212.2$, $p<0.000$). Tidal cycle had significantly more detections during the flood tide, while no significant trends were found for tidal phase (Figure 44).

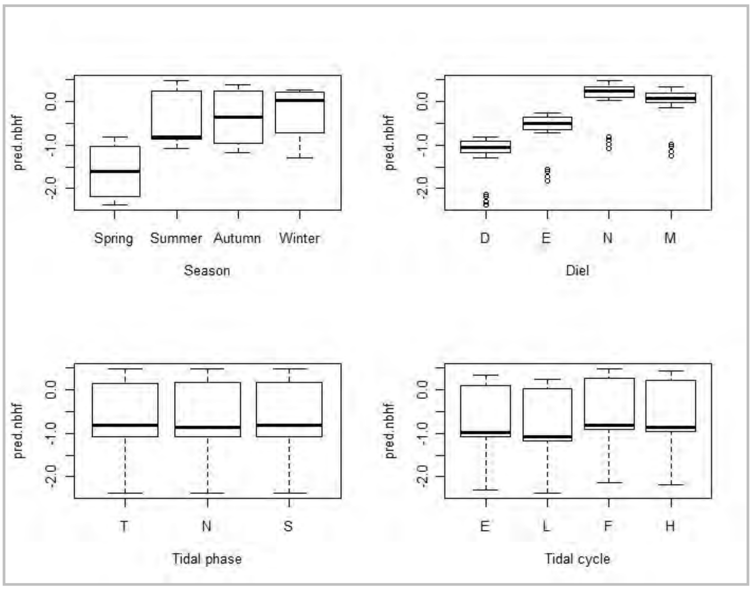


Figure 44. Predicted proportion of detection positive hours, in the narrow band high frequency channel at GDD2 (Co. Dublin) Mar – Dec 2015 across the four variables of season; diel, where D =day, E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high.

At GDD2, results for 2016 showed season to be a significant factor, similar to results from GDD1 from 2015, with detections in spring significantly higher (χ^2= 140.1, p<0.000). Similarly to 2015 across sites, more detections were recorded during the hours of darkness and the intermittent hours between dawn and dusk (χ^2= 140.1, p<0.000), and during high tide (χ^2= 29.2, p<0.000), with tidal phase having no significant effect (χ^2= 21.1, p=7.0; Figure 45).

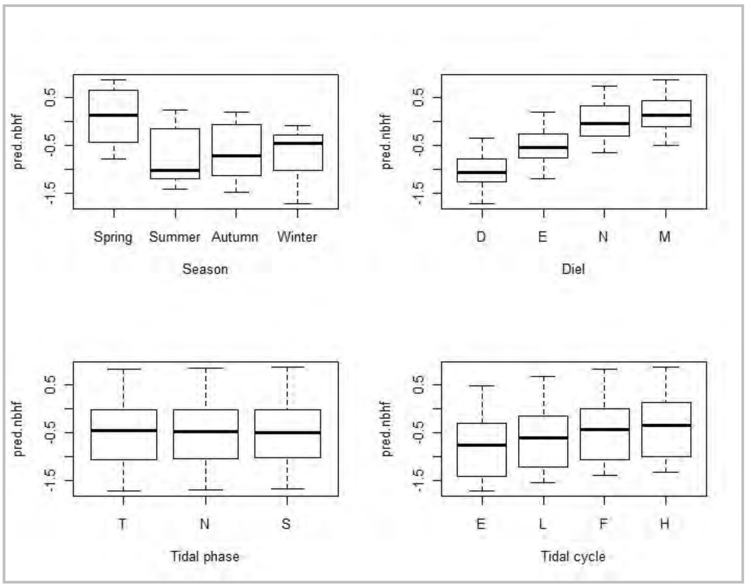


Figure 45. Predicted proportion of detection positive hours, in the narrow band high frequency channel at GDD2 (Co. Dublin) Jan – Dec 2016 across the four variables of season; diel, where D =day, E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high.

At GDD2 in 2017, results showed all factors to be significant except tidal phase (Table 9; Figure 46).

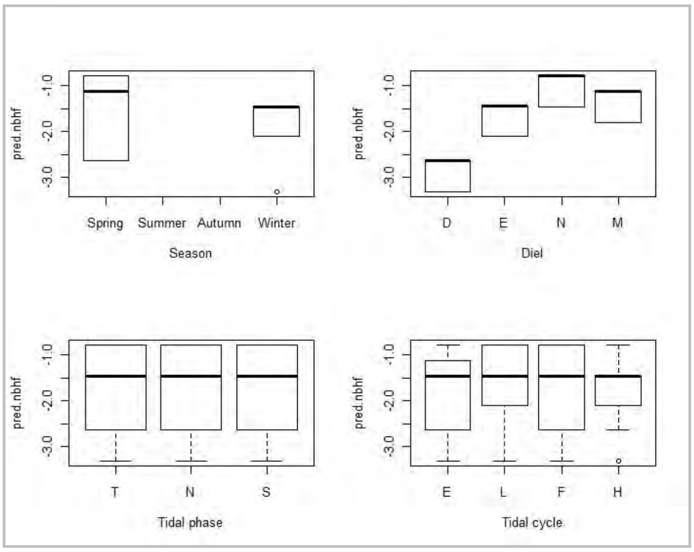


Figure 46. Predicted proportion of detection positive hours, in the narrow band high frequency channel at GDD2 (Co. Dublin) Jan – Mar 2017 across the four variables of season; diel, where D =day, E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high.

As for GDD1, all data from GDD2 were combined across years for the 544 days monitored and results showed that three of the four factors were significant. In this instance, significantly more detections occurred during winter (χ2= 279.9, p<0.000), with most detections during the night and morning hours (χ2= 204.2, p<0.000), while significantly more detections were recorded at slack high tide (χ2= 168.6, p<0.000), which is plausible given this site, is very shallow (Figure 47).

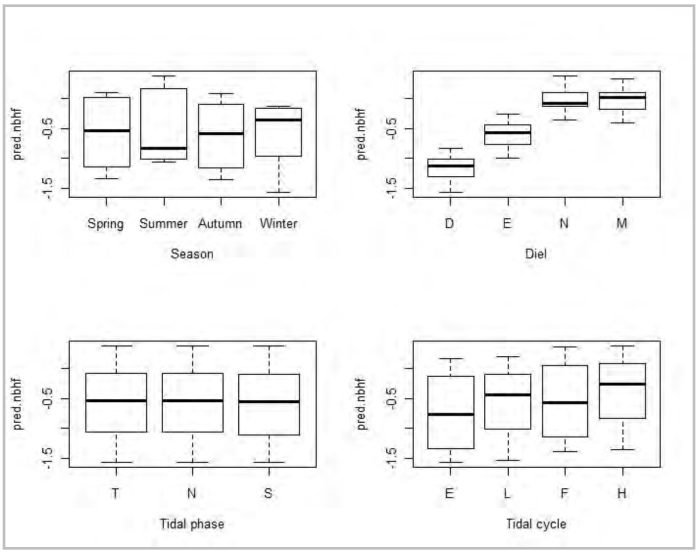


Figure 47. Predicted proportion of detection positive hours, in the narrow band high frequency channel at GDD2 (Co. Dublin), March 2015 – Mar 2017 (544 days) across the four variables of season; diel, where D =day, E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high.

3.3.2.4 GDD 3

GDD3 was the furthest site offshore, 1.5km from GDD2, and 2.5km from GDD1 (5km from land) and in a depth of approximately 24m. Similarly, for GDD3, the same analytical approach was followed and results showed all factors to be significant in 2015, 2016 and 2017. It was clear that there was a lot of variability between years and across factors (Table 10), but when all years were combined it was evident that all factors except tidal cycle were significant at GDD3.

Table 10. Results from GLMM's per year and all data combined from GDD3.

Location	Year	Variable	X^2	df	P-value
GDD3	2015	Season	30.5	4	0.000
		Diel	30.5	4	0.000
		T.P	30.4	3	0.000
		T.C	16.4	4	0.000
GDD3	2016	Season	119.4	4	0.000
		Diel	119.4	4	0.000
		T.P	43.9	3	1.0
		T.C	29.9	4	0.000
GDD3	2017	Season	279.0	4	0.000
		Diel	340.0	4	0.000
		T.P	26.3	3	1.3
		T.C	38.3	4	0.000
GDD3	all years combined	Season	105.5	4	0.000
		Diel	760.5	4	0.000
		T.P	144.3	3	0.000
		T.C	59.9	4	3.0

For GDD3 2015, results showed significantly more detections occurred across spring, summer and autumn when compared with winter. Although no significant difference was apparent in the box plot, the Walds test showed significance existed (χ^2= 30.5, p<0.000). Tidal phase and tidal cycle were also significant although again not apparent from the diagram (Table 10, Figure 48).

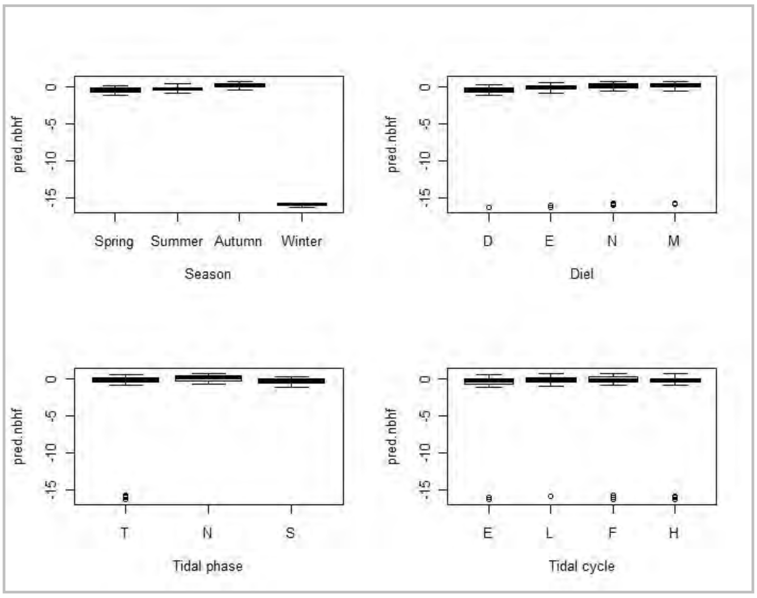


Figure 48. Predicted proportion of detection positive hours, in the narrow band high frequency channel at GDD3 (Co. Dublin) Mar– Dec 2015 across the four variables of season; diel, where D =day, E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high.

GDD3 for 2016 showed similar results to GDD1 and 2 where season showed significantly more detections during the spring and winter months (χ2= 119.4, p<0.000), and across diel cycle night and morning (χ2= 119.4, p<0.000). Significantly, more detections were recorded during the neap phase of the tide (χ2= 43.9, p<0.000), and during slack periods of the tidal cycle (χ2= 29.9, p<0.000; Figure 49).

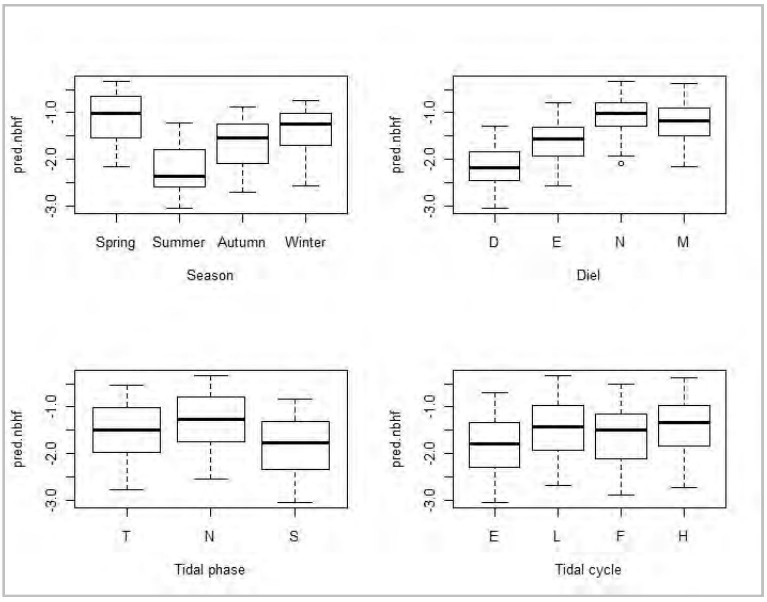


Figure 49. Predicted proportion of detection positive hours, in the narrow band high frequency channel at GDD3 (Co. Dublin) Jan– Dec 2016 across the four variables of season; diel, where D =day, E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high.

At GDD3 in 2017, results showed all factors to be significant except tidal phase (Table 10; Figure 50), and mirroring the results of GDD3 2016.

