What the F-POD? Comparing the F-POD and C-POD for monitoring of harbour porpoise (Phocoena phococena).

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Abstract

Passive acoustic monitoring (PAM) is a cost-effective method for monitoring cetacean populations compared to techniques such as aerial and ship-based surveys. The C-POD (Cetacean POrpoise Detector) has become an integral tool in monitoring programmes globally for over a decade, providing standardised metrics of occurrence that can be compared across time and space. However, the phasing out of C-PODs following development of the new F-POD (Full waveform capture Pod) with increased sensitivity, improved train detection, and reduced false positive rates, represents an important methodological change in data collection, particularly when being introduced into existing monitoring programmes. Here, we compare the performance of the C-POD with that of its successor, the F-POD, co-deployed in a field setting for 15 months, to monitor harbour porpoise (Phocoena phocoena). While similar temporal trends in detections were found for both devices, the C-POD detected only 58% of the detection positive minutes (DPM), recorded by the F-POD. Differences in detection rates were not consistent through time making it difficult to apply a correction factor or directly compare results obtained from the two PODs. To test whether these differences in detection rates would have an effect on analyses of temporal patterns and environmental drivers of occurrence, generalised additive models (GAMs) were applied. No differences were found in seasonal patterns or the environmental correlates of porpoise occurrence (month, diel period, temperature, environmental noise, and tide). However, the C-POD failed to detect sufficient foraging buzzes to identify temporal patterns in foraging behaviour that were clearly shown by the F-POD. Our results suggest that the switch to F-PODs will have little effect on determining broad-scale seasonal patterns of occurrence, but may improve our understanding of fine-scale behaviours such as foraging. We highlight how care must be taken interpreting F-POD results as indicative of increased occurrence when used in time-series analysis.

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Abstract:

Passive acoustic monitoring (PAM) is a cost-effective method for monitoring cetacean populations compared to techniques such as aerial and ship-based surveys. The C-POD (Cetacean POrpoise Detector) has become an integral tool in monitoring programmes globally for over a decade, providing standardised metrics of occurrence that can be compared across time and space. However, the phasing out of C-PODs following development of the new F-POD (Full waveform capture Pod) with increased sensitivity, improved train detection, and reduced false positive rates, represents an important methodological change in data collection, particularly when being introduced into existing monitoring programmes. Here, we compare the performance of the C-POD with that of its successor, the F-POD, co-deployed in a field setting for 15 months, to monitor harbour porpoise (*Phocoena phocoena)* . While similar temporal trends in detections were found for both devices, the C-POD detected only 58% of the detection positive minutes (DPM), recorded by the F-POD. Differences in detection rates were not consistent through time making it difficult to apply a correction factor or directly compare results obtained from the two PODs. To test whether these differences in detection rates would have an effect on analyses of temporal patterns and environmental drivers of occurrence, generalised additive models (GAMs) were applied. No differences were found in seasonal patterns or the environmental correlates of porpoise occurrence (month, diel period, temperature, environmental noise, and tide). However, the C-POD failed to detect sufficient foraging buzzes to identify temporal patterns in foraging behaviour that were clearly shown by the F-POD. Our results suggest that the switch to F-PODs will have little effect on determining broad-scale seasonal patterns of occurrence, but may improve our understanding of fine-scale behaviours such as foraging. We highlight how care must be taken interpreting F-POD results as indicative of increased occurrence when used in time-series analysis.

Key words:

Long-term monitoring programmes, click detector, cetaceans, C-POD, F-POD, echolocation

Introduction:

Passive acoustic monitoring (PAM) is a well-established method used to monitor acoustically active species and the habitat they reside in (Merchant *et al.* , 2015). Over the years PAM technology has greatly advanced the field of cetacean ecology, allowing a cost-effective alternative to extensive visual surveys that is not reliant on daylight hours, favourable weather conditions and availability of observers. Passive acoustic monitoring of cetaceans has resulted in high-resolution data providing us with insights of population size and abundance (Marques *et al.* , 2013; Amundin*et al.* , 2022), habitat use (Fleming *et al.* , 2018; Palmer*et al.* , 2019), and behaviour (Pirotta *et al.* , 2014; Malinka *et al.* , 2021; Todd et al., 2022) for many species. Such technology is also fundamental for long-term monitoring, particularly with the increase in coastal developments and potential disturbance from construction, marine renewable devices, shipping, and fisheries (e.g., Todd et al., 2020, 2022; Omeyer *et al.* , 2020; Ramesh *et al.* , 2021; Fernandez-Betelu, Graham and Thompson, 2022).

