Using passive acoustic monitoring to investigate the occurrence of cetaceans in a protected marine area in Northwest Ireland

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Abstract

Under the EU Habitats Directive, cetacean species must be maintained at favourable conservation status in European waters. Whether this is achieved via protected area designation, curtailment of activities such as fishing or construction, or time restrictions on noise, it is dependent on understanding the temporal patterns in occurrence. Our ability to study this is often limited by the relatively short time-series of data available to researchers. This study uses nine years of passive acoustic monitoring data paired with environmental covariates to better understand the spatio-temporal dynamics of harbour porpoise and dolphin species using generalised estimating equations-generalised linear models (GEE-GLMs). This long-term time-series included periods of increased disturbance due to construction of an underwater gas pipeline in the area, enabling us to investigate the effect of construction on species occurrence. Harbour porpoise and dolphins occurred in every season, with detections peaking in winter. We found a negative association between dolphins and porpoises throughout the year. Inter-annual variation in occurrence was evident, with a cyclical bi-annual pattern highlighted for both species suggesting a complex pattern of movement. Construction activity had a significant negative effect on the presence of porpoise but not dolphins. However, no long-term decrease in detection rates of porpoise was recorded. This study highlights the importance of understanding what factors influence cetacean occurrence as well as the temporal scale of disturbance effects for planning and management of construction activities in coastal areas.

Key words

Harbour porpoise; dolphin; acoustic monitoring; PAM; Ireland; construction; tide

Highlights

- This study represents the longest passive acoustic monitoring dataset in Ireland, providing an understanding of the potential drivers of occurrence and distribution in a northeast Atlantic exposed site.
- We find a bi-annual pattern of occurrence for porpoise and dolphin species, suggesting a more complex movement pattern than previously suggested.
- We demonstrate a negative effect of construction activity on harbour porpoise occurrence.
- Spatio-temporal differences in harbour porpoise and dolphins may suggest possible avoidance consistent with previous studies showing aggressive interactions between these species.

- A winter peak in cetacean occurrence is markedly different to other European regions and highlights the importance of region-specific studies when applying seasonally dependent conservation or mitigation strategies.

Introduction

Identifying patterns of occurrence of wide-ranging cetaceans may be the most pragmatic way of protecting suitable sites for conservation in order to minimise disturbance during important activities such as feeding, breeding, and resting. The distribution patterns of cetaceans are largely determined by their behaviour as predators foraging for a patchy prey resource (Redfern et al., 2006), and has been shown to differ seasonally and inter-annually (e.g. Mendes et al., 2002; Lusseau, 2005; Rako et al., 2012). A range of environmental variables have been used as proxies for prey distribution and abundance to investigate broad-scale distribution patterns for cetaceans (e.g. Bailey & Thompson, 2009; Edrén et al., 2010; Embling et al., 2010). However, our understanding of the drivers of space-use in highly mobile marine species is often hampered by a lack of adequate long-term data that encompasses a range of environmental variability.

Harbour porpoise (*Phocoena phocoena*) are among the most frequently observed, and most widely distributed cetacean species in European waters (Hammond et al., 2002), and are considered an important top predator and indicator species (Gilles et al., 2011). Due to their small body size and high energetic demands, an important driver of harbour porpoise distribution is the availability of their prey (Johnston et al., 2005). Harbour porpoise are wide-ranging, inhabiting shallow continental shelf waters throughout the northern hemisphere (Hammond et al, 2002; Hammond et al, 2017). Similarly, bottlenose dolphins (*Tursiops truncatus*) typically maintain an inshore distribution (Berrow, 2010), occupying a wide variety of habitats, although offshore waters are exploited by some populations (Ingram & Rogan, 2002). For example, in the Moray Firth, northern Scotland, bottlenose dolphins show a preference for deeper channels of water, associated steep topography of the sea floor and strong tidal currents (Wilson et al., 1997), while resident dolphins in Florida prefer shallow coastal areas with a depth of ca.3m (Irvine et al., 1981). Unlike bottlenose dolphins, the common dolphin (*Delphinus delphis*) occurs across inshore and offshore waters < 200m in depth (Gordon et al. 1999; Berrow, 2010), and it has been suggested that they move further offshore in the summer months to reduce potential competition with other inshore habitat users (MacLeod et al, 2008).