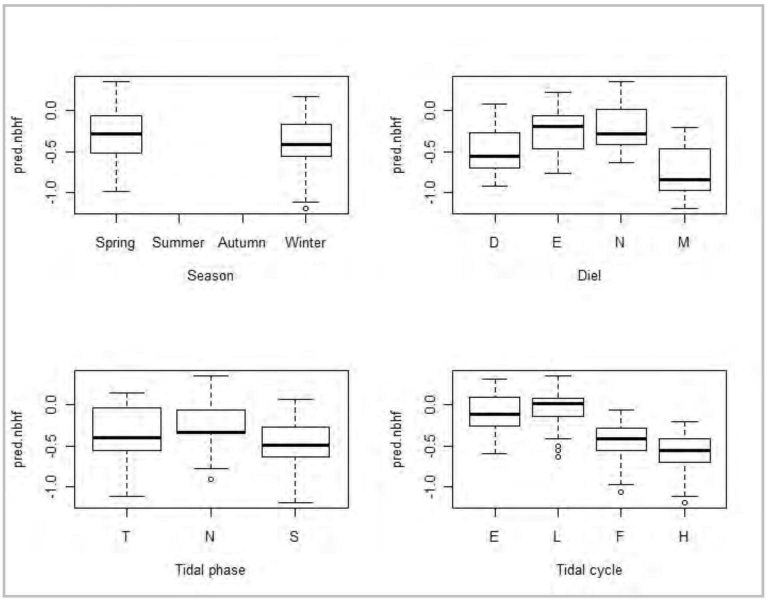


Figure 50. Predicted proportion of detection positive hours, in the narrow band high frequency channel at GDD3 (Co. Dublin) Jan – Mar 2017 across the four variables of season; diel, where D =day, E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high.

All GDD3 data across years were combined for the 530 days monitored at the site and results showed that all four factors were significant. In this instance significantly more detections occurred in Autumn ($\chi2= 279.1$, $p<0.000$), with most detections during the night and morning hours ($\chi2= 340$, $p<0.000$), while significantly more detections were recorded the neap tidal phase ($\chi2= 65.5$, $p<0.000$) at slack high tide ($\chi2= 38.3$, $p<0.000$; Figure 51).

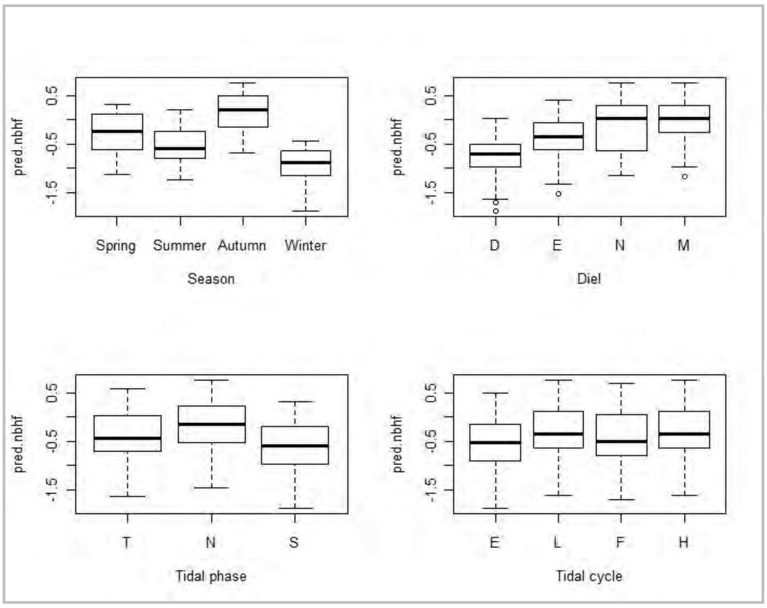


Figure 51. Predicted proportion of detection positive hours, in the narrow band high frequency channel at GDD3 (Co. Dublin) all months, March 2015 to March 2017 across the four variables of season; diel, where D =day, E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high.

In summary, results across all days monitored at each of the sites showed harbour porpoise to be present on average 98% of days monitored. The highest presence was detected across the autumn and winter months, during the hours of darkness (incl. dawn and dusk), during high tide and at GDD3 during the neap cycle of the tidal phase (Table 11). The site with the highest overall detections was GDD2.

Table 11. Significant results from the long-term dataset at each site (*no significance).

Significant factors	GDD1	GDD2	GDD3
Season	Autumn	Winter	Autumn
Diel	Night	Night	Night
Tidal phase	*	*	Neap
Tidal cycle	High	High	High

DISCUSSION

A combination of visual and acoustic, land and boat-based methodologies has provided a very detailed, high resolution assessment of the marine mammal community and its use of the site in line with best international practice. Visual surveys provided information on species identification, distribution and abundance and behaviour while acoustic data provided high resolution information on the use of the site by harbour porpoise including diel, tidal and temporal patterns.

4.1 Visual surveys

Marine mammals were recorded on 100% of survey days demonstrating the importance of the area for this important group of high nature conservation animals. Species recorded comprised of harbour porpoise, grey seal, harbour seal and minke whale.

Harbour porpoise were recorded on 83% of land-based surveys and 100% of boat-based surveys. Abundance was lowest from May to July, 2015 and from April to June, 2016. Harbour porpoise in Irish waters move offshore during spring and early summer, which is believed to associated with calving (Wall et al. 2013) and trends during the present study were consistent with this. Harbour porpoise abundance increased between August and January 2015 and between August and October 2016. Group size also increased during this period which coincided with a peak in sightings of young animals. In the North Atlantic, harbour porpoise calves are born in mid to late summer (Rogan & Berrow, 1996, Lockyer, 2003; Learmonth et al. 2014) and reliant on their mothers for 8-10 months (Learmonth et al. 2014). Female harbour porpoise may time calving so that high energetic demands such as lactation coincides with the availability of seasonally abundant local prey (Learmonth et al. 2014). In Irish waters, harbour porpoise feed primarily on fish with *Trisopterus* and gadoid species being important (Rogan & Berrow 1996, IWDG 2009, Hernandez-Milian 2014). The peak in abundance of harbour porpoise may therefore be attributed to the inshore movement of porpoise to feed on locally abundant prey. The increase in group size recorded during this time is most likely due to the presence of nursing calves.

The area has also been shown to be important for grey seals with individuals recorded on 100% of land-based surveys and 91% of boat surveys. Sightings were highest in April 2015 which coincided with the end of the male moulting season and January 2016 which coincided with the end of the female moult (Kiely et al. 2000). High numbers were also recorded in September 2015, November 2015 and October 2016 which spans the grey seal breeding and pupping season (Ó Cadhla, 2007). Sightings largely consisted of single adults although two juveniles were recorded in September 2015 beside Ireland's Eye. Seals tended to occupy more westerly waters than the harbour porpoise and were often seen following fishing boats, feeding and hauling out on Ireland's Eye at low tide.

Few other marine mammal species were recorded. Although Lambay Island SAC is designated for both grey seal and harbour seal, only two individual harbour seals were recorded during this study, one each in April and August 2015. Two sightings of single minke whales were recorded during two boat-surveys, one in June 2015 and one in August 2016. These records are similar to a previous study where minke whales were recorded from late April to early August off north Co. Dublin (Wall et al. 2013).

4.1.1 Density and abundance for harbour porpoise

For seven of the eleven surveys carried out, the number of sightings were sufficient to derive density and abundance estimates for harbour porpoise. Within the area surveyed, the density of harbour porpoise varied from 0.61 to 2.29 harbour porpoise per km^2, with a mean density of 1.32, which was similar to previous surveys in the area (Table 12). Densities were lowest in April 2015 and February 2016, peaking in August 2015, November 2015 and August 2016, with lower but still relatively high densities in October 2016 and January 2017.

Harbour porpoise densities were previously derived for two sites off Co Dublin in 2008 and for the Rockabill to Dalkey Island SAC in 2013 and 2016. The area surveyed off North County Dublin was similar to the area surveyed in the present study. Density estimates from North County Dublin in 2008 varied considerably but the highest density of porpoises recorded at any site in Ireland so far was recorded at 6.93 porpoises per km^2 in August 2008. However estimates during other surveys during 2008 were much lower, which resulted in an overall density estimate of 2.03 harbour porpoise per km^2.

Table 12. Density, abundance and group size estimates for harbour porpoise in North County Dublin

Location	**Year**	**Area (km^2)**	**Mean group size**	**Density (per km^2)**	**Abundance ± SE (95% CI)**	**CV**	**Reference**
Greater Dublin Drainage	2015-17	201	1.39	1.32	248	-	This report
Rockabill to Dalkey Island SAC	2016	273	1.62	1.55	424±45 (335-536)	0.10	O'Brien and Berrow (2016)
Rockabill to Dalkey Island SAC	2013	273	1.47	1.44	391±25 (344-445)	0.06	Berrow and O'Brien (2013)
North County Dublin	2008	104	1.41	2.03	211±47 (137-327)	0.23	Berrow *et al.* (2008a)
Dublin Bay	2008	116	1.19	1.19	138±33 (86-221)	0.24	Berrow *et al.* (2008a)

If we use the average of the overall density estimates from 2008 for the two sites it equates to 1.61 which is higher but similar to the present survey. A previous wider-scale line-transect survey in the north Irish Sea, to the east and north of the current SAC, derived a density estimate of 1.59±0.22 porpoises per km^2 (Berrow et al. 2011). This was also of a similar magnitude to that calculated from the present survey.

Density estimates within the Rockabill to Dalkey Island SAC were greater in 2016 than presented here but only by 10-15% which suggests the present study area is very favourable for porpoise with densities similar to those within an SAC. Indeed, there was remarkable consistency in density estimates across all surveys carried out in North County Dublin since 2013 which were consistently elevated compared to sites surveyed elsewhere in Ireland (Berrow et al. 2014).

Thus this survey has, despite quite considerable variability in density estimates, provided a mean density very similar to previous studies. This density is high and emphasizes the importance of this site for this species as these are some of the highest densities of harbour porpoise recorded to date in Ireland.

4.2 Static Acoustic Monitoring

Cetaceans live in an acoustic world and increasingly attempts have been made to develop acoustic monitoring techniques rather than relying on visual methods, where efficacy is dependent on light, weather conditions and sea-state, especially for species such as the elusive harbour porpoise. Their reliance on vocalisations for navigation and communication is essential and therefore acoustic monitoring is a very valuable tool for determining presence and assessing fine-scale habitat use. The main advantage of acoustic monitoring is that it can provide information on species that spend up 95% of the time underwater and thus can be difficult to observe (Read & Westgate 1995). 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, O'Brien et al. 2013), diel cycles (Cox & Read 2004, Carlström 2005, Todd et al. 2009, O'Brien et al. 2013) and tidal patterns (Marubini et al. 2009, O'Brien et al. 2013). In order to evaluate the importance of an area, it is fundamental that the presence of small odontocetes is fully understood and this requires monitoring over varying time scales. Although SAM can provide a much more complex account of cetacean activity at a site in comparison to visual monitoring, it cannot present accurate estimates of abundance for which visual surveys are required.

The aim of the present study was to produce a detailed assessment of the use of the site by marine mammals and to provide baseline data. Cetacean occurrence in the general area was achieved through visual surveys but detailed information on the use of the proposed route of the discharge pipe off Portmarnock sites was achieved through static acoustic monitoring. The data collected at Portmarnock was compared with the smaller dataset collected off Loughshinny, which was treated as a control site and with other regional sites.

The acoustic data demonstrated that the all three sites monitored along the proposed route of the outfall pipe off Portmarnock are used consistently by harbour porpoises on a daily basis. However, presence was greater during autumn and winter, during hours of darkness and at slack high tides. When the data from Portmarnock are compared to Loughshinny data collected in 2015 (Meade et al. 2015) results were similar with autumn having the highest detections, however, only six months were monitored. Tidal cycle was not significant at Loughshinny in contrast to Portmarnock, where more detections were recorded during spring tidal phase. Monitoring index at Loughshinny was high at 9.8%, while at Portmarnock values ranged between 2.8 and 6.6 across sites, suggesting Loughshinny is the most important site monitored for harbour porpoise during the GDD project.

Trends in the presence of harbour porpoise with diel cycle on the east coast of Ireland have been found to differ geographically, but they are consistently 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).

The results from Portmarnock and Loughshinny are compared to other sites around Ireland (Table 13). Some of the highest DPM's recorded to date were from Loughshinny, especially given deployments were only for six months. Some of the early studies used T-PODs, which are an earlier version of the C-POD. Previous work by O'Brien et al. (2013) showed that C-PODs recorded on average, seven times more data than T-PODs during simultaneous deployments in Galway Bay. However, it is clear that deployments from the east coast have a greater number of detections per deployment from any other monitored site in the country. Previous deployment off Howth Head recorded 12.2 DPM/hr, in comparison to the present study with an average across sites of 2.7. However, the Howth deployment was over a short duration using a T-POD. The Portmarnock dataset is similar to that at Spiddal in Galway Bay with a similar number of deployment days. Galway Bay is not a designated SAC while the Portmarnock area lies within the boundaries of the Rockabill to Dalkey SAC. When the present data is compared with other deployments around Ireland, such as the Blasket Islands SAC, the number of detections from Co. Dublin were still much greater.