While there are many useful applications of PAM, fixed autonomous acoustic recording devices can increase deployment times and sampling frequencies (Sousa-Lima *et al.* , 2013). Data loggers or echolocation click detectors, such as the C-POD (Cetacean POrpoise Detector) (Chelonia Ltd., 2022) are a user-friendly, relatively inexpensive device which can be deployed for continuous monitoring periods of 3-6 months. C-PODs detect individual echolocation clicks between 20-160 kHz and have been a popular tool used to study odontocete ecology and behaviour worldwide (e.g. Carstensen, Henriksen and Teilmann, 2006; Simon et al., 2010; Nykänen, 2016; Jaramillo-Legorreta et al., 2017; Garagouni, 2019). Although no waveform data are stored by the devices, summary data on each click are preserved allowing post-deployment classification of detected sounds into sequences called click trains. Further data analysis is then performed where click trains are assigned to dolphin or porpoise origins based on frequency and bandwidth. While it is often not possible to differentiate between dolphin species (Robbins et al., 2015), based on in-field testing, Roberts and Read (2015) reported that C-PODs perform well with a relatively high accuracy in detecting cetacean echolocation. C-PODs have been used for over a decade and now form the basis of valuable long-term monitoring datasets. The F-PODs (Full waveform capture Pods) are the successor of the C-PODs, and the manufacturer is recommending a transition from C-PODs to F-PODs as availability and support for C-PODs will be limited in the coming years. This may have important implications for long-term monitoring programmes (and the associated archival data from such) as C-PODs are replaced due to equipment loss (often as a result of storms, theft etc.) or reach the end of their operational lifetimes. The F-PODs have been designed to improve and upgrade the data associated with C-PODs by recording more details of selected clicks including position of loudest cycle, frequency range and capture of full waveform (Chelonia Ltd., 2022). These new features enhance train detection, providing increased sensitivity with lower false positive rates compared to C-PODs (Chelonia Ltd., 2022).

One of the main advantages of PAM is its potential to be implemented in long-term monitoring programmes to study the change in species occurrence and behaviour over longer temporal scales. Many studies currently using C-PODs need to ensure the longevity of their data for monitoring purposes, particularly in the light of climate change and habitat alterations through coastal developments. However, to date there have been no studies reporting how the C-POD and its successor the F-POD compare in detection capacity and ability to identify trends in spatio-temporal drivers of detected cetaceans. In this study, we used data from a co-deployed C-POD and F-POD to compare the performance of the PODs in detecting habour porpoise (*Phocoena phocoena)* across various commonly used detection metrics. Additionally, Generalised additive models (GAMs) were used to explore how both PODs identifed spatiotemporal variation in harbour porpoise occurrence and foraging activity in relation to environmental variables.

Methods:

Data collection:

Between April 2021 and July 2022 click detectors were deployed off Sherkin Island in Roaringwater Bay (51°27'40.7"N, 9°26'24.7"W), a Special Area of Conservation (SAC) for harbour porpoise. Porpoise occur in the bay throughout the year, peaking in autumn months, with an estimated population (in 2008) of 117-201 individuals (NPWS, 2014), although density estimates have reportedly declined in recent years with the 2020 estimate of 0.61 individuals per km^2 (O'Brien & Berrow, 2020). The deployment site is a relatively sheltered site on the southwest coast of Sherkin Island, approximately 18m water depth, with a predominantly sandy seafloor. A C-POD and F-POD were co-deployed on a mooring line anchored to the seabed, positioned 5m above the seabed, side by side in a custom-built acetal plastic frame to optimise simultaneous detections on both devices (Appendix, Figure S1). The devices were retrieved and redeployed every 3-4 months to ensure continuity of acoustic recordings.