Cetaceans are highly vulnerable to disturbance, injury or death resulting from interaction with anthropogenic activities (Dähne et al., 2013). While bycatch is the main direct threat to small cetacean species in European waters (Read et al., 2006), additional threats include depletion of prey abundance, noise pollution, vessel traffic, or habitat degradation as a result of chemical pollution (e.g. DeMaster et al., 2001; Herr et al., 2009; Dähne et al., 2013). Effective monitoring of these species can be challenging due to the difficulty and expense involved in locating them over their extensive ranges (Stevick et al., 2002). Cetacean surveys often encompass visual methodologies which provide valuable information on patterns of abundance and distribution (Hammond et al., 2013). However, despite their benefits, visual surveys can be expensive (particularly vessel-based surveys), time-consuming to undertake, and limited to periods of suitable weather and daylight hours (Teilmann 2003). In addition, cryptic species may be missed by observers, and visual detection rates of harbour porpoise in particular decline dramatically in sea states greater than Beaufort sea state 2 (Teilmann, 2003; Akamatsu et al., 2008). Passive acoustic monitoring (PAM) is an increasingly used, cost-effective tool to provide year-round data on the occurrence of cetacean species. Odontocete species use echolocation signals for navigation and foraging (Verfuß et al., 2007; Villadsgaard et al., 2007) making them particularly suitable for PAM approaches. An important advantage of PAM is that it allows for continuous monitoring in all weather or sea state conditions (Todd et al., 2009) and across hours of darkness where visual observations are not possible.

Irish waters, and the habitats therein, are recognised as one of the most important areas for cetaceans in Europe (Wall et al., 2006; McGovern et al., 2016). Within Irish coastal waters, Broadhaven bay, northwest Ireland, has been identified as having a high cetacean species richness, with nine species sighted. The bay has become the site of the longest marine mammal monitoring programme of its kind in Ireland (Anderwald et al., 2012a) providing visual sightings of cetaceans since 2001, and acoustic monitoring since 2002. We use a long-term passive acoustic dataset beginning in 2009 and collected year-round until 2017 to investigate the seasonal and temporal patterns in occurrence of harbour porpoise and dolphin species and investigate the effect of environmental variables on the occurrence of both species.

Methods

Study area

Broadhaven Bay is situated on the northwest coast of Co. Mayo, Ireland (54.2845 N, -009.8868 W (Fig. 1). In 2000, Broadhaven Bay was designated as a candidate Special Area of Conservation (cSAC) due to the presence of key marine and coastal habitat types listed under Annex I, EU Habitats Directive (EEC, 1992) including large shallow inlets and bays, mudflats and sandflats, reefs, salt meadows and sea caves. The northward facing bay is relatively small (approximately 64 km^2) and shallow with a maximum water depth of 50m. Strong tidal fronts are known to occur around the western headland (Erris Head) and there are multiple tidal inlets and estuaries in the inner bay (Culloch et al., 2016).

Data collection

Acoustic data were collected from Broadhaven Bay between April 2009 and November 2017 using CPODs (Cetacean-Porpoise Detectors, Chelonia Ltd, U.K.). The maximum detection range of the CPODs is approximately 400m for harbour porpoise and 1km for delphinid species. However, these ranges are dependent on conditions, including ambient levels and orientation of the cetacean species (Roberts & Read 2014). Echolocation clicks are detectable within the frequency range of 20kHz – 160k and can therefore detect clicks of all odontocete species with the exception of sperm whales (Chelonia Ltd, http://www.chelonia.co.uk CPODs were deployed at two locations within the bay year-round (inner and outer bay); three CPODs were deployed in the inner part of the bay ca. 500m apart (Listening Stations (LS)1-3), at an average depth of 17m at high tide, and one CPOD was deployed in the tidally active waters in the outer part of the Bay near Erris Head at a depth of 37m (LS4). All CPODs were secured to a fixed mooring line at ca. 5-7m, which was anchored to the sea bed and attached to a surface buoy. CPODs were retrieved and re-deployed every 3-4 months, and were calibrated regularly to ensure no systematic bias in detections at any site (Dähne et al., 2013).

Data processing

CPOD data were downloaded using the CPOD.*exe* software (Version 2.044, Chelonia Ltd, http://www.chelonia.co.uk) and the KERNO classifier was used to automatically filter the data and identify cetacean click trains. Data were summarised as DPM (detection positive minutes) per hour. To reduce the rate of false positive harbour porpoise detections, only click trains with a high or moderate classification were exported. Dolphin detections (Other cet) used high, moderate and low-quality classifications. Low-quality trains were included to maximise possible dolphin detections (Robbins et al., 2016). To eliminate false-positive detections, data was visually validated across all years, for both harbour porpoise and dolphin detections, as false-positive porpoise detections have previously been shown to be an issue within Broadhaven Bay (Culloch et al., 2014). Visual validation followed a standardized methodology, using parameters based on the acoustic characteristics of both dolphin species occurring within the bay. Detections were validated on an hourly temporal scale, i.e. hours with a dolphin or porpoise detection were classified as a Detection Positive Hour (DPH). For each classified detection in the CP3 file produced by the CPOD software, the CP1 file was screened within the surrounding minute for a verified detection. Once visually verified detections were present within an hour, the whole hour was regarded as a true-positive detection. Prior to further analysis, DPM/hour data were converted to binomial presence/absence data (1/0), with '1' representing one or more DPM within a given hour, and '0' indicating no detections within the hour.