Table 13. Monitoring results from SAM across Ireland (green line denotes data collection using T-PODs so some caution necessary when interpreting results.

County	Site	Total days	DPD %	Total PPM	%DPM	Mean DPM/day	Mean DPM/hr	Reference
Dublin	GDD1	556	96	29,851	2.8	41.3	1.7	*Present study*
Dublin	GDD2	544	98	46,379	6.6	94.3	4.0	*Present study*
Dublin	GDD3	540	99	31,266	3.0	57.6	2.4	*Present study*
Dublin	Loughshinny	189	100	26,281	9.6	137	5.8	Meade *et al.,* 2015
Galway	Spiddal	572	541	27,902	3.4	48.8	2.0	O'Brien *et al.,* 2013
Kerry	Inishtooskert	264	236	3930	1.04	14.9	0.6	O'Brien *et al.,* 2013
Kerry	Wild Bank	289	221	2097	0.51	7.3	0.3	O'Brien *et al.,* 2013
Kerry	The Gob	52	49	3015	4.1	58.0	2.4	O'Brien *et al.,* 2013
Dublin	Howth	47	100	13718	10.1	291.9	12.2	Berrow *et al.* (2008a)
Cork	Castlepoint	63	100	1379	2.0	21.9	0.9	Berrow *et al.* (2008a)
Cork	Sherkin	23	44	707	1.0	30.7	1.3	Berrow *et al.* (2008a)
Cork	Galley Head	63	30	1614	2.4	25.6	1.1	Berrow *et al.* (2008a)

It is clear from both the visual and acoustic surveys that North County Dublin is an important area for marine mammals, especially harbour porpoise. Marine mammals were present during 100% of visual surveys although abundance did vary throughout the year. The site is also important for grey seals which were recorded throughout the year. Grey seals can be sensitive to disturbance particularly during the breeding season (Kiely et al. 2000), which occurs from August to December (O'Cadhla, 2007). The proposed outfall site is 8km to Lambay Island SAC which is the most important site for grey seals on the east coast of Ireland (Kiely et al. 2000).

Harbour porpoise numbers increased in late summer during both 2015 and 2016 which coincided with the presence of calves and may be due to seasonally abundant food sources such as sprat, herring and *Trisopterus* and gadoid species. Reduced numbers were recorded during late spring/early summer which may be associated with an offshore movement of this species before calving. The density estimate of harbour porpoise was high and emphasizes the importance of this site for this species as these are some of the highest densities recorded in Ireland to date. Acoustic monitoring provided an insight into the habitat use of the site across time and diel and tidal cycles, which could not be recorded from visual surveys. Harbour porpoise were present almost daily at the Portmarnock site, with their presence influenced by seasonal, diel and tidal factors.

4.3 Recommendations

Harbour porpoises and grey seals, both of which are listed under Annex II of the Habitats Directive, are entitled to strict protection including their habitat, and extreme care must be taken to ensure the proposed development does not degrade this habitat or cause undue disturbance. These results will serve to inform protocols of best practice if work goes ahead and thus ensure the presence of marine mammals in the area is not negatively impacted upon.

Mitigation measures should take into account the acoustic disturbance of marine mammals at the site and any associated noise input or long-term potential disturbance should be reviewed to minimise displacement and to prevent habitat exclusion or hearing impacts such TTS or PTS. Mitigation measures should be in accordance with the NPWS document "*Guidance to Manage the Risk to Marine Mammals from Man-made Sound Sources in Irish Waters*" to ensure impacts through habitat exclusion or noise impacts are minimised. In order to assess if any displacement of harbour porpoise occurs, we recommend acoustic monitoring is carried out at a control site such as the Loughshinny site during and after installation works, with additional monitoring close to the actual outfall point post construction.

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APPENDIX – Results from the Loughshinny Marine Mammal Surveys

5.1 Land-based Observations

Land-based monitoring commenced on 18 March and finished on 7 September 2015. Twenty hours of monitoring was conducted over six surveys throughout the monitoring period (Table 14).

5.1.1 Environment

The weather was favourable throughout the surveys with no swell, sea state ≤2and visibility of 6-20km. Precipitation was recorded on two days in July and September. On 13 July, rain was recorded for 39% of the survey. Thirty one (31%) of the rain was recorded as light intermittent and eight (8%) was recorded as heavy. On 07 September, light intermittent rain was recorded for 13% of the survey (Table 14).

Table 14. Environmental conditions recorded during the Loughshinny land-based surveys

Date	Sea state (predominant)	Swell (m)	Visibility (km)	Cloud cover (*/8)	Precipitation (%)	Precipitation Intensity
18 March	1	0	6-10	0	0	-
21 April	1	0	16-20	0	0	-
23 May	1	0	16-20	7	0	-
13 July	2	0	16-20	8	46	Light intermittent
12 August	1	0	16-20	2	0	-
7 September	1	0	16-20	8	13	Light intermittent

5.1.2 Marine Mammal Sightings

Marine mammals were sighted on 86% of land-based survey days. Two marine mammal species were recorded; harbour porpoise and grey seal. Harbour porpoise were present on 67% of days with a peak in numbers recorded in September (Figure 52, Figure 53). Two harbour porpoise calves were recorded during the September survey. Seal species were present on 67% of days (Figure 54, Figure 55). All seal sightings were of adult individuals and consisted of 10 grey seals and two unidentified seal species.

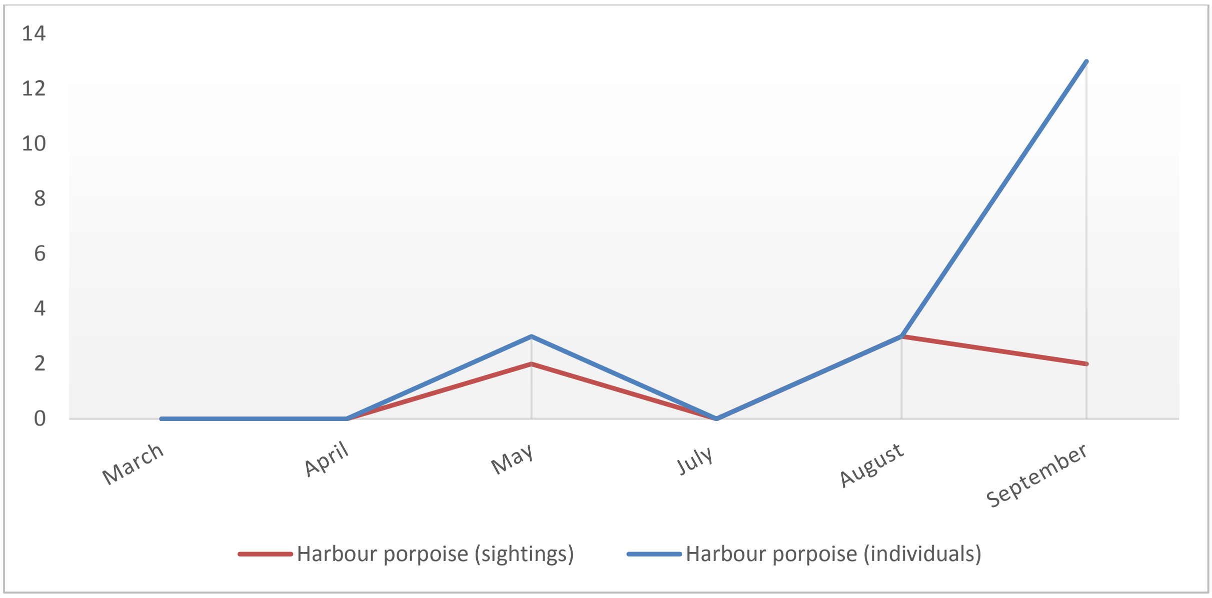

Figure 52. Number of harbour sightings and individuals recorded during Loughshinny land-based surveys

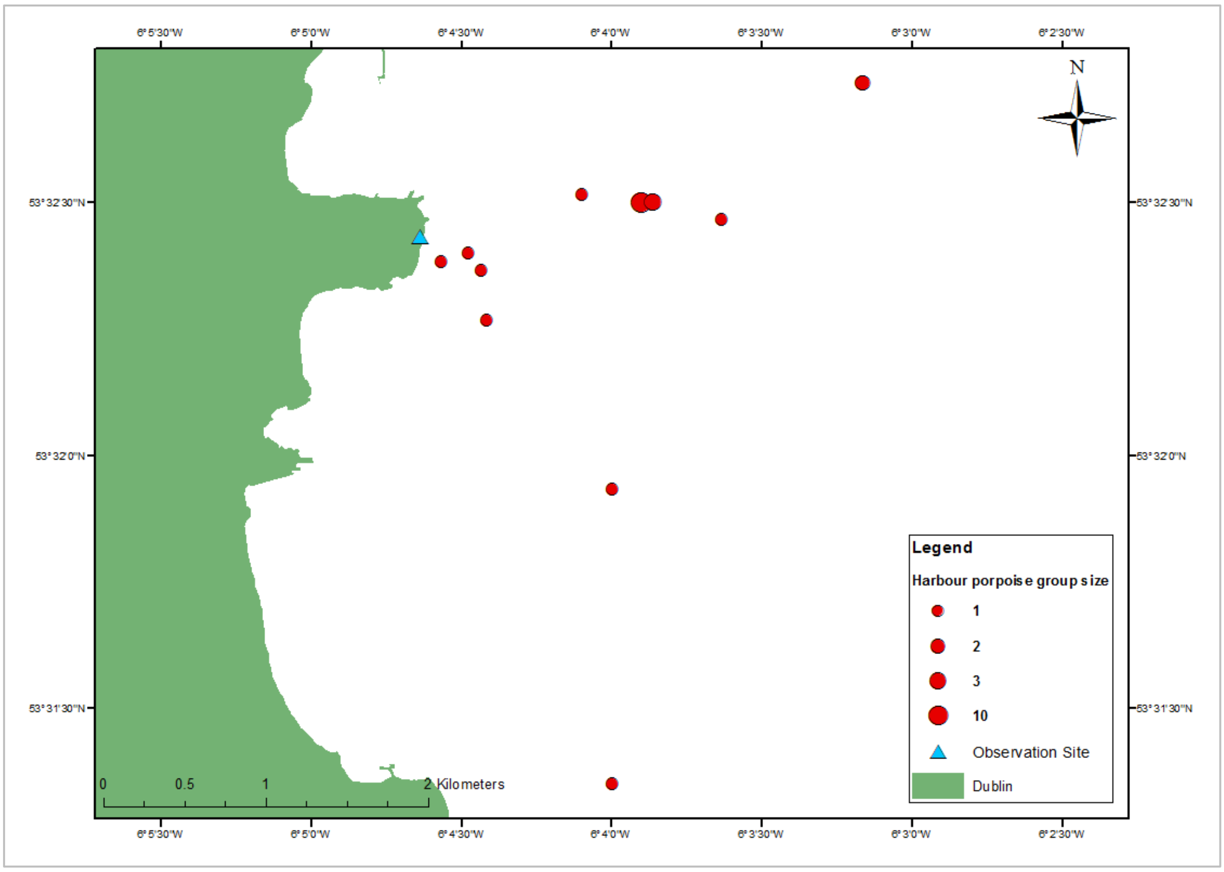

Figure 53. Distribution and group size of harbour porpoise sightings off Loughshinny

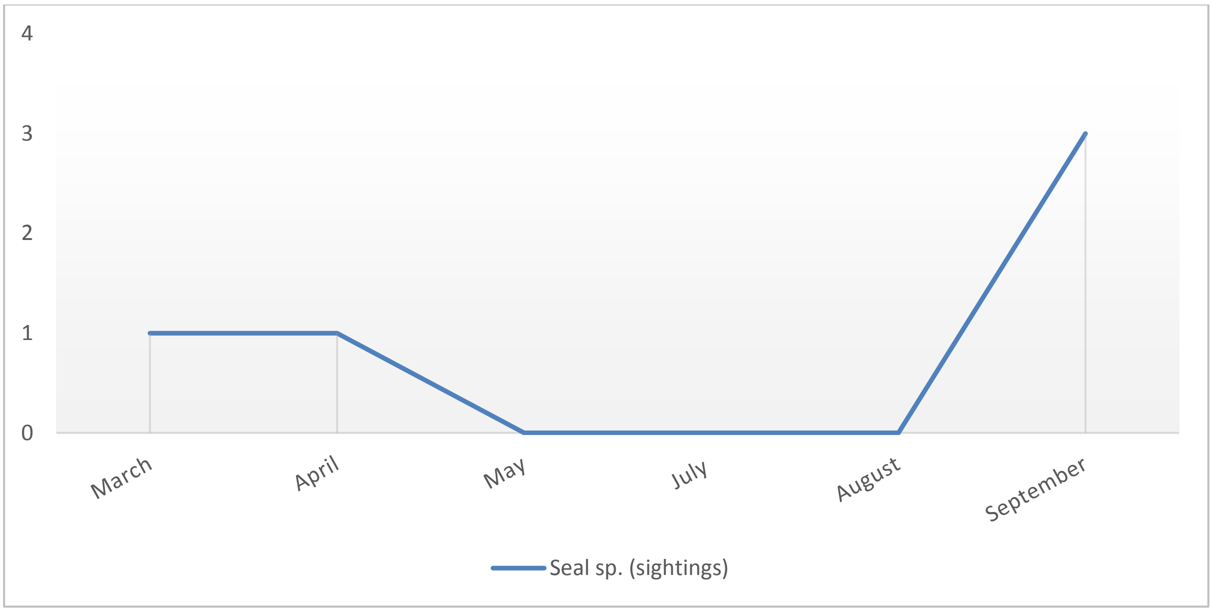

Figure 54. Number of seal sightings recorded during Loughshinny land-based surveys (all single adults)