Data analysis:

C-POD data were processed using the Chelonia CPOD.exe software (V. 2044) and inbuilt KERNO classifier to detect harbour porpoise click trains. F-POD data were processed in a similar manner using the custom F-POD.exe software (V 1.1) and KERNO-F classifier (Chelonia Ltd., 2022). Click trains were classified as "NBHF" (narrowband high frequency) and all train quality classes were exported for further examination. Train quality filters are defined as "Hi" (high)," Mod" (moderate), and "Lo" (low). All detections were visually verified following guidelines from the manufacturer (Chelonia Ltd., 2022). Data were exported as different detection metrics; number of clicks 'NClx', detection positive days 'DPD', detection positive hours 'DPH' and detection positive minutes 'DPM'.

Detection metrics were summarised for each deployment across three groupings of train quality filters, specifically HiModLo, HiMod, and Hi, reflecting commonly used groupings in the literature (Sarnochinska et al., 2016; Clausen et al., 2018). Kendall's rank (non-parametric) correlation tests were carried out between the detections on the C-POD and F-POD at the scale of each temporal detection metric and for each train quality classification.

Both monthly and seasonal DPH were summarised for both the C-POD and the F-POD and compared using a detection ratio, expressed as: CF = Det_C/Det_F. This ratio was used to explore the comparability between the PODs across time and by what margin the F-POD detects more echolocation clicks than the C-POD.

Data on echolocation clicks were also exported and used to identify buzzes, assumed to be foraging behaviour (Verfuß et al., 2009), based on the duration of the inter-click interval (ICI). Gaussian mixture models were used to categorise echolocation clicks based on their ICI (Pirotta*et al.* , 2014). Buzzes were defined as echolocation clicks with an ICI of less than 10 ms (Carlström, 2005). Detections were then summarised as foraging buzzes per hour (BPH) for further analysis.

Environmental data:

Sunrise, sunset and civil twilight times were extracted from (www.timeanddate.com/sun) for Sherkin Island, and were used to calculate the diel cycle phases (morning, day, evening, and night) (Carlström, 2005; Todd *et al.* , 2009). Tide data were extracted from tide tables for Roaringwater Bay (www.tides4fishing.com/ie/munster/roaringwater-bay). Time difference to nearest high tide was calculated, as well as phases of the tidal cycle (ebb/flow/high/low water). Tidal range was also calculated as an indicator of spring and neap tides. Hourly water temperature data were obtained from the PODs, taken as the average value recorded by both PODS to avoid any recording bias between PODs. While the PODs cannot provide a direct measure of environmental noise levels, the click detection algorithms record unfiltered short click-like events within the 20kHz – 160kHz bandwidth (*Nall*), and is recorded for each sampling minute. A positive correlation has been found between*Nall* and environmental noise levels using a full-bandwidth recorder and is used as a proxy for general noise levels (Clausen et al., 2018; Nuuttila et al., 2018). We included this in models to investigate the effect of varying environmental noise levels on POD detection performance. For the purpose of interpretation of the results, seasons were defined as Spring (March to May), Summer (June to August), Autumn (September to November) and Winter (December to February).

Statistical modelling:

Statistical analyses were undertaken using R version 4.1.2 (R Core Team, 2022). Prior to statistical modelling, data exploration was conducted following Zuur et al., (2010). Autocorrelation was observed in the data using ACF plots with *itasdug* package (van Rij et al., 2015). Generalised Additive Models (GAMs) were conducted using the function*bam* within the *mgcv* package which is optimised to deal with large data sets. GAMs were fitted with autoregressive (AR(1)) correlation structure to account for observed autocorrelation, and a negative binomial error distribution (*theta* values obtained using function *gam* and *nb* distribution), with logarithmic link function, to deal with zero-inflation in the data (Wood, 2011; Wood*et al.,* 2015). The *rho* values for the AR structure (which control the degree of permitted autocorrelation (Wood, 2017)) were determined using the *itsadug* package and ACF plots. The parameter gamma was set to 1.2 to reduce potential overfitting of splines.

The data were analysed for every hour and the response variables used were the number of minutes with porpoise detections for each hour (0-60 Detection positive minutes, or DPM) and the number of foraging buzzes (ICI <10ms) recorded per hour. Explanatory variables included diel period as a factor and month, temperature, noise, difference to high tide and tidal range as smooth terms. Circular smoothers were used for month and difference to high tide. Thin-plate regression splines with shrinkage were used for the remaining smooth terms which return the simplest effective spline. Generalized-cross validation and manual knot selection were used, with chosen values visually selected based on the trade-off between the overall simplicity of the model and the explanatory power of smooth graphs. To decide between the appropriate tidal variable for analysis each were included in the full model and models compared based on AIC score. Time difference to high tide resulted in the model with the lowest AIC and was used for further analysis.