Environmental Data

Tidal data was obtained from a tide gauge within Broadhaven Bay at Ballyglass (Ireland's Digital Ocean, https://www.digitalocean.ie/) with occasional gaps in tidal data filled from nearby stations at Killybegs (approx. 120km northeast of Broadhaven Bay), accounting for the relatively small tidal offset between these locations. Tide data was used to create a single tidal variable between 0-3 as a proxy for tidal currents (tidal speed proxy), according to the rule of twelfths (based on a smooth rate of tidal flow reaching a max. height halfway between low and high tide). Sunset data were obtained for Belmullet, Co. Mayo (54.2239N, -9.9876W), (http://sunrise.maplogs.com/) and time to sunset was calculated from the GMT hourly data. Records of construction-related activities (e.g. dredging, trenching, multibeam surveys) within the bay were available between 2009 and 2015 from marine mammal observer reports, sourced through the Department of Communications, Climate Action and the Environment. Records were not detailed enough to obtain hourly construction data or to separate between various construction activities, so were used to indicate the daily presence or absence of construction activities throughout the study period. An effort term was generated to account for the unequal number of CPODs deployed within the inner and outer bay, with a value of 1-3 corresponding to the number of CPODs in the water during a given recording period (i.e. always a value of 1 at the outer bay site, and a value of 1 to 3 for the inner bay). This was to prevent overestimation of porpoise and dolphin detections in the inner bay.

Statistical analysis

All statistical analyses and plots were undertaken using the statistical software R (version 1.1.442, R Core Team 2016). To account for autocorrelation in the data, generalised estimating equations-generalised linear models (GEE-GLMs) were employed for both the harbour porpoise and dolphin models using the *geepack* package in R (Højsgaard & Halekoh 2006). The presence or absence of harbour porpoise or dolphin species were used as the response variables, hence GEE-GLMs were run under the binomial family. The following explanatory variables were included in the analysis; (1) location, i.e inner or outer bay (LS1-LS3 were pooled together as 'inner bay' due to their close proximity to each other) (factor); (2) tidal speed proxy (continuous); (3) time to nearest sunset (continuous); (4) season (factor) (spring: March- May, summer: June - August, autumn: September- November, winter: December- February); (5) Julian date (factor); (6) daily presence/absence of construction activity (factor); (7) hourly presence/absence of dolphin detections (factor) (harbour porpoise model only, due to possible aggressive interactions or displacement by dolphins (Ross & Wilson 1996; Jepson & Baker 1998)); and (8) year (factor). The effort term was also included in the models as an offset, and Julian date was chosen as the blocking ID. All variables included in the model haven been shown to affect the behaviour, presence and/or the distribution patterns of cetaceans in previous studies (e.g. Johnston et al., 2005; Todd et al.¸ 2009; Culloch et al., 2016). The collinearity of response variables was assessed using variance inflation factors (VIF) in the *car* package in R (Fox & Weisberg 2011). Variables with a VIF value of 2 or greater were deemed to be collinear. For collinear variables, the lower resolution variable was omitted from the analysis, retaining the higher resolution variable. An autoregressive correlation structure (AR-1) was included in models to account for temporal autocorrelation in the data, at an hourly scale. This structure assumes regular distances/time intervals between observations, and is commonly used when there is a time order in the dataset (Zuur et al., 2009). Model predictions were produced using the *stats* package and plotted using the *ggplot2* package in R on the scale of the response variable (Wickham, 2009).

Model selection and model checking

A stepwise approach was taken for model selection, where non-significant variables were omitted from the global models one at a time. A Quasi-likelihood Information Criterion (QIC) was used to compare models (Pan 2001) using the *MESS* package in R. Models were ranked according to their QIC values, and the model with the lowest QIC was chosen as the best model. Model validation and goodness-of-fit was carried out using a confusion matrix in R, package *ROCR* (Sing et al., 2005), where binary predictions from the selected model were compared to observed presence or absence of the species. This gives a value ranging from 0-1, with values closer to 1 indicating a good model fit. The true positive rate versus the false positive rate for the binary response variable was then plotted using an Area Under the Curve plot (AUC) (*Presence/Absence* (Freeman & Moisen, 2008)). Models were deemed to be of a good fit when the distance between the curve and the plotted 45° diagonal was maximised (Pirotta et al., 2011). The AUC value was calculated to further validate model performance, also generating a value on a 0-1 scale, where the closer to 1 indicates a better model (Boyce et al., 2002).

Results

Between April 2009 and November 2017, a total of 168,091 hours of acoustic data, an average of 18, 677 per year, were gathered using CPODs within Broadhaven Bay. Data were collected each year from all stations, with the exception of 2016 and 2017 when there was no CPOD deployed in the outer bay at LS1, and during periods when CPODs were lost or not recovered. Construction activities took place in the bay on 430 days across the nine-year monitoring period (years 2009, 2010, 2012-2015), with approximately 30% of this activity occurring in 2009.