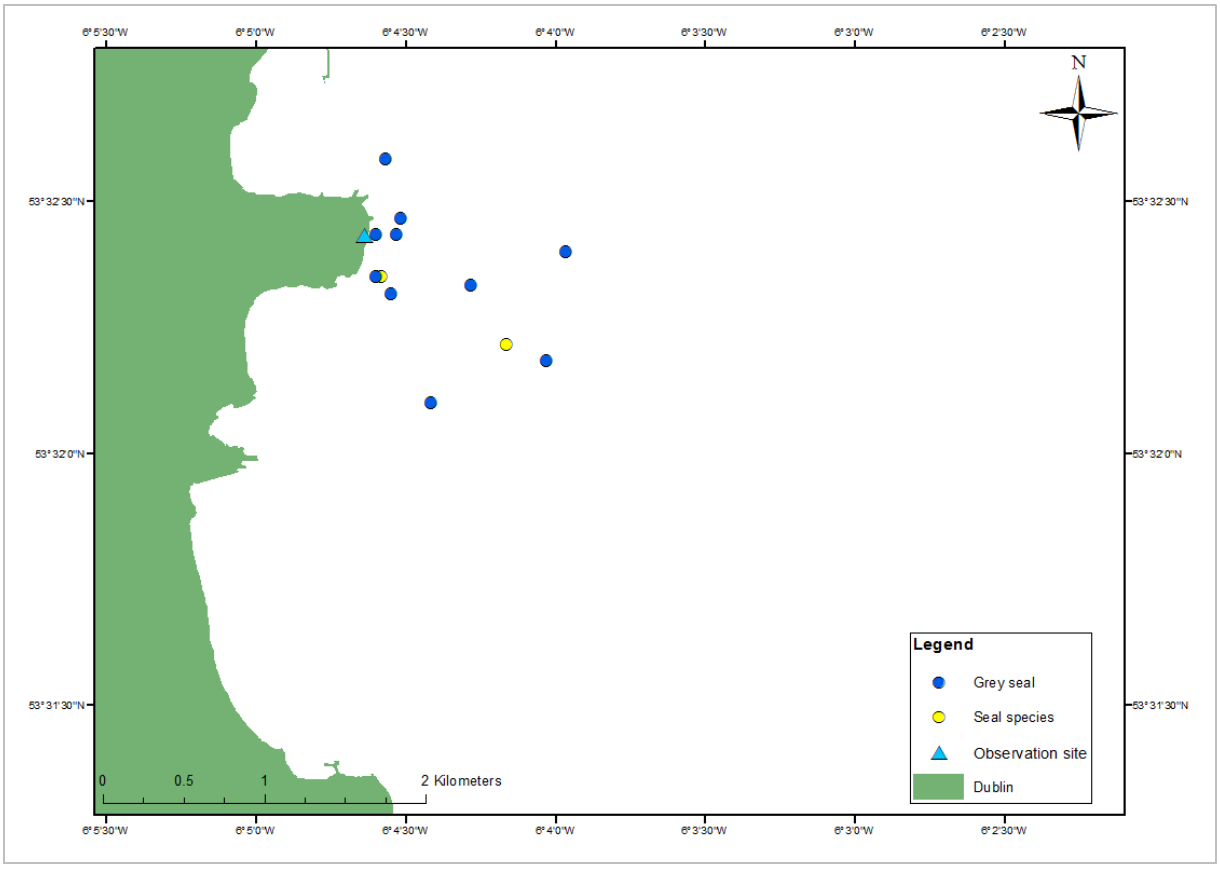

Figure 55. Distribution of seal sightings off Loughshinny

Table 15. Summary of Loughshinny land-based marine mammal surveys showing percentage sea state during survey.

Date	Sea state (% of total survey time)				Number of harbour porpoise sightings	Number of seal sightings	Number of harbour porpoise individuals	Number of seal individuals
	0	1	2	3				
18 March	0	66	33	0	2	5	2	5
21 April	0	100	0	0	0	2	0	2
23 May	40	60	0	0	3	1	4	1
14 July	0	8	92	0	0	0	0	0
12 August	31	69	0	0	3	0	3	0
7 September	7	93	0	0	3	4	14*	4
Total					**11**	**12**	**23**	**12**

*includes 2 calves

5.1.2.1 Focal Follow Observations

Two focal follows were obtained over two days in March and May. During March, a single adult harbour porpoise was tracked with every behaviour recorded for a total of 18 minutes and in May, an individual adult harbour porpoise was followed for 26 minutes (Figure 56).

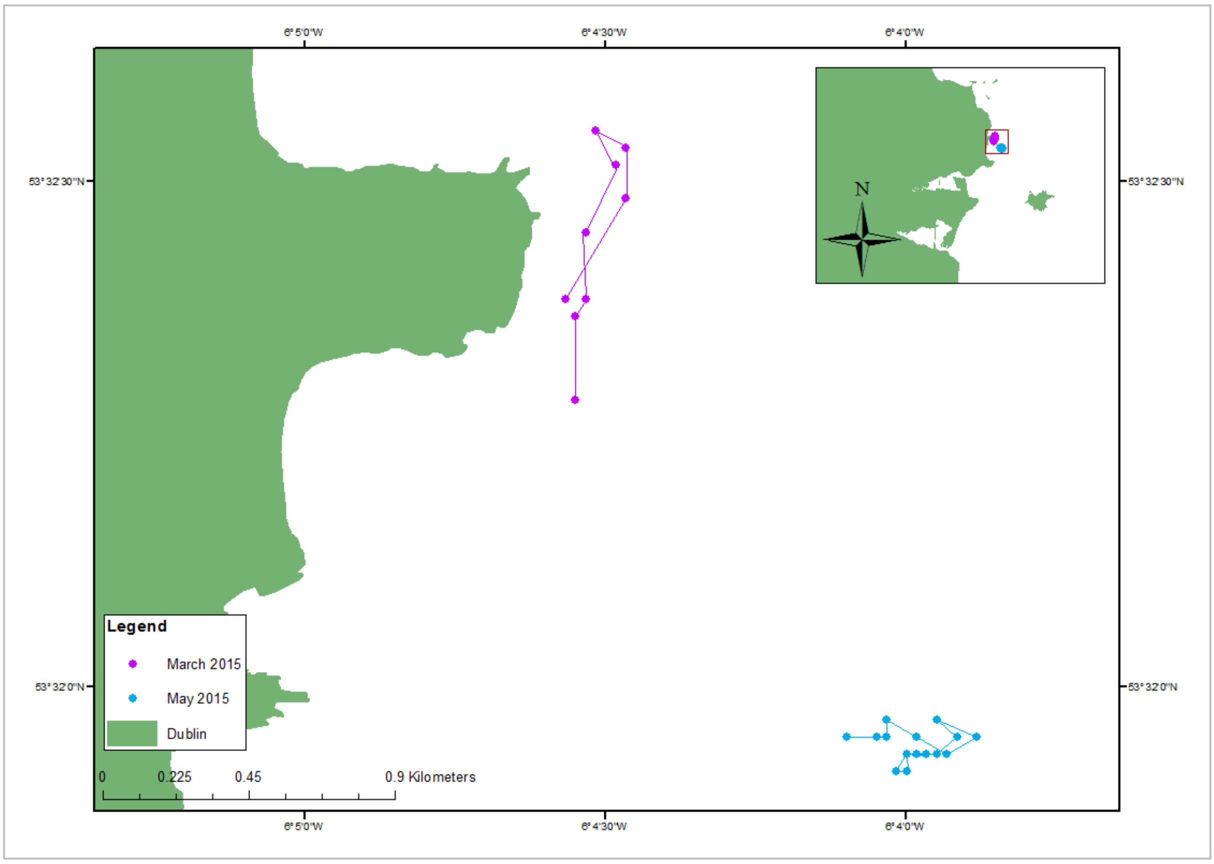

Figure 56. Focal follow tracks of single harbour porpoise during March and May 2015 from Loughshinny land-based site

5.2 Boat-based Surveys

A boat-based survey was attempted on 19 March but fog prevented the vessel from leaving Dun Laoghaire harbour. Three successful surveys were carried out on 20 April, 10 June and 11 August 2015.

5.2.1 Environment

Environmental conditions were generally favourable with the exception of the June survey (Table 16) which although 64% of effort was within the targeted sea state (≤2), was not ideal for detecting harbour porpoises. Weather forecasts for the day consistently reported light winds of 5-7kts from NE for the survey day and minimal swell. We experienced 10 and up to 14kts during the survey with an occasional moderate swell. Even during the survey the forecasts checked (at least three independent forecasts) stated light winds however sea-state was greater than predicted. These local variations have been experienced before during IWDG surveys at this location (e.g. Berrow and O'Brien 2013).

Table 16. Environmental conditions recorded during boat-based marine mammals surveys

Date	**Sea state (%)**				**Predominant swell (m)**	**Predominant visibility (km)**
	0	**1**	**2**	**3**		
20 April	0	27	65	8	1	16-20
10 June	0	14	50	36	0	16-20
11 August	17	63	20	0	0	16-20

5.2.2 Marine Mammal Sightings

Marine mammals were sighted on 100% of survey days (Table 17). Four marine mammal species were recorded during the survey period; harbour porpoise, grey seal, harbour seal and minke whale (Figure 57, Figure 58, Figure 59). All sightings were of adults with the exception of the August survey where four juvenile harbour porpoise and one calf were recorded.

Table 17. Summary of boat-based marine mammal surveys covering Loughshinny in 2015

Date	**No. of harbour porpoise sightings**	**No. of seal sightings**	**No. of harbour porpoise individuals**	**No. of seal individuals**	**No. of other marine mammals**
20 April	11	2	15	2	0
10 June	3	1	3	1	1 (minke whale)
11 August	20	2	37	2	0
Total	**34**	**5**	**55**	**5**	

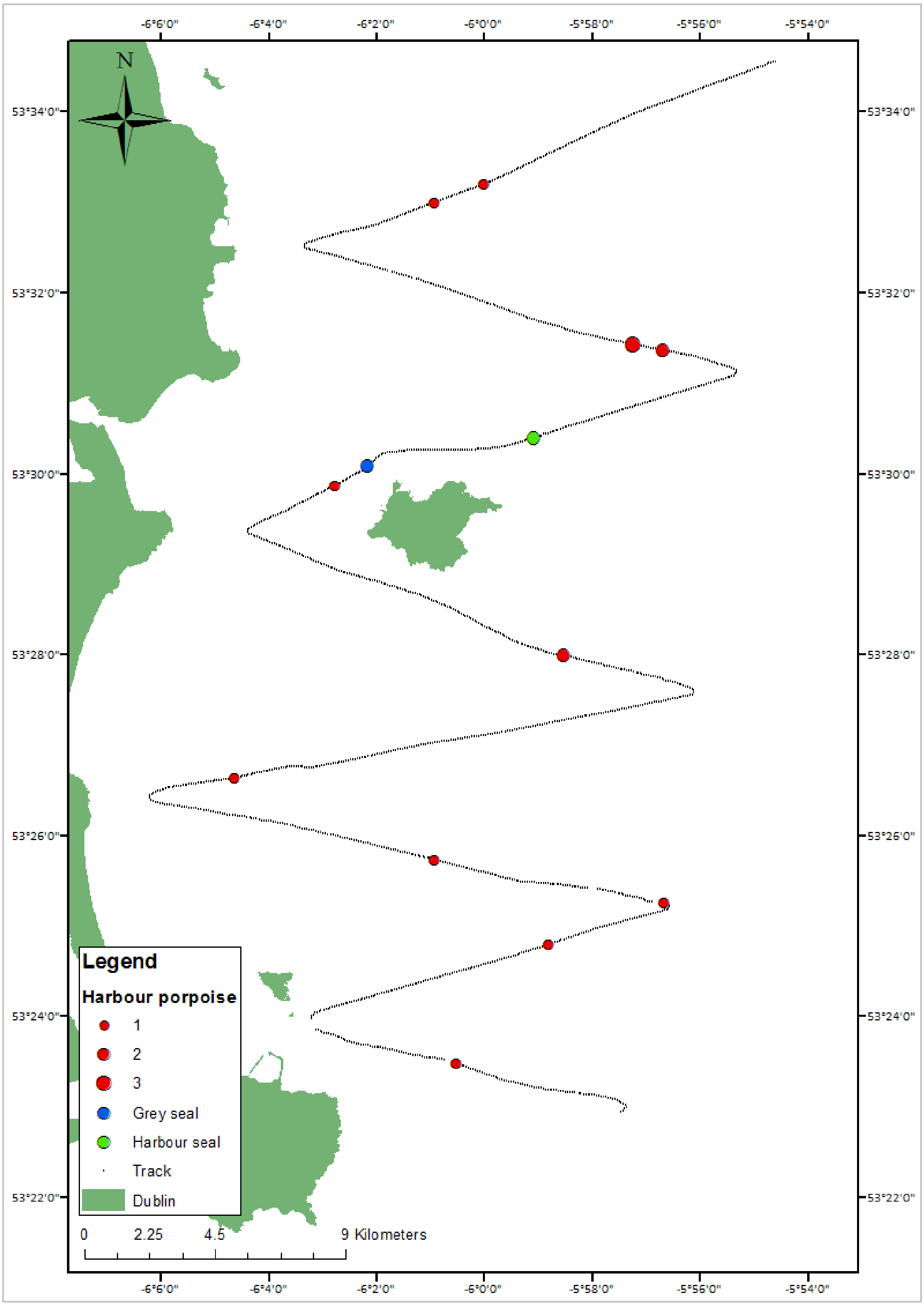

Figure 57. Map of transect line and marine mammal sightings for April 2015 boat-based survey