The relatedness between the smooth terms in the model were measured using the function *concurvity,* in a similar manner to variance inflation factors used for Generalised Liner Models (GLM). Relatedness was measured on a scale of 0-1, with 0 indicating no difference and 1 indicating that terms are identifiable from each other. Concurvity was not found, so all terms were retained for analysis. Stepwise model selection was performed where non-significant interactions were dropped from the model (starting with the least significant) and model validation repeated. Models were compared using AIC to choose the best and final model. Model performance was checked using gam.check based on traditional QQ plot and residual plots (Wood, 2006). Model goodness of fit was described by deviance explained, and area under the receiver operator curve (AUC), package *caret* (Kuhn, 2008). AUC was calculated by predicting a binomial response variable from the fitted model and compared to the observed presence/ absence of the variable. This results in a value ranging from 0-1, with values closer to 1 indicating better model fit (Boyce *et al.,* 2002). Graphical outputs were produced using the *mgcViz* package (Fasiolo *et al* ., 2018) and *ggplot2* (Wickham, 2009).

Results:

Comparability in the detection of harbour porpoise

The C-POD and F-POD were co-deployed for a continuous period of 444 days between April 2021 and July 2022. Harbour porpoise detections were recorded on 94% of days on the C-POD (419 days), and 98% on the F-POD (433 days).

Across all deployments, total C-POD detections were lower than those recorded using the F-POD (Figure 1). The margin of difference was highly dependent on the detection metric and the train quality classification category examined, with smallest differences noted when combining all (visually validated) quality categories. While there was a significant correlation between the detections on the co-deployed PODs at all temporal scales, PODs were in greatest agreement at the broadest scale metric of detection positive days (filter HiMod $r= 0.86$, $p<0.05$; HiModLo $r=0.84$, $p<0.05$, Appendix Table S2), and least comparable at the scale of number of clicks per hour (Figure 1, Appendix Table S2). Although variable across time, the increased capacity for click detection by the F-POD was evident, with the F-POD detecting 10 times or more the number of clicks detected by the C-POD (Figure 1, Appendix Table S1). Considering the "Hi" filter alone showed limited comparability between the C-POD and the F-POD, with significant but weak correlation (Appendix Table S2). Moreover, using only the high-quality classification filter meant that on average 75% of the F-POD DPH were not detected by the C-POD within the same quality grouping. Using the HiMod or HiModLo groupings increased the comparability of PODs, but the F-POD still consistently recorded more harbour porpoise detections overall. There was a small proportion of detection positive hours recorded on the C-POD that were not matched by the F-POD. However, these visually validated C-POD detections often matched unclassified NBHF clicks (i.e. not defined to be click trains by any of the quality classes) on the F-POD. Furthermore, most unmatched C-POD detections were weaker trains of Low-quality, occurring during periods of increased ambient noise, and not classified by the more conservative F-POD algorithms.

Over total 15-month period the PODs were deployed, a detection ratio of 1.38 was calculated using detection positive hours. Seasonal variability in this detection ratio occurred with PODs least comparable in the spring-summer when detection rates where lowest (ratios: Spring: 1.52, Summer: 1.48, Autumn: 1.07, Winter: 1.37, Figure 2). Despite the detection differences, both PODS similarly identified temporal patterns of occurrence at hourly scales (DPM and DPH) using the HiMod or HiModLo train quality groupings. There was a decrease in detections from April to July and consistently more detections throughout the winter months (Figure 2).

Harbour porpoise foraging behaviour was detected by both of the co-deployed PODs throughout the deployment period. Buzz positive hours (BPH), i.e. hours where foraging buzzes were identified, made up a low proportion of the total recording hours, particularly for the C-POD which detected less than a third of the BPH detected by the F-POD. Foraging buzzes were found to account for approximately 8% of the total clicks recorded by the C-POD, compared to 26% for the F-POD. The number of buzz positive hours per day was found to vary seasonally, reflecting the temporal patterns shown in overall harbour porpoise detections (Figure 2), with low counts of BPH from May till July, and peaks shown throughout winter as well as for August (Figure 2).