Harbour porpoise

A total of 21,863 detection positive hours (DPH) were recorded for harbour porpoise throughout the study period. Julian date and year were found to be collinear with a variance inflation factor (VIF) value greater than 2, therefore, to reduce the effect of collinearity, year was omitted from the model and Julian date was retained as it is considered the more detailed temporal variable. The models for harbour porpoise, ranked according to their QIC values, are presented in Table 1. Model validation indicated good performance with a confusion matrix score of 0.77, and AUC equalling 0.79. The best harbour porpoise model retained all of the explanatory variables (Table 1).

The probability of detecting harbour porpoise was significantly greater at the outer bay station compared to the inner bay after accounting for the additional monitoring effort at the inner bay site ($P<0.001$, Table 2, Fig. 2A). Julian date had a significant effect on the presence of harbour porpoise ($P<0.001$, Table 2), and there was considerable variation between years in the probability of detecting a harbour porpoise. A strong biannual pattern of peak harbour porpoise occurrence was noted, with the greatest detection rates of harbour porpoise occurring for the winter months in alternate years (Fig. 2 B, C). The occurrence of harbour porpoise was shown to be negatively affected by the presence of dolphin species ($P<0.001$, Table 2), with 88% of DPM/H for harbour porpoise occurring in the absence of dolphin detections within the same hour. Construction activity in the bay was also found to have a significant negative influence on the presence of harbour porpoise ($P<0.001$, Table 2). During the days of construction activity there was an overall decrease in harbour porpoise DPM/H, with greater than 90% of detections on construction free days. Neither time to sunset or tidal currents had any significant effect on the occurrence of harbour porpoise in Broadhaven bay, but were retained in models (Table 2).

Dolphin species

A total of 32,635 DPH were recorded for dolphin species over the deployment period. The models are presented in Table 3 ranked according to their ΔQIC value. ΔQIC is explained as the difference in QIC between any model and the model with the lowest QIC value. Model validation indicated good performance with a confusion matrix score of 0.68, and an AUC of 0.52. The explanatory variables for tidal currents and construction activity were not retained in the best dolphin model, with all remaining variables being significant (Table 4).

Similar to harbour porpoise, the model results indicated that there was a significant difference in the occurrence of dolphin species between the inner and outer bay (P<0.001, Table 4), with an increased probability of detecting dolphin species in the outer bay (Fig. 3A). Julian date also had a significant effect on the dolphin presence (P<0.001, Table 3), with biannual peaks in occurrence evident, and a large peak in late 2016 (Fig. 3B). A significant seasonal pattern of occurrence was also found for dolphin species, with the greatest probability of detection during the winter months (P<0.001, Table 4, Fig. 3C). There was a significant effect of time to sunset, where greatest dolphin detections were shown farthest from sunset, i.e. dawn (P<0.001, Table 4).

Discussion

Understanding the drivers of occurrence and habitat use in a highly mobile marine species is often hampered by a lack of adequate long-term data that encompasses environmental variability. This study utilised nine years of data to investigate the temporal patterns of occurrence of both harbour porpoise and dolphin species. While poor weather conditions often limit visual sightings effort in winter months, our study utilised PAM which could operate year-round to provide reliable data on occurrence.

Similar to studies in other regions (e.g. Marubini et al., 2009; Forney, 1999), we detected harbour porpoise and dolphin species occur year-round within Broadhaven Bay. However, large-scale inter-annual variation was noted, which may reflect wider movements of individuals in and out of the bay. While inter-annual fluctuations in sighting rates of harbour porpoise have been attributed to variations in sea-surface temperature (Forney, 1999), the small size of Broadhaven Bay meant that sufficiently detailed sea-surface temperature data could not be sourced using satellite-derived products to test this hypothesis. A strong repeating, bi-annual peak of occurrence was noted for both harbour porpoise and dolphin species. To our knowledge, such a finding has not previously been reported, and suggest that populations have a more complex movement pattern than simple onshore-offshore movements suggested by Mirimin et al (2011). Satellite tracking studies for harbour porpoise in Danish waters have shown that immature harbour porpoises have twice the home range of mature individuals, moving greater distances to locate prey (Sveegaard, 2011). Our study area is assumed to represent only a small fraction of the effective range of harbour porpoise in Irish waters (Rogan et al., 2018), and large interannual fluctuations in Broadhaven bay may reflect movements in and out of the region and along the Irish coastline. Certainly, investigating whether this bi-annual pattern correlates with processes occurring at the wider Northeast Atlantic scale warrants further research.

Although present year-round within the bay, both harbour porpoise and dolphin species displayed marked seasonal patterns in occurrence, peaking in winter months. Studies in wider European waters have highlighted differences in the seasonal occurrence of harbour porpoises. For example, in the German blight and Baltic sound, harbour porpoise peaked during the summer months (Gilles et al., 2011; Sveegaard et al., 2012) while peak harbour porpoise occurrence has been observed during late summer/early spring within the coastal waters of Northwest Scotland (Evans et al., 2003; Weir et al., 2007; Marubini et al., 2009). The results of these studies suggest that changes in harbour porpoise abundance is linked to the abundance and distribution of their prey (Santos et al. 2004; Sveegaard et al., 2012), and highlight the importance of undertaking regional studies.