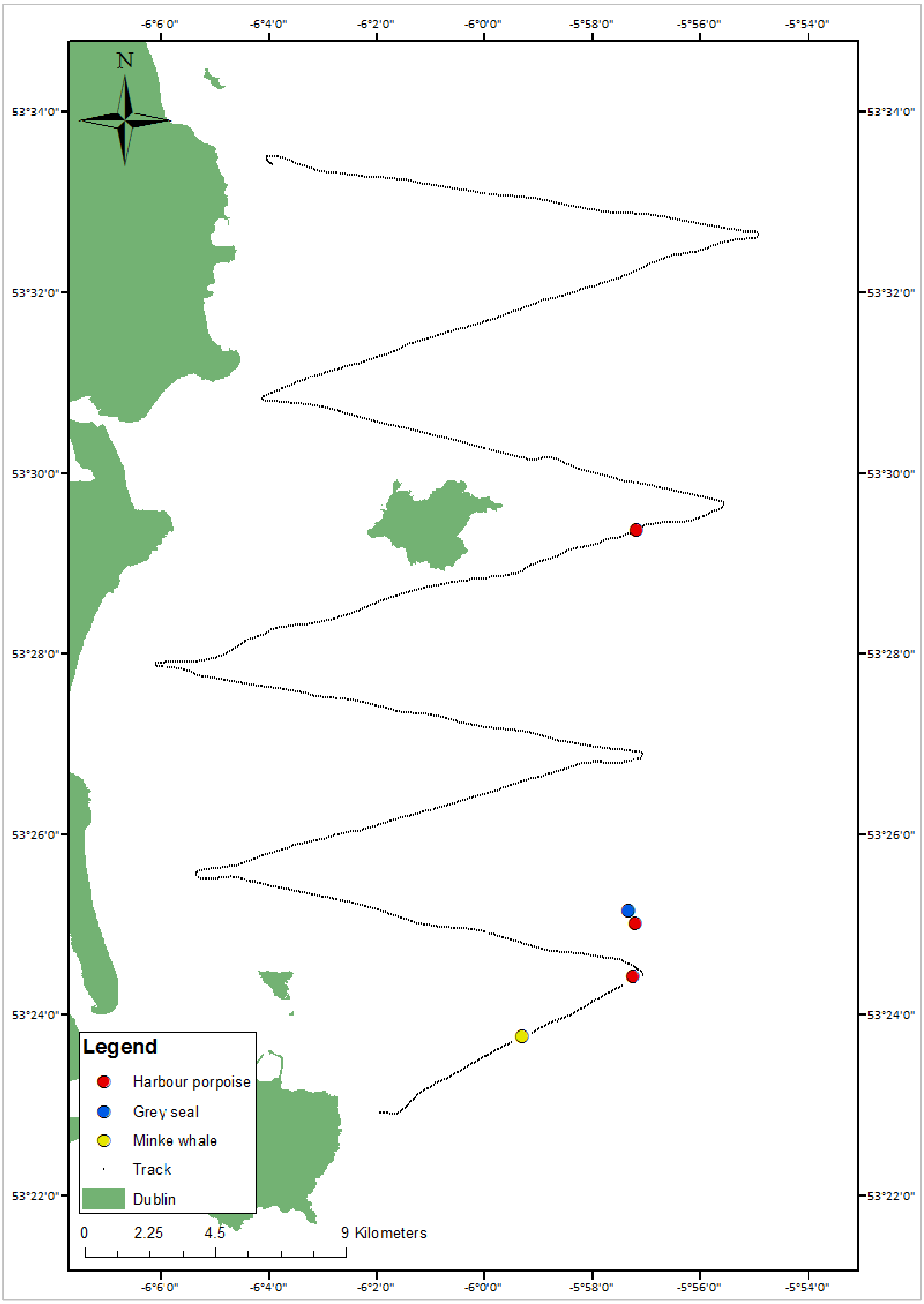

Figure 58. Map of transect line and marine mammal sightings for June 2015 boat-based survey

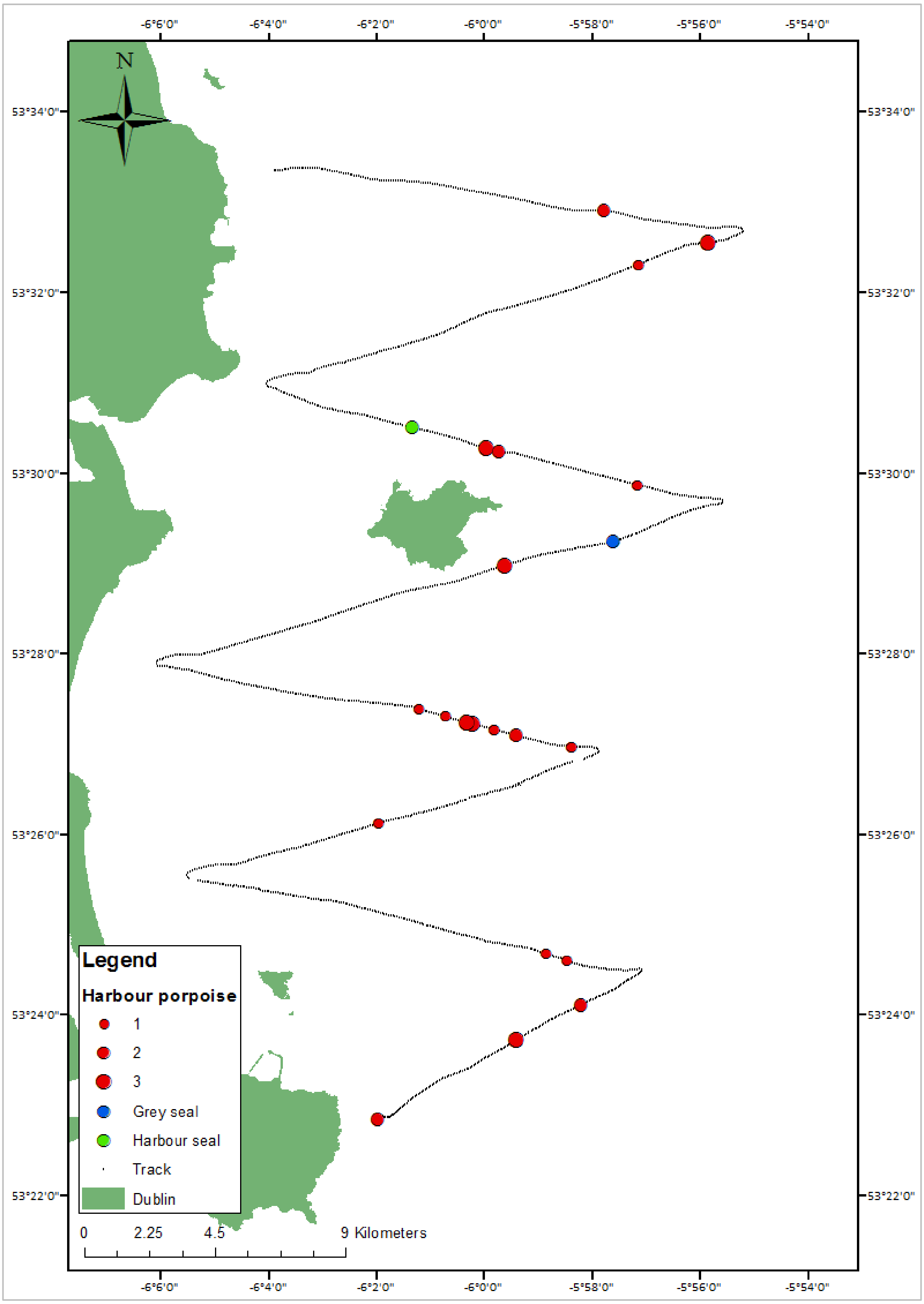

Figure 59. Map of transect line and marine mammal sightings for August 2015 boat-based survey

5.2.2.1 *Density and abundance estimation*

Density estimates for harbour porpoises calculated for two of the three survey days and not for survey two as the number of sightings (n=5) were too few to derive a reliable density estimate. The detection functions for harbour porpoise during all surveys are shown graphically (Figure 60). Using the Chi-squared test for goodness of fit to the DISTANCE model data for the first survey were poor (P=0.92) but for survey 2 better (P=0.62).

Evasive reactions of porpoises from the survey vessel were most evident on survey 1, with a peak in sightings some 50-100m from the track-line (Figure 60), most likely resulting in an underestimate of animal density. Variation in cluster size was greater during the first survey which contributed a greater proportion of the variability.

Mean group (cluster) size was greater on survey 3 (1.85±0.20) compared to survey 1 (1.44±0.27) suggesting a trend of increasing group size with time which was consistent with land-based observations.

Table 18. Model data used in the harbour porpoise abundance and density estimation process for the Greater Dublin Drainage project(Note: A half-normal model with cosine series adjustments and sightings data truncated at 200m for Survey 1 and 300m for Survey 2 and Overall analysis was used).

Sample Day	Chi^2 P value	Effective Strip Width (m)	Number of sightings	Mean Cluster size ± SE	Variability (%)		
					Detection	Encounter	Cluster
1	0.924	104.65	11	1.44±0.27	67.6	-	32.4
3	0.602	148.78	20	1.85±0.20	84.1	-	15.9
Overall	**0.811**	**144.2**	**31**	**1.68±0.15**	**38.3**	**55.0**	**6.7**