Spatiotemporal drivers of harbour porpoise occurrence and foraging activity

GAMs were run to compare the temporal trends and environmental predictors of harbour porpoise occurrence between C and F-PODs. The best models for detection positive minutes per hour (DPM/h) from both PODs retained all explanatory variables (all variables significant in both the C-POD and the F-POD models). Effect sizes of variables retained within the models were remarkably consistent between the C-POD and F-POD models, with the exception of noise, where this showed a considerably higher effect within the C-POD model (Table 1).

Similar temporal trends were highlighted by the C-POD and F-POD models in terms of harbour porpoise DPM/h per month and throughout the diel cycle (Figure 3). Both tidal range and time to high tide were significant, reflecting similar trends from both devices with an increase in detections during the ebb tide and during tidal ranges associated with spring tides (Figure 3), however, both variables had relatively small effect sizes within the model (Table 1). The C-POD model highlighted a much greater effect of noise on harbour porpoise detections, with a clear decrease in porpoise detections at higher noise levels, occurring at a much lower noise threshold for the C-POD than the F-POD (Figure 3). Harbour porpoise detections were found to decrease with increasing water temperature for both devices (Figure 3).

In contrast to the similar temporal patterns shown via the occurrence, strong differences occurred between models of foraging buzzes between C-PODS and F-PODS using buzz clicks per hour (BPH) as the response variable.

The C-POD foraging model did not retain any temporal variables despite them remaining the most influential covariates within the F-POD foraging model, likely due to a much-reduced sample size of identified feeding buzzes by the C-POD. Neither time difference to high tide or tidal range were found to influence harbour porpoise foraging behaviour in either C-POD or F-POD models. The F-POD model suggested a decrease in foraging buzzes between July and September, and an increase in foraging buzzes detected during the day (Figure 4). Similar to the detection model, foraging activity decreased with increasing water temperature, with highest buzz detections around 10° C. In contrast to the C-POD model, the F-POD foraging model found no significant effect of noise on foraging activity (Table 2).

Discussion:

To the best of our knowledge, this study is the first to evaluate the performance of co-deployed C-POD and F-POD devices in a field setting for monitoring harbour porpoise. Previous studies have evaluated the performance of the C-POD with other types of full bandwidth recorders (incl. Soundtrap, DMON), with the C-POD typically performing well with an overall high degree of accuracy (Roberts and Read, 2015; Sarnocinska et al., 2016; Jacobson et al., 2017). Our results suggest that at appropriate temporal scales, C-PODs provide comparable results to the newer F-PODs and with certain caveats, F-PODs would be suitable replacements for C-PODs in existing monitoring programmes as C-PODs reach the end of their serviceable lifetime.

Data from click detectors such as C-PODs, its predecessor T-PODs, and now the F-PODs have been used to monitor small cetaceans, as well as their responses to anthropogenic activities in numerous settings including pile driving, seismic surveys, and fisheries deterrent devices (e.g. Philpott et al., 2007; Thompson *et al.* , 2013; Omeyer*et al.* , 2020; Todd et al., 2020). Our results show that the F-POD consistently detects more echolocation clicks and foraging buzzes than the C-POD across the temporal scales of minutes, hours and days, as well as all train quality classification groupings. Lower detection rates by the C-POD is to be expected due to advances in F-POD electronics and software to capture more information on individual echolocation clicks and enhance train detection (Chelonia Ltd, 2022). This poses a potential issue for researchers engaged in long-term monitoring, with questions about how comparable different POD types may be, potentially affecting time-series as C-PODs are eventually replaced by F-PODs. This study shows that both C-PODs and F-PODs detected similar patterns of occurrence and echolocation activity. As indicated by Garrod et al. (2018), detection metrics at a minimum of an hourly scale are representative of relative occurrence, enabling temporal trends to be determined. Detections at the broader scale of detection positive days were found to match best between both PODs with little discrepancy between them. Therefore, for direct comparison between C-POD and F-POD data, detection positive days, and using combined classifications of Hi Mod and Lo, is the only detection metric recommended. However, such a metric would be insufficient for identifying fine-scale temporal patterns of occurrence of behaviour in response to factors such as diurnal changes in prey availability or tidal state, both known to influence harbour porpoise occurrence and feeding behaviour (Schaffeld et al., 2016; Zein et al., 2019)