Delphinid detections cannot be differentiated by species using CPOD data alone due to similar click train characteristics (Robbins et al., 2016). However, visual surveys carried out in Broadhaven Bay highlighted that common dolphins were the only dolphin species to show seasonal patterns of occurrence within the bay, with their greatest occurrence in autumn and winter (Anderwald et al., 2012b; Culloch et al., 2016). Bottlenose dolphins are also prevalent within Broadhaven Bay (Anderwald et al., 2012b; Culloch et al., 2016), but have been described as transient individuals belonging to a large population which utilises the inshore coastal waters off Ireland's west coast (Mirimin et al., 2011). It is possible that common dolphins are driving the seasonal pattern observed, particularly as similar winter peaks in common dolphin occurrence have been found on the southern coast of Ireland (Berrow et al., 2010). However, it should be acknowledged that patterns of individual dolphin species may be masked by the lack of species differentiation in the acoustic data.

While broad seasonal patterns of occurrence were demonstrated, our data also enabled an investigation of fine-scale environmental factors on occurrence. Time of day had a significant effect on the occurrence of dolphin species. Dolphin detections peaked at dawn (farthest time from sunset), presumably related to the distribution and abundance of prey at this time. No such effect was found for harbour porpoise. Previous studies have shown that porpoise foraging behaviour is primarily driven by the prevalence and activity of their prey (Todd et al., 2009), with increased porpoise echolocation activity often related to the schooling behaviour of prey species such as herring or sprat (Fréon et al. 1996).

Strong currents are often associated with increased noise due to sediment movement which may mask and reduce detection rates (Nuuttila et al., 2017). Despite this, the highest detection rates of both harbour porpoise and dolphin species was found at the outer region of Broadhaven Bay, near an area of tidal upwelling and strong current flow. Visual validation of the data ensured that these detections were not false positives. Previous studies have found that harbour porpoise show strong preference for foraging in topographically dynamic areas (Pierpoint 2008; Gilles et al., 2011) and associated with strong current flow (Johnston et al., 2005; Pierpoint 2008), where larger aggregations of prey are typically observed (Gilles et al., 2011). The current study did not find tidal speed (as a proxy for tidal currents) to be an important driver of cetacean occurrence at this site. Further study should use more precise measurements of tidal flow and velocity to help understand the patterns of occurrence shown in the outer bay area. Harbour porpoises have also been found to show low preference for waters less than 20m in other areas (Isojunno et al., 2012). Our inner bay site had a maximum depth of 17m at high tide compared to the outer bay site (37m), which may have contributed to higher detections at the outer bay. Spatial segregation of dolphin species has previously been documented within Broadhaven Bay, with bottlenose dolphins occurring more in the inner bay while common dolphins occurred more in the outer bay (Robbins et al. 2016).

The temporal negative correlation in acoustic detection rates between harbour porpoise and dolphin species found in this study may suggest possible segregation between the two groups. This finding has also been observed from a population on the North-western coast of Spain (Pierce et al., 2010). In British waters, bottlenose dolphins have been reported to attack harbour porpoises, leading to mortality of porpoises in some areas where the species coexist (Ross & Wilson 1996; Jepson & Baker 1998). It has been suggested that violent attacks on harbour porpoise by bottlenose dolphin are a result of competitive interactions for food due to partial dietary overlap (Spitz et al., 2006). Despite no direct evidence for such aggressive behaviour within Broadhaven Bay, harbour porpoise may avoid encounters with dolphins, leading to the observed segregation. Acoustic studies in Cardigan Bay SAC have shown that although harbour porpoise and bottlenose dolphin are sympatric, simultaneous detections of the two species are rare (Simon et al., 2010), suggesting avoidance or temporal habitat partitioning similar to the findings of this study.

The construction of an underwater gas pipeline in the bay during monitoring efforts enabled investigation into the effects of construction on the occurrence of porpoise and dolphin species. Construction activities recorded between 2009 and 2013, refers to noise-generating activities including acoustic surveys (seismic surveys, multi-beam, single-beam and sub-bottom profiling), dredging, rock trenching, pipe laying and rock placement operations. From 2013, maintenance activities were conducted using multi-beam and remotely operated vehicle (ROV) surveys for the inspection of the underwater pipeline. No effect of construction activity on the occurrence of dolphin species was found. However, we noted a significant negative effect of construction activity on harbour porpoise detections. While this is consistent with previous findings in Broadhaven Bay based on visual sightings effort (Culloch et al. 2016), our study was able to investigate this effect over a longer time, during periods where visual surveys could not be undertaken (i.e. unfavourable sea states), and accounting for fine-scale environmental effects, such as time of day and tide. Compared to other odontocetes, harbour porpoise are particularly sensitive to anthropogenic noise (Ketten 2000; Lucke et al., 2009), with previous studies reporting changes in foraging behaviour and displacement due to noise disturbance (Dähne et al., 2013; Thompson et al.¸ 2013; Pirotta et al., 2014). Unfortunately, the construction data provided by on-board observers prevented a differentiation between percussive and continuous noise sources in the models, so we are unable to speculate on the type of noise that had the greatest contribution to the observed decrease in harbour porpoise detections. However, as there was a considerable increase in harbour porpoise detections after the cessation of construction-activities, we speculate that such impacts are temporary, with no evidence long-term changes in acoustic detection rate.