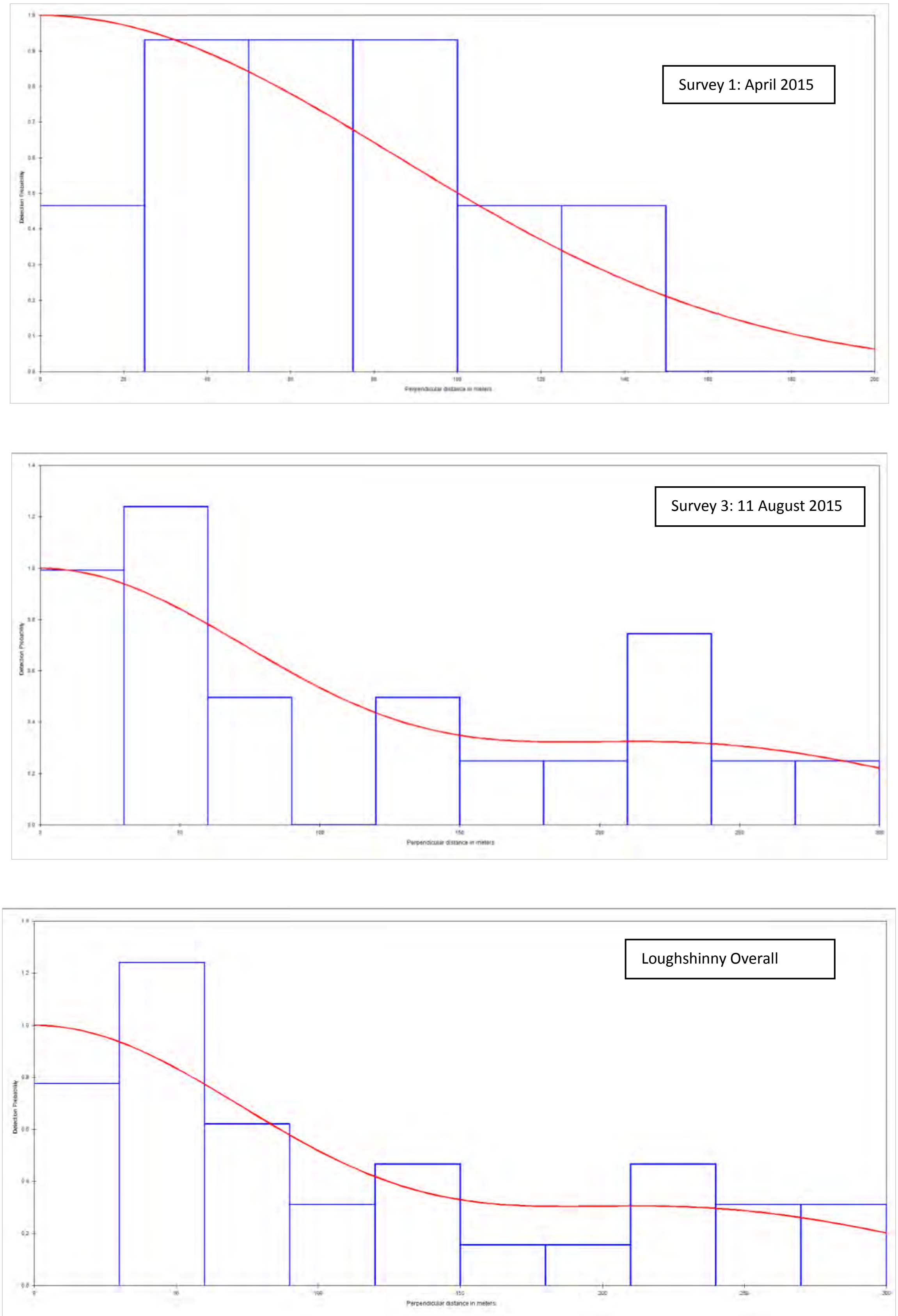

Figure 60. Detection functions plots for harbour porpoise during boat-based surveys

Density and abundance estimates for harbour porpoise in the Rockabill to Dalkey Island SAC are shown in Table 19. The density estimates were quite different between surveys with highest densities on survey 3 correlating with the survey with the greatest number of sightings as the track length and area surveyed were the same. This produced an overall abundance estimate of 256±93 porpoises with 95% Confidence Intervals of between 87-751 porpoises and a CV of 0.37.

Table 19. Estimated density, abundance (N) and group sizes of harbour porpoise recorded for the Greater Dublin Drainage project

Sample Day	N (95% CI)	SE	CV	Density (per km^2)	Mean group size (95% CI)
1	154 (77-306)	54	0.33	0.78	1.44 (1.00-2.12)
3	361 (192-681)	114	0.32	1.91	1.85 (1.48-2.30)
Overall[1]	**256 (87-751)**	**93**	**0.37**	**1.31**	**1.67 (1.39-2.01)**

[1] – includes combined sightings and effort data from both surveys

5.3 Static Acoustic Monitoring

5.3.1 C-POD Calibrations

All units used over the duration of the present study were calibrated as part the long-term GDD monitoring project (Loughshinny and Portmarnock). Results of both trials are presented below (Figure 61-66). From the calibration trials, results showed that there were some discrepancies between units. Further exploration into individual unit performance showed that C-POD performance was within the acceptable error margin of ±20% DPM per hour (Figure 63-Figure 66) and therefore no correction factor was required to be applied to the data to make it comparable (O'Brien *et al*. 2013). During analysis of the long-term dataset, differences in sensitivities between units is accounted for by inserting the C-POD number as a random factor when running the generalized linear mixed-effect models.

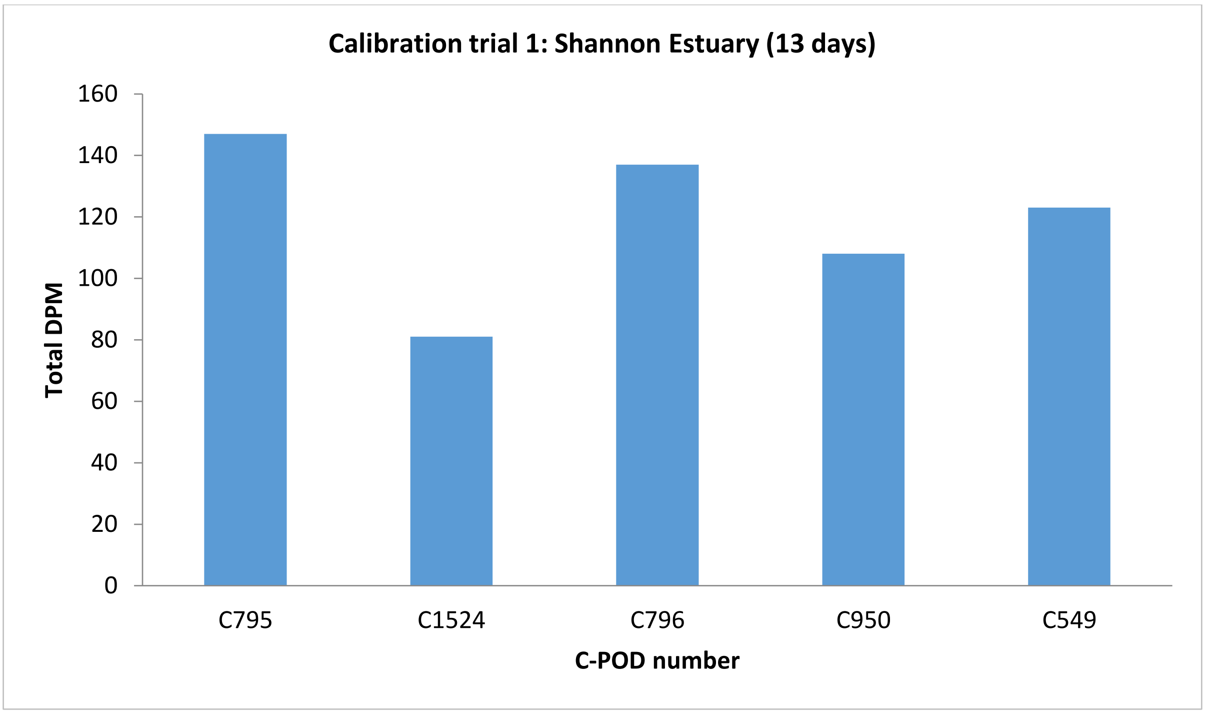

Figure 61. Detection Positive Minutes from all C-PODs deployed during calibration trial 1 in the Shannon Estuary

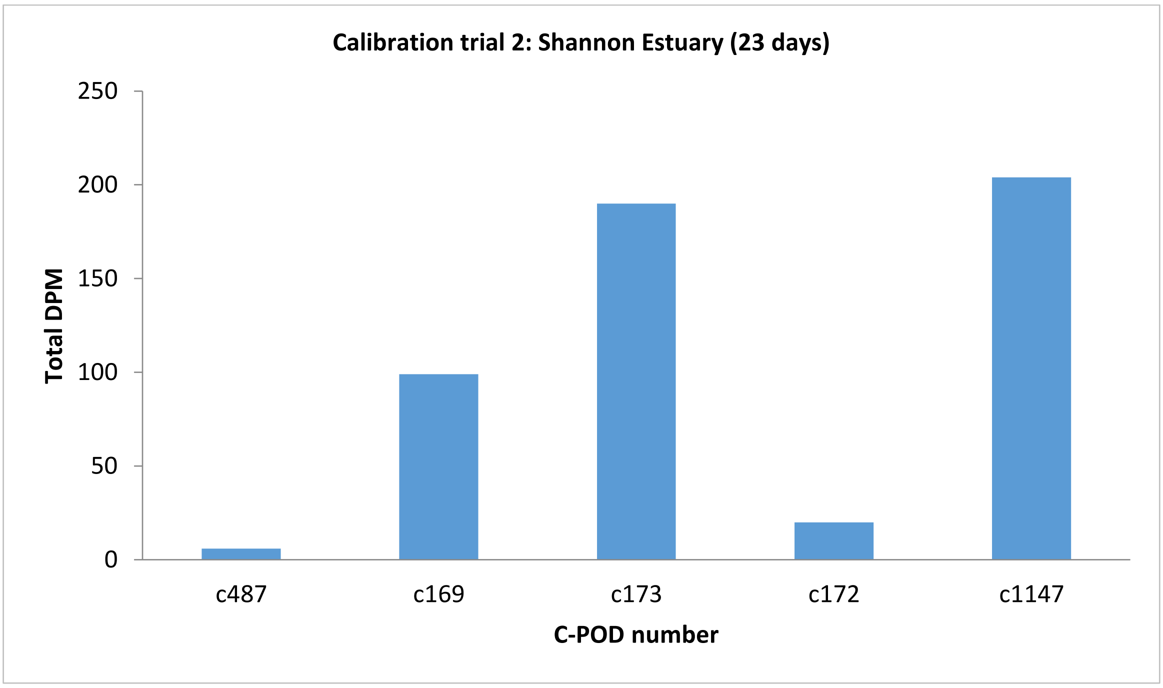

Figure 62. Detection Positive Minutes from all C-PODs deployed during calibration trial 2 in the Shannon Estuary

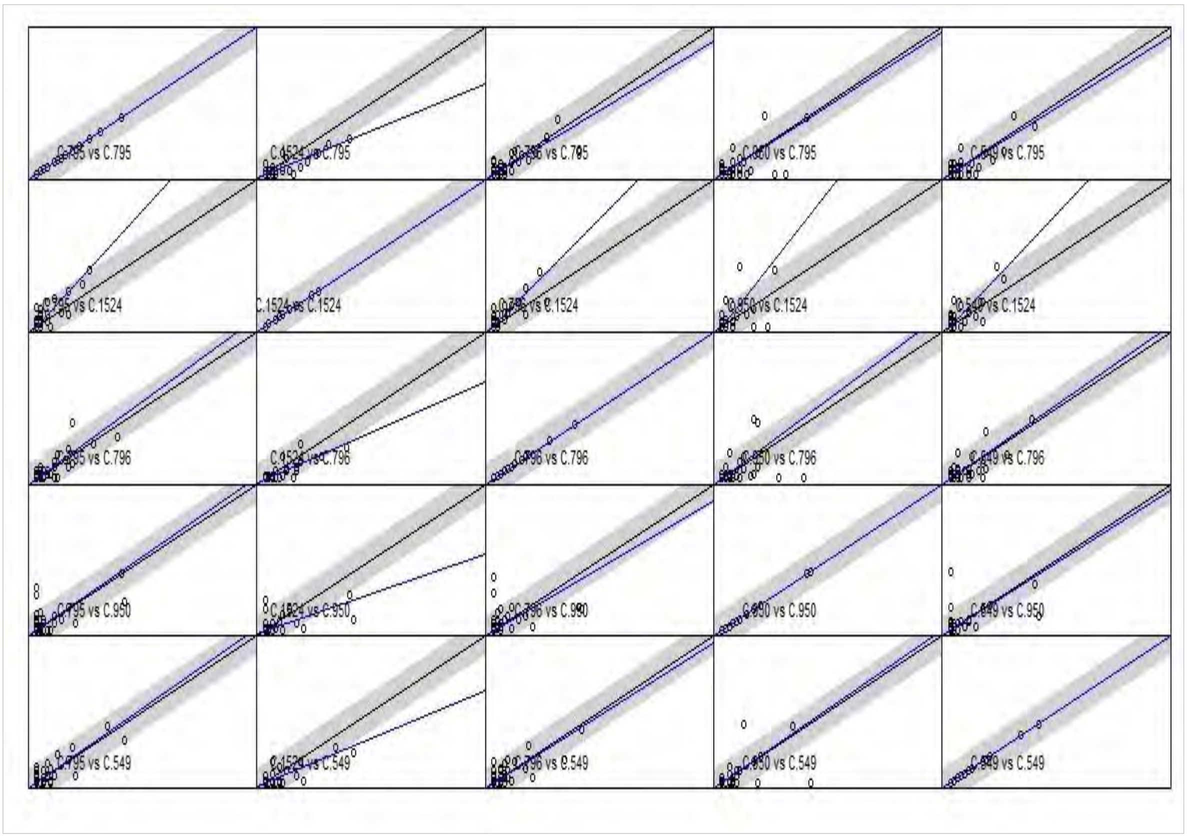

Figure 63. Orthogonal regression plot of C-POD comparisons in calibration trial, in blue, with a null model where each unit performs exactly the same, in black and an acceptable error margin of ±20%, in grey from Calibration 1, January 2015