Our results highlighted that F-PODs appear to be much more capable at identifying harbour porpoise click trains with confidence than the C-POD (i.e. classified as high quality by the KERNO classifier). However, when considering the combined train quality classification groupings (i.e. HiMod and HiModLo) the two PODs are substantially more comparable. Researchers considering using a time series consisting of data from C-PODs and F-PODs for analysis of temporal trends should consider using the combined classifications, provided extensive visual validation is followed, particularly for low quality trains to eliminate possible false positive detections. The enhanced train detection specified by the manufacturer has also been demonstrated in our results with F-POD continually detecting more harbour porpoise detections than the C-POD by a factor of 1.38 across the deployment period. Comparability between the PODs was however found to be variable between seasons, with the highest detection ratio in spring and summer making detection rates on the PODs less comparable. Detection ratios such as explored here could be investigated further within monitoring programmes looking to transition to the use of F-PODs. Understanding how the devices compare in various deployment sites can help for the interpretation of long-term data beyond the lifespan of the C-POD and avoid misinterpretation of the data (for example interpreting a false increase in occurrence due to differing device sensitivities).

Investigating spatial and temporal patterns in species occurrence is often the crux of ecological monitoring (e.g., Jones et al., 2014; Williamson et al., 2017; Zein et al., 2019). Generalised additive models were used to investigate whether detections from both types of POD have the capacity to identify the same temporal drivers of porpoise occurrence and foraging activity. The occurrence models for both PODs highlighted the same temporal patterns, and same environmental predictors with very similar effect sizes, suggesting that analyses using data from both C-PODs and F-PODs will not be affected greatly by POD type. However, it would be prudent to include POD type as a fixed factor in any such analysis. Conversely, the models investigating feeding buzzes did not provide analogous results. No temporal patterns were found using the C-POD data, possibly due to the much lower detection rates of feeding buzzes using C-PODs, with the F-POD detecting three times as many foraging buzzes in comparison, and 10 times as many echolocation clicks overall. The higher detection rates of feeding buzzes by the F-POD enabled detection of temporal patterns including an increase in foraging buzzes from autumn to winter, and an increase in foraging activity during the day. The specific nature of the relationships and their ecological context is outside of the scope of the current study, but the contrasting ability of the PODs to detect feeding buzzes is particularly relevant in the context of integrating F-PODS into long-term datasets. The increased click detection capacity of the F-POD now enables fine-scale analysis of foraging or social behaviours (demonstrated by high click rates (Clausen *et al.,*2010)), that has perhaps been missed or underestimated using C-PODs. Additionally, F-PODs were found to be less effected by environmental noise levels within the 20-160KHz noise band, as indicated by*Nall* (Clausen et al., 2018). It is plausible that decreased detections on the C-POD during periods of increasing environmental noise is a consequence of detector performance, which has been overcome during the development of the F-POD in conjunction with the increased click detection ability.

Long-term datasets and consistency of monitoring methods throughout the duration of monitoring programmes are important to enable long-term trends to be identified, particularly in areas of high conservation importance. Changing controllable factors such as monitoring equipment can skew our understanding of these long-term trends and in turn make it more difficult to interpret a change in habitat use, or behaviour of a species, which can be detrimental in the event of a disturbance or imminent threat. Static acoustic monitoring using PODs has been an integral part of cetacean monitoring programmes exploring habitat use and behaviour. Our results show than the C-POD and the F-POD are consistently comparable at the broad scale of identifying porpoise presence, and produce similar results when modelling environmental correlates of occurrence. However, the C-POD failed to detect the more nuanced patterns detected by the F-POD, particularly when investigating foraging behaviour versus occurrence. On account of its greater sensitivity and increased detection rates for harbour porpoise the F-POD certainly can be a useful tool to integrate into acoustic monitoring programmes. While the introduction of F-PODs into long-term time series is unlikely to change our understanding of the environmental drivers of occurrence, it is advisable that detections from one POD type should not be directly compared with detections from another as this could give erroneous results of increased occurrence due to differing detection rates rather than a true increase in individuals. Furthermore, any studies transitioning between PODs or combining C-POD and F-POD data should consider including POD type as a factor when conducting time-series. While the current study only investigated comparability in POD performance for detecting acoustic activity of harbour porpoise, it is likely that analogous differences would be seen for other cetacean species recorded by PODs. This study has given insights that the F-POD will be invaluable for future monitoring of harbour porpoise and other cetacean species, however care and consideration must be taken to make C-POD data adaptable for the integration into future studies.