Conclusion

There is a growing need to ensure that cetacean populations are maintained at favourable conservation status. This increases the importance of long-term datasets that can be used to understand the drivers of distribution and quantify the effect of anthropogenic disturbance. Notably, this study demonstrated that winter is the most important season for cetaceans in Broadhaven Bay. This differs from other research in European waters, highlighting the importance of regional studies to understand temporal patterns of occurrence and to inform mitigation strategies such as the timing of activities to reduce disturbance.

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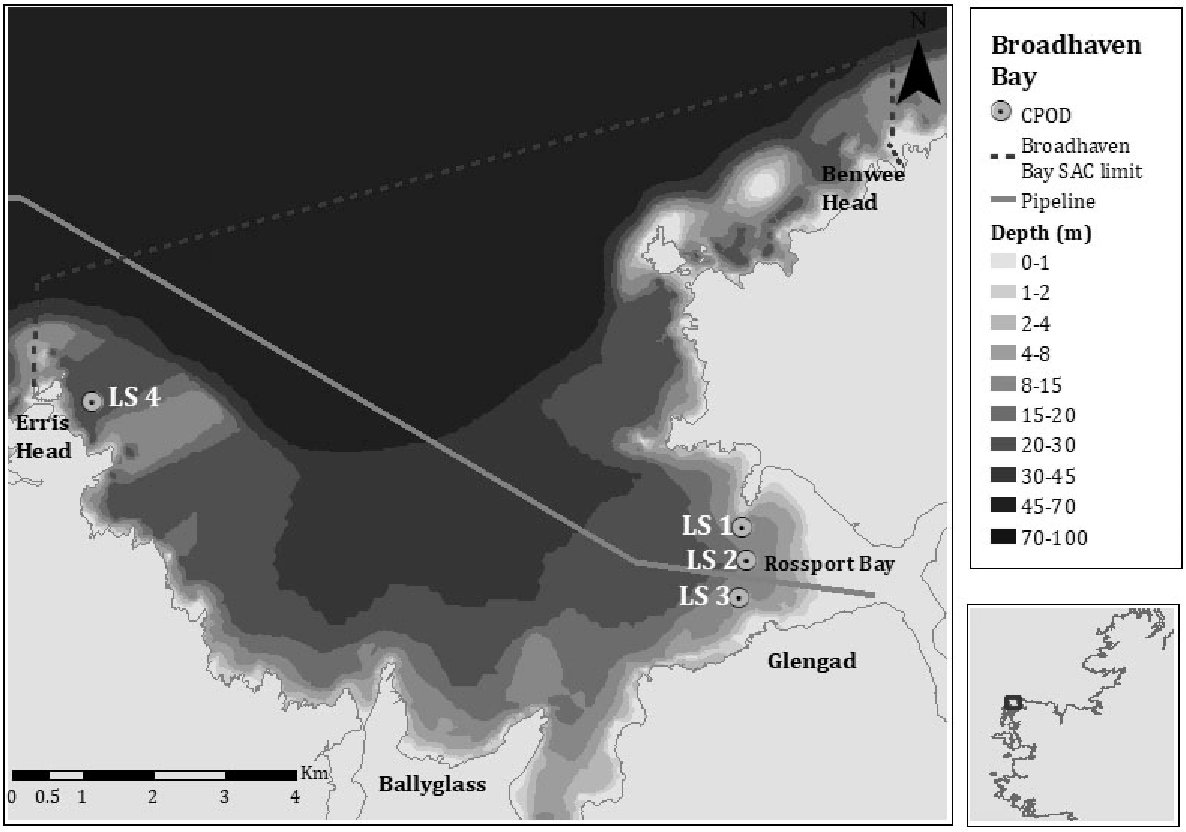

Fig. 1: Map of Broadhaven Bay indicating the four CPOD Listening Stations (LS 1, 2, 3 and 4), the SAC boundary and the position of the installed corrib gas pipeline. **Insert:** The position of Broadhaven Bay within western Ireland (adapted from Culloch et al., 2015*)*

Table 1: Quasilikelihood information criterion (QIC) for the global model (M1) and derivative models (M2, M3) from stepwise selection for the harbour porpoise. Stepwise selection was carried out until all variables retained in the model were significant. Variables retained in the models are indicated by 'Y'. The best model (M1) with the lowest ΔQIC is highlighted in bold. Julian day (Julian), Dolphin presence (Dolphin), Construction presence (Construction), Tidal speed proxy in relation to high or low tide (Tide), Time to sunset (Sunset).