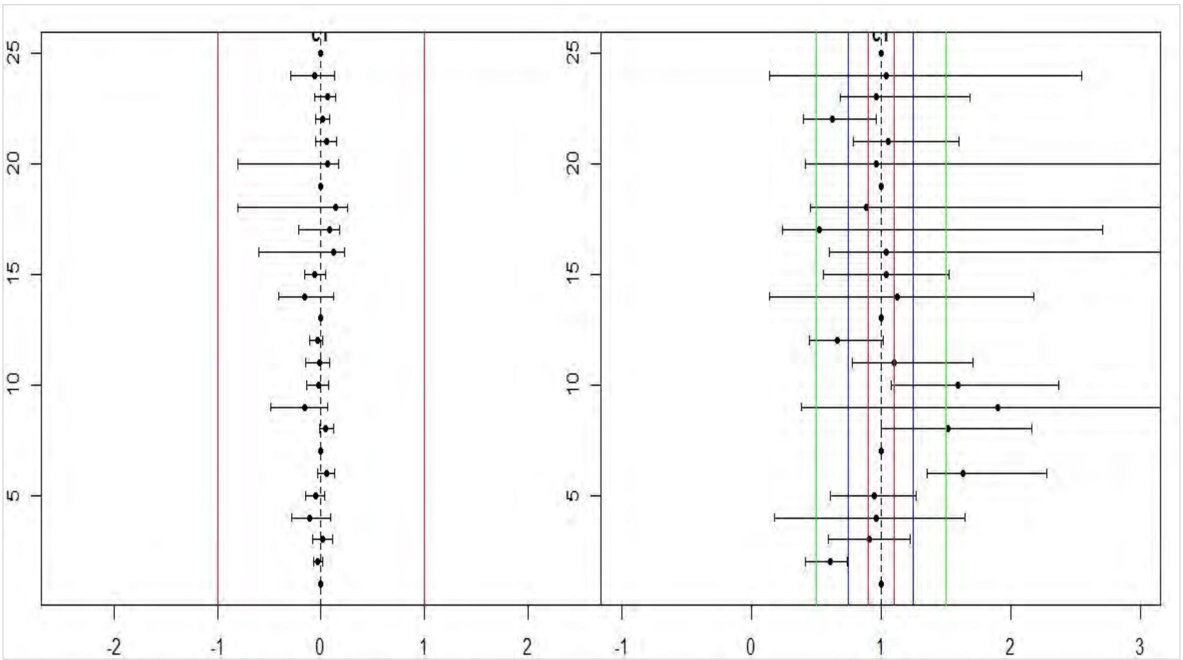

Figure 64. Centipede plot of the intercept and slope values (±std), of the orthogonal regression plots, for each pod performance comparison in calibration trail 1 at Money Point, January 2015.Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model assuming no variation. Plot indicates that a greater extent of variation is found within the gradient values

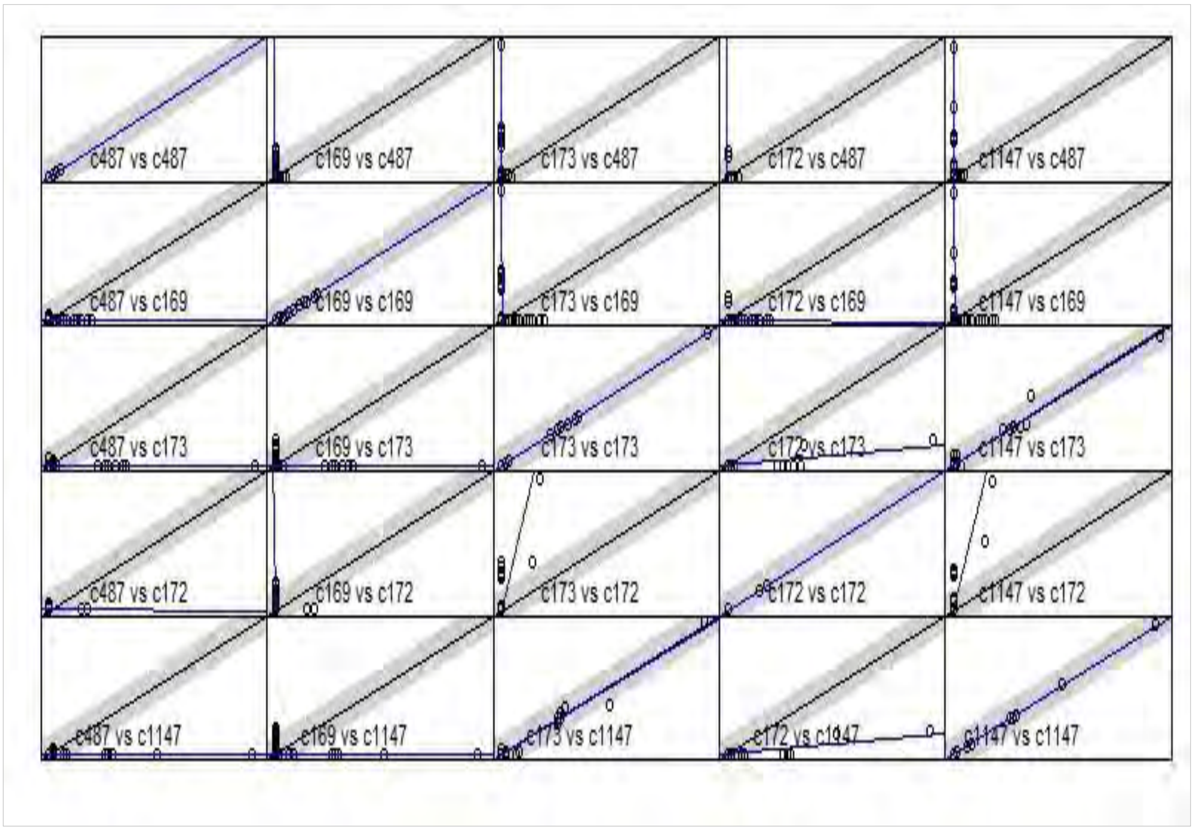

Figure 65. Orthogonal regression plot of C-POD comparisons in calibration trial, in blue, with a null model where each unit performs exactly the same, in black and an acceptable error margin of ±20%, in grey from Calibration 2, February 2015

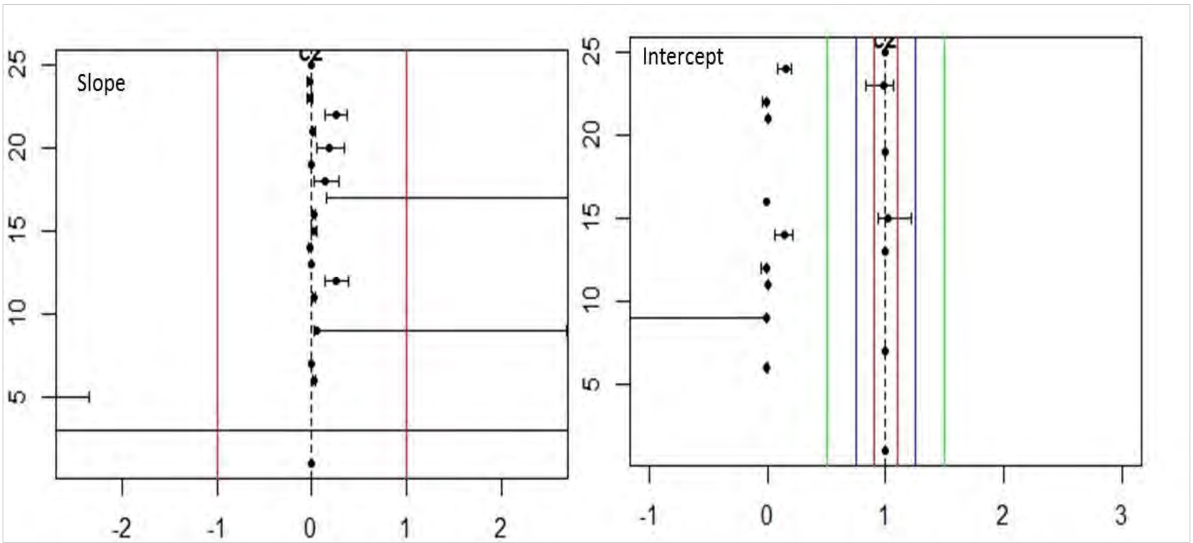

Figure 66. Centipede plot of the intercept and slope values (±std), of the orthogonal regression plots, for each pod performance comparison in calibration trail 1 at Money Point, January 2015.Deviation from the red dotted lines, 0 on the intercept plot and 1 on the gradient plot, indicates deviation from the null model assuming no variation. Plot indicates that a greater extent of variation is found within the gradient values

5.3.2 Static Acoustic Monitoring

Static Acoustic Monitoring using C-PODs was carried out at Loughshinny for a total of 189 days. Detections were recorded on 100% of days (Table 20). The number of Porpoise Positive Minutes (PPM) ranged from 8 to 475 per day with a mean of 139 PPM (Figure 67). Very few dolphin detections were recorded and those that were determined to be false positives. A monitoring index of the mean number of detection positive minutes per hour for porpoises was generated (Table 20). This unit of measurement can be compared across locations, or with results from previous studies that have taken place. This index will serve as a means to compare Loughshinny with the similar data derived from Portmarnock as part of the current study but additionally facilitate comparison with other sites regionally.

Table 20. Deployment summary from Loughshinny

Location	No of days	Dates	CPOD	PPM	% days detected	Mean DPM/Day	Mean DPM/hr	%DPM
Loughshinny	90	13 Mar-10 Jun	c950	7893	100	87.7	3.7	6.1
Loughshinny	99	10 Jun-16 Sep	c487	18388	100	185.8	7.7	12.9
TOTAL	**189**			**26281**	**100**	**137**	**5.8**	**9.6**

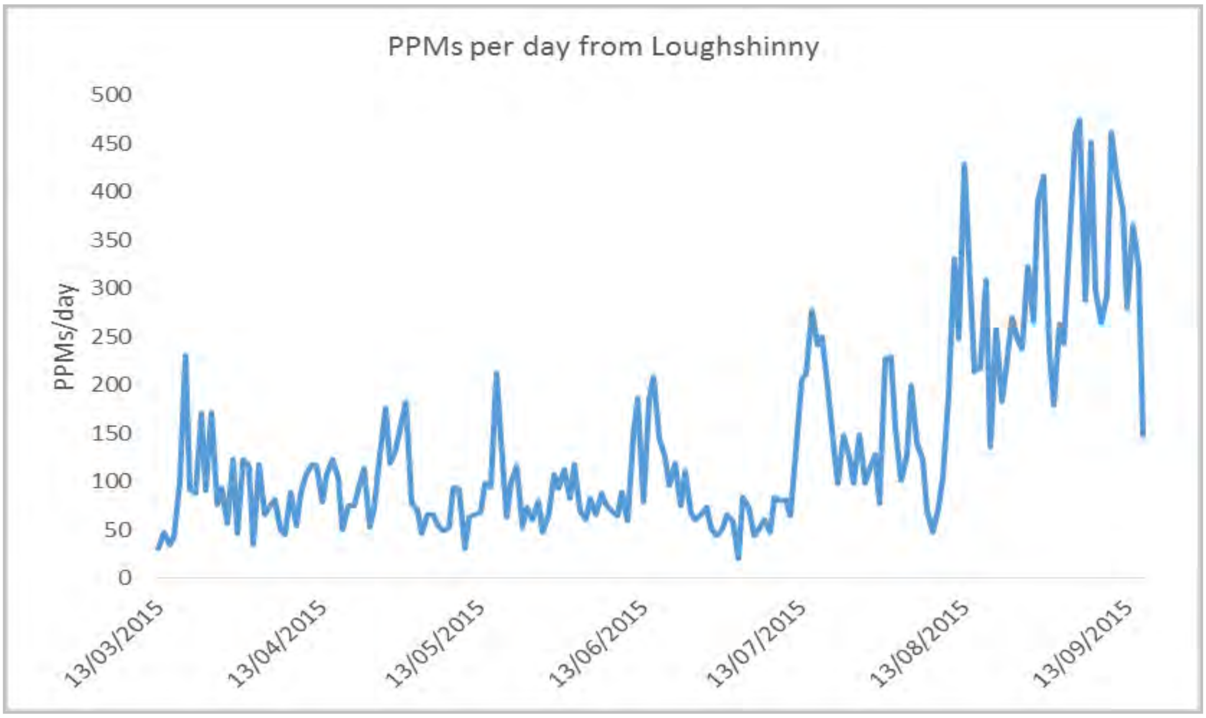

Figure 67. Porpoise Positive Minutes per dat (PPMs) recorded over the deployment period (March to September (139 days)).

5.3.2.1 Generalized linear mixed-effect model (GLMM) analyses

Results from the generalized linear mixed-effect model (GLMM) analyses (Figure 68) showed that season had a significant effect on the presence of porpoises at the site. A significant peak in porpoise detections was recorded during the autumn (χ^2= 174.5, p<0.000). Most porpoise detections were recorded during the diel phase morning, and from the raw data this peak can be seen during the early morning (χ^2= 174.5, p<0.000) showing they are more active at the site during night-time and early morning hours. Tidal cycle was not found to be a significant factor in the presence of porpoises off Loughshinny (χ^2= 5.3, p<0.2) but tidal phase was, with significantly more detection recorded during spring cycles (χ^2= 9.2, p<0.02). The box plots below show the distribution of the data or each of the variables, with the usual box plot format, representing the median, quartiles and outliers.