Model	Station	Tide	Sunset	Season	Julian	Construction	Dolphin	ΔQIC
M1	Y	-	-	Y	Y	Y	Y	**0**
M2	Y	-	Y	Y	Y	Y	Y	0.1
M3	Y	Y	Y	Y	Y	Y	Y	1.62

Table 2: Model output from the best harbour porpoise model. Output demonstrates model estimates, standard errors, Wald test statistic and P-values. Significant P-values are highlighted in bold. Positive estimates indicate a positive relationship between the predictor and the response variable, whereas negative estimates indicate a negative relationship.

Model variables	**Estimate**	**SE**	**Wald**	***P***
Intercept	-3.81	0.0642	3528.62	< 0.001
Station (relative to Inner)				
Outer	2.75	0.0508	2924.74	**< 0.001**
Tidal speed	-0.00932	0.0091	0.01	0.9180
Time to Sunset	0.0210	0.00161	1.86	0.1727
Season (relative to winter)				
Autumn	-1.74	0.0592	859.49	**< 0.001**
Spring	-1.08	0.0543	394.83	**< 0.001**
Summer	-2.36	0.0620	1449.50	**< 0.001**
Dolphin presence	-0.142	0.0275	26.69	**<0.001**
Julian date	0.0002	0.0001	60.11	**<0.001**
Construction (relative to absence)				
Presence	-0.272	0.0731	13.39	**<0.001**

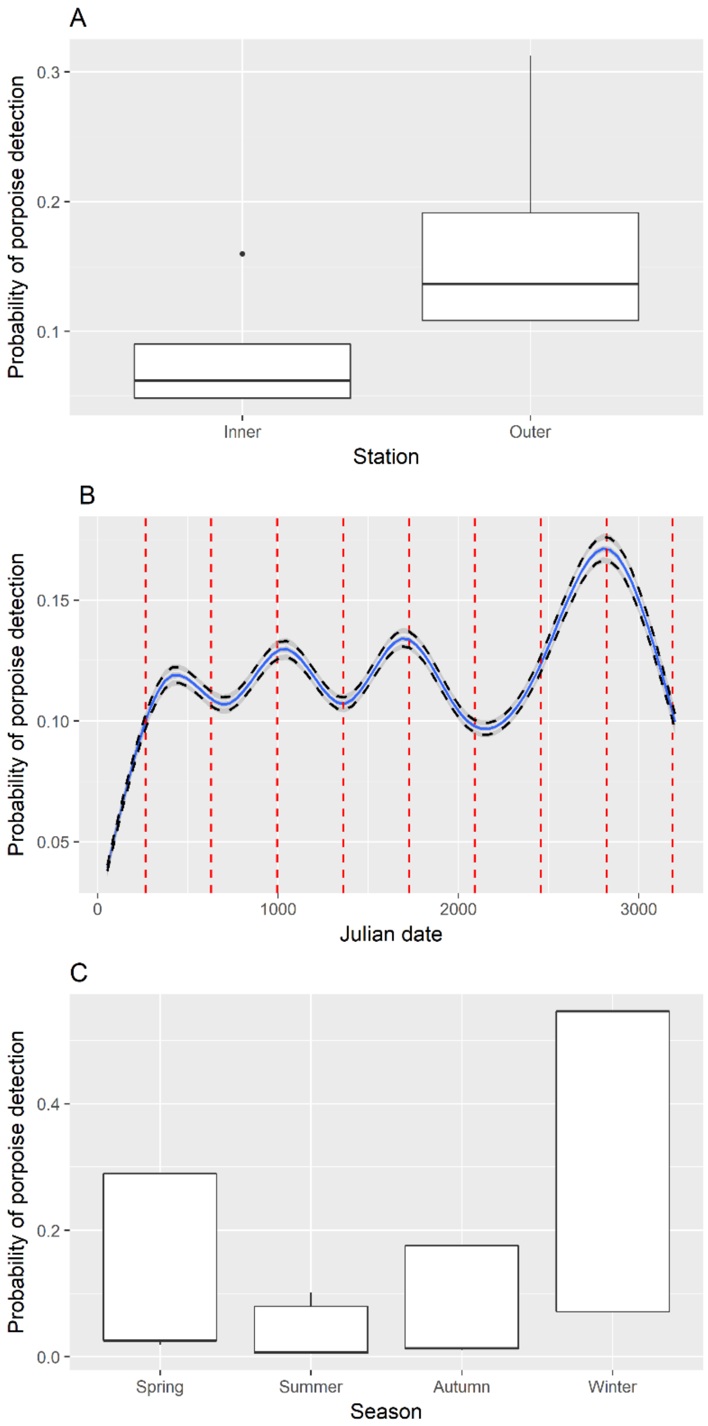

Fig. 2 A-C: Prediction plots based on model output. A) Probability of detecting harbour porpoise at either the inner or the outer stations. B) Probability of detecting harbour porpoise according to Julian date. Grey area shows the 95% Confidence Intervals (CI). Vertical dashed vertical lines represent November of each year of the deployment period (2009-2017). C) Probability of harbour porpoise detections across all seasons in any given year.

Table 3: Quasilikelihood information criterion (QIC) for the best model (M1) and futher models (M2, M3) from stepwise selection for dolphin species. Variables included in the model is indicated by 'Y'. Model with the lowest ΔQIC model is chosen as the best model and is highlighted in bold. Julian day (Julian), Construction presence (Construction), Tidal speed proxy in relation to high or low tide (Tide), Time to sunset (Sunset).

Model	Station	Tide	Sunset	Season	Julian	Construction	ΔQIC
M1	Y	-	Y	Y	Y	-	**0**
M2	Y	Y	Y	Y	Y	-	31.1
M3	Y	Y	Y	Y	Y	Y	33.1

Table 4: GEE_GLM model output from the selected model for dolphin species. Output demonstrates model estimates, standard errors, Wald test statistic and P values. Significant P values are highlighted in bold. Positive estimates indicate a positive relationship between the predictor and the response variable, whereas negative estimates indicate a negative relationship.

Model variables	**Estimate**	**SE**	**Wald**	***P***
Intercept	-2.79	0.0669	1741.85	< 0.001
Station (relative to inner)				
Outer	0.874	0.0565	233.53	**< 0.001**
Time to Sunset	0.0542	0.00153	12.65	**<0.001**
Season (relative to winter)				
Autumn	-0.648	0.0564	132.00	**< 0.001**
Spring	-1.06	0.0637	275.88	**< 0.001**
Summer	-1.31	0.0593	490.55	**< 0.001**
Julian date	0.0001	0.0001	15.32	**<0.001**

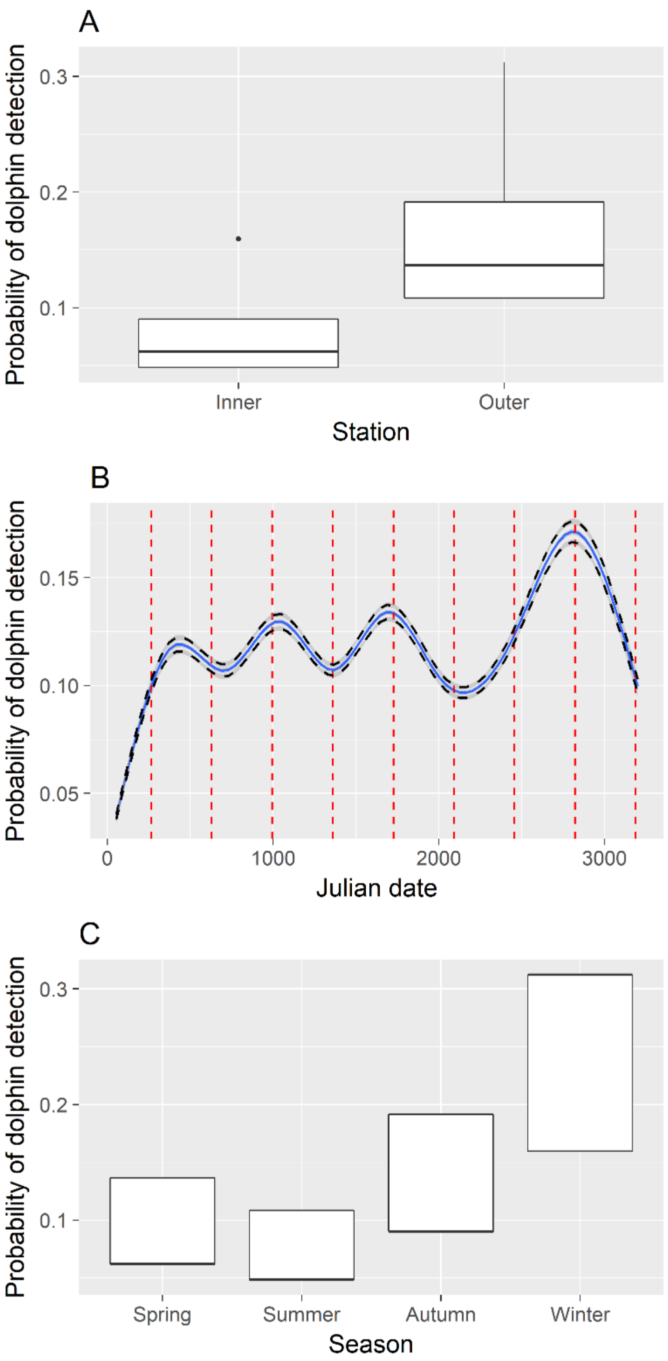

Fig. 3A-D: Prediction plots based on model output. A) Probability of detecting dolphin species at either the inner or the outer stations. B) Probability of detecting dolphin species according to Julian date. Grey area shows the 95% Confidence Intervals (CI). Vertical dashed lines represent November of each year of the deployment period (2009-2017). C) Probability of dolphin detections across all seasons in any given year.