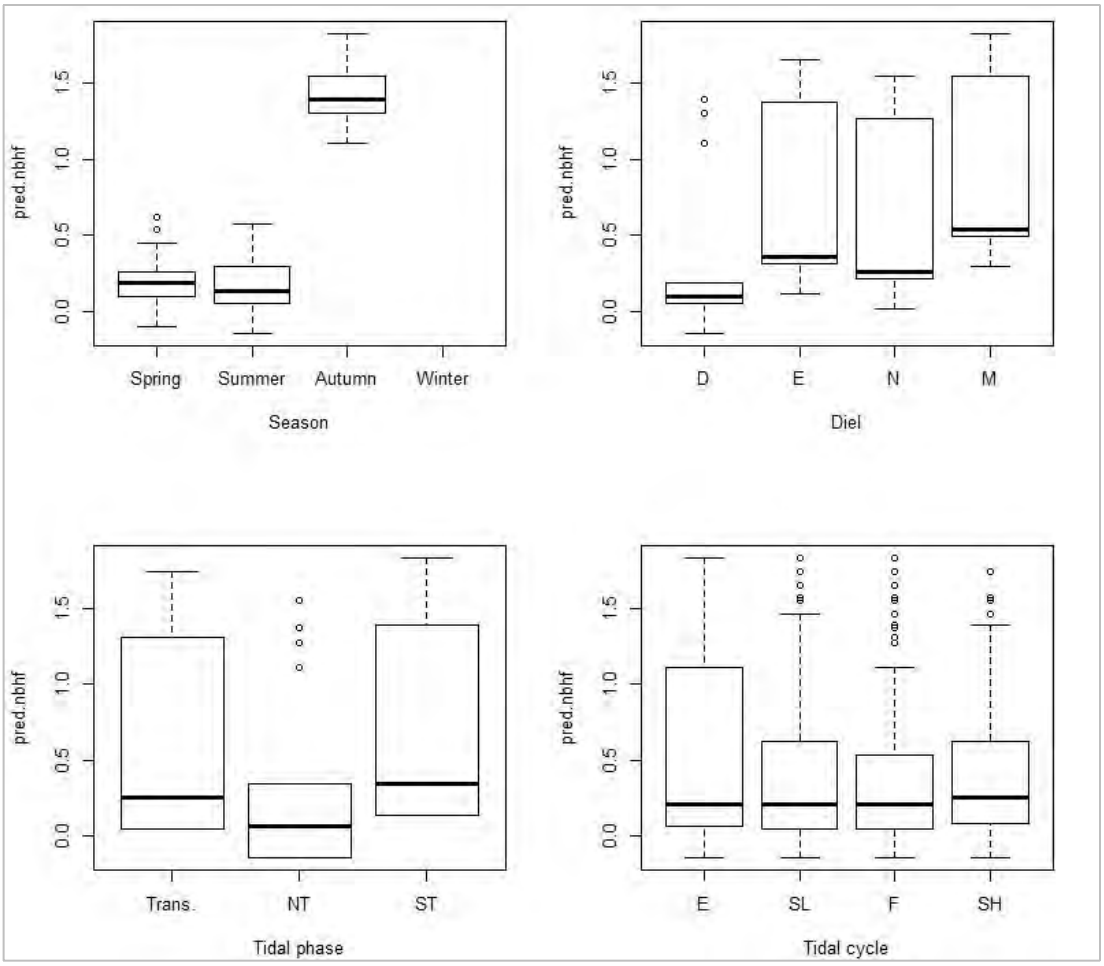

Figure 68. Predicted proportion of detection positive hours, in the narrow band high frequency channel at Loughshinny (Co. Dublin) Mar-Sept, 2015 across the four variables of season; diel, where D =day, E= evening, M= morning and N = night; tidal phase, where Trans.=transitional phase, NT= neap tide and ST=spring tide; and tidal cycle, where E =ebb, L = slack low, F= flood and H=slack high.

5.3.3 Assessment of usage of the site

Feeding buzzes and click bursts have been described in many odontocete species (Herzing, 2000; bottlenose dolphin; Miller *et al.*, 1995; narwhal, Leeney *et al.*, 2011; Heaviside's dolphin). 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.

A total of 100,421 NBHF click trains were recorded at Loughshinny over the 6 month deployment. The average number of clicks per train was 13.5, with on average 131 clicks recorded per second, and with an average frequency of 128.1 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 95% (95,509 trains) of the total click trains recorded fell under the category foraging, highlighting Loughshinny as a very important feeding site. Modelling of the dataset according to the factors as previously done was not repeated given that 95% of trains were classed as foraging, showing that porpoises present at Loughshinny are feeding and more significantly during the times of night and morning, during the autumn and spring tidal cycle.

Table 21. Train details from porpoise detections at Loughshinny, Co. Dublin

No of trains	Foraging	Other	Min frequency	Max Frequency	clx per train
100421	95509	4911	124	132.4	13

5.4 Discussion

Despite the poor summer weather experienced during 2015, we successfully carried out this survey in favourable conditions. Only one boat-based survey was compromised with around 40% of effort above that stated in the contract. Although conducted over only over a relatively short duration the results do provide an insight into the use of the area by marine mammals and demonstrate its importance for harbour porpoise.

Although limited observations were made there was evidence of an increase in use of the site through the survey period peaking in September. A notable observation included a large group of 14 harbour porpoise in early September. This group contained two calves and was the only sighting of calves during the land-based surveys. Berrow and O'Brien (2013) showed a similar pattern of harbour porpoise numbers and group size increasing off North Co. Dublin in late August. No marine mammals were recorded during the July land-based survey, probably largely due to the sea state ≤2 for 92% of the sampling which could decrease the likelihood of sightings. Two focal follows of harbour porpoise were carried out in March and May for 18 minutes and 26 minutes respectively. During focal follows, harbour porpoise were tracked swimming in tidal currents. This and the presence of feeding gulls suggests that these individuals were foraging in the area.

For two of the three boat surveys carried out, the number of sightings were sufficient to derive density and abundance estimates. The track-lines surveyed an area to the south and a lesser extent to the north of the Loughshinny site. It is important to try and obtain as many sightings as possible to derive robust density estimates. During the two surveys analysed track-lines were 78 and 75km in length and sightings numbered a total of 11 and 20 respectively.

Within the area surveyed the number of sightings of harbour porpoise per survey varied considerably but the overall density estimate was quite consistent, to previous surveys in the area (Table 22). Harbour porpoise density estimates were previously generated for two Dublin sites in 2008 and for Rockabill to Dalkey Island SAC in 2013. North County Dublin was similar to the area surveyed in the present study. Density estimates in North County Dublin in 2008 varied very considerably and the highest density of porpoises recorded at any site in Ireland so far was recorded in August 2008 (i.e., 6.93 porpoises per km^2). However other individual survey estimates during 2008 were much lower, so this single survey had a strong influence on the overall pooled density estimate of 2.03 animals per km^2.

If we take the average of the overall density estimates in 2008 for the two sites it equates to 1.61 which is quite similar to 1.31 porpoises per km^2 from the present survey. The CV of the present density estimate is high (CV=0.32) compared to the other surveys but this was based on only two survey days while all others used data from six survey days. A previous wider-scale line-transect survey in the north Irish Sea, to the east and north of the current SAC, delivered a density estimate of 1.59±0.22 porpoises per km^2 (Berrow *et al.* 2011). This was also of a similar magnitude to that derived from the present survey. These density estimates are some the highest recorded anywhere in Ireland (Berrow *et al*. 2014).

Table 22. Density, abundance and group size estimates for harbour porpoise in the Greater Dublin Drainage area

Location	Year	Area (km^2)	Mean group size	Density (per km^2)	Abundance ± SE (95% CI)	CV	Reference
Greater Dublin Drainage	**2015**	**192**	**1.67**	**1.31**	**256±37 (87-751)**	**0.37**	**This study**
Rockabill to Dalkey Island SAC	2013	273	1.47	1.44	391±25 (344-445)	0.06	Berrow and O'Brien (2013)
North County Dublin	2008	104	1.41	2.03	211±47 (137-327)	0.23	Berrow *et al.* (2008a)
Dublin Bay	2008	116	1.19	1.19	138±33 (86-221)	0.24	Berrow *et al.* (2008a)

Cetaceans live in an acoustic world and increasingly attempts have been made to develop acoustic monitoring techniques rather than relying on visual methods, whose efficiency is hugely dependent on light, weather conditions and sea-state, especially for species such as the elusive harbour porpoise. Additionally, the reliance on sound by these animals is extremely important and therefore SAM is a very valuable tool for determining presence and assessing fine scale habitat use by various odontocete species. The main advantage of SAM is that it can provide information on species that can go undetected visually for up 95% of the time (harbour porpoise; Read & Westgate, 1995). 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; O'Brien *et al.* 2013) diel cycle (Cox & Read 2004; Carlström, 2005; Todd *et al*., 2009; O'Brien *et al.* 2013) and tidal patterns (Philpott *et al*., 2007; Marubini *et al*., 2009; O'Brien *et al.* 2013). 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 varying time scales depending on monitoring methods. Although SAM can provide a much more complex account of cetacean activity at a site in comparison to visual monitoring, it fails to inform on the numbers present and hence the need for visual surveys.

The aim of the present study was to compile a dataset of cetacean occurrence at Loughshinny and use this dataset to compare with monitoring datasets gathered under the same Greater Dublin Drainage project but from monitoring locations further south, off Portmarnock Co. Dublin. From the data presented here, it is clear that the Loughshinny site is an important feeding area for the harbour porpoise especially in the autumn, during the night and early morning and during a spring tidal cycle.

Winter could not be analysed as monitoring only lasted six months at this particular site. In order to try to understand the relevance of these detections, comparisons can be made with other locations from around the coast where SAM was previously carried out. The index of mean porpoise positive minute per hour (PPM/hr) were compared across eight sites, with varying durations of monitoring. By using the mean PPM/hr, we can compare across sites for different monitoring durations (Table 23). Data highlighted in green were collected using T-PODs an earlier version of the C-POD. Previous work by O'Brien *et al*. (2013) has shown that C-PODs recorded an average of seven times more data than T-PODs during simultaneous deployments in Galway Bay and thus data are biased downwards.

However, it is clear that more DPM's are recorded per deployment from sites in Dublin than anywhere else. Previous deployment off Howth Head yielded 12.2DPM/hr, in comparison to the present study of 5.8. However, the Howth deployment was over a shorter duration but data was gathered using a T-POD.

When the present CPOD data are compared with other deployments around Ireland, such as the Blasket Islands SAC, the detections from Co. Dublin were much greater. These results support visual survey results by Berrow *et al.* (2014) where abundance estimates for North County Dublin produced some of the highest density estimates to date (e.g. O'Brien and Berrow, 2015).

Table 23. Monitoring results from SAM across Ireland (green line denotes data collection using T-PODs so some caution necessary when interpreting results.

County	Site	Total days	% DPD	Total PPM	%PPM	Mean DPM/day	Mean DPM/hr	Reference
Dublin	Loughshinny	189	100	26281	9.6	137	5.8	This study
Galway	Spiddal	572	541	27902	3.4	48.8	2.0	O'Brien *et al.,* 2013
Kerry	Inishtooskert	264	236	3930	1.04	14.9	0.6	O'Brien *et al.,* 2013
Kerry	Wild Bank	289	221	2097	0.51	7.3	0.3	O'Brien *et al.,* 2013
Kerry	The Gob	52	49	3015	4.1	58.0	2.4	O'Brien *et al.,* 2013
Dublin	Howth	47	100	13718	10.1	291.9	12.2	Berrow *et al.* (2008a)
Cork	Castlepoint	63	100	1379	2.0	21.9	0.9	Berrow *et al.* (2008a)
Cork	Sherkin	23	44	707	1.0	30.7	1.3	Berrow *et al.* (2008a)
Cork	Galley Head	63	30	1614	2.4	25.6	1.1	Berrow *et al.* (2008a)

Although SAM does not provide information on the numbers of animals using a site, it has given an insight into the temporal patterns of habitat use of the site which could not be identified from visual monitoring alone. Loughshinny is an important feeding site for porpoises who are present on a daily basis, especially during the hours of darkness and early mornings.

As harbour porpoises (Annex II species of the Habitats Directive) are present at such significant levels, strict habitat protection should be ensured at the site, and due care must be taken to ensure any development does not degrade this habitat or cause undue disturbance. These visual SAM results will serve to inform protocols of best practice for the area if work is to go ahead and thus ensure the presence of small cetaceans in the area is not negatively impacted upon.

5.5 Appendix References

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