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Conflict of interest:

The authors declare no conflict of interest.

Author contributions:

Nicole R. E. Todd: Conceptualization; data curation; formal analysis; investigation; methodology; writing – original draft; writing – review and editing. **Ailbhe S. Kavanagh** : Conceptualization; supervision; writing – review and editing. **Emer Rogan** : Conceptualization; supervision; writing – review and editing.**Mark Jessopp** : Conceptualization; project administration; supervision; writing – review and editing.

Data accessibility statement:

All processed data and R code files to reproduce the results given in this paper will be uploaded to Dryad repository.

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Tables :

Retained terms	**C-POD model**	**C-POD model**
	p-value	Effect size
Month	**<0.001**	18.84 (++)
Temp	**0.002**	6.07 (+)
Nall- noise proxy	**<0.001**	59.57 (+++)
Tidal range	**0.01**	6.53 (+)
Diff. to HT	**<0.001**	2.91 (+)
Diel period (Relative to Day)	*Evening:* 0.2048 *Morning:* 0.1271 *Night:* **<0.001**	*Evening:* -1.27 (-) *Morning:* -1.53 (-) *N*

Retained terms	**C-POD model**	**C-POD model**	**F-POD model**
	p-value	Effect size	p-value

Retained terms	C-POD model	C-POD model	F-POD model
Month			**<0.001**
Temp	**<0.001**	21.09 (++)	**<0.001**
Nall- noise proxy	**<0.001**	17.38 (++)	0.62
Tidal range			0.08
Diff. to HT	0.49	0	0.49
Diel period (Relative to Day)			*Evening:* **<0.001** *Morning:* **<0.001** *Night:* **<0.001**

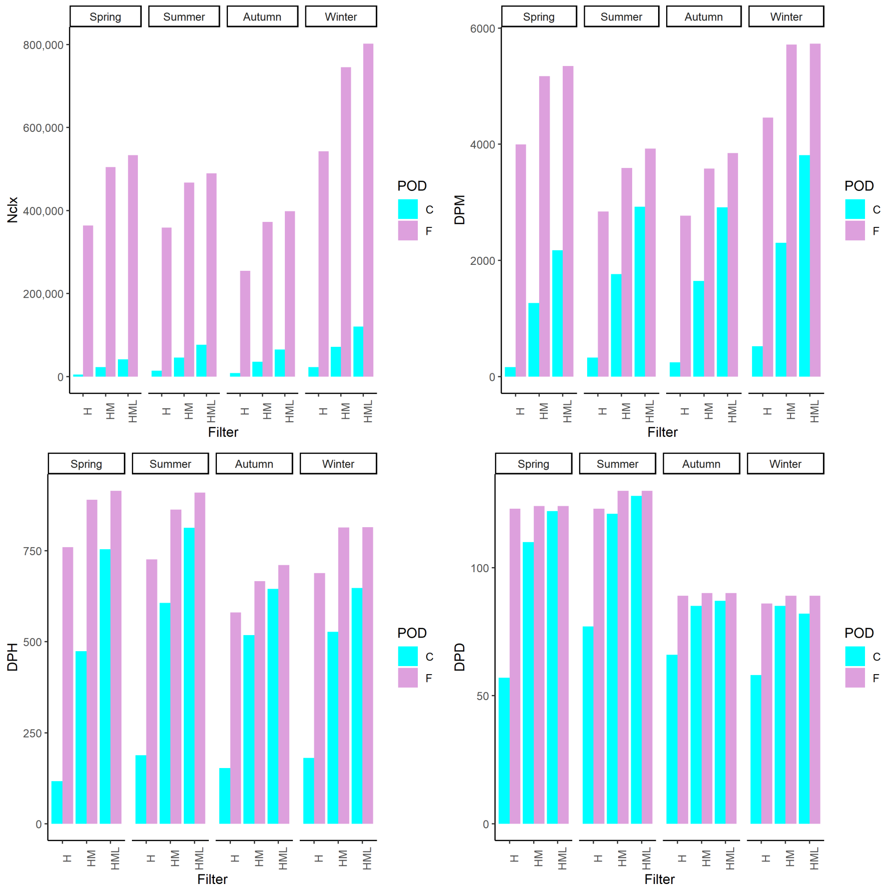
Figure captions:

Figure 1: Total Number of clicks (NClx), Detection positive minutes (DPM), Detection positive hours (DPH), and Detection positive days (DPD) for C-POD and F-POD co-deployment (different PODs specified in the legend) collated per season across the deployment period (Note total deployment days per season: Spring: 128, Summer: 138, Autumn: 92, Winter: 91). HML represents High, Moderate, and Low-quality train classification categories.

Figure 2: A) Median detection positive hours (DPH) for C-POD and F-POD co-deployment. B) Median buzz positive hours (BPH, i.e. cumulative number of hours per day where at least one foraging buzz was detected. Different PODs specified in the legend. Boxplot shows the lower quartile, the median, the upper quartile with the whiskers extending to the most extreme data points (1.5 times either side of the interquartile range).

Figure 3: Significant relationships for the final C-POD (left) and F-POD (right) harbour porpoise detection model based on GAM/BAM standard errors. Shaded areas represent 95% confidence intervals.

Figure 4: Significant relationships for the final C-POD (left) and F-POD (right) harbour porpoise foraging model based on GAM/BAM standard errors. Shaded areas representing 95% confidence intervals


Spring
Summer
Autumn
Winter
Nclx
800,000
600,000
400,000
200,000
0
DPM
6000
4000
2000
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DPH
750
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250
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DPD
100
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POD
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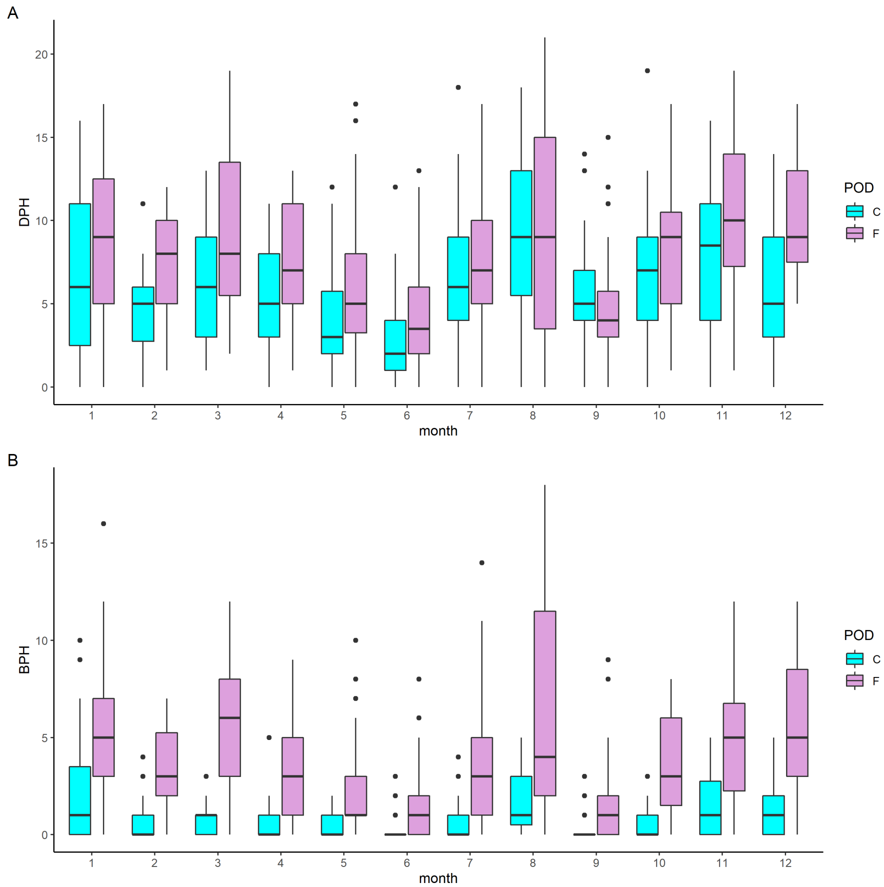
A
DPH
month
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B
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month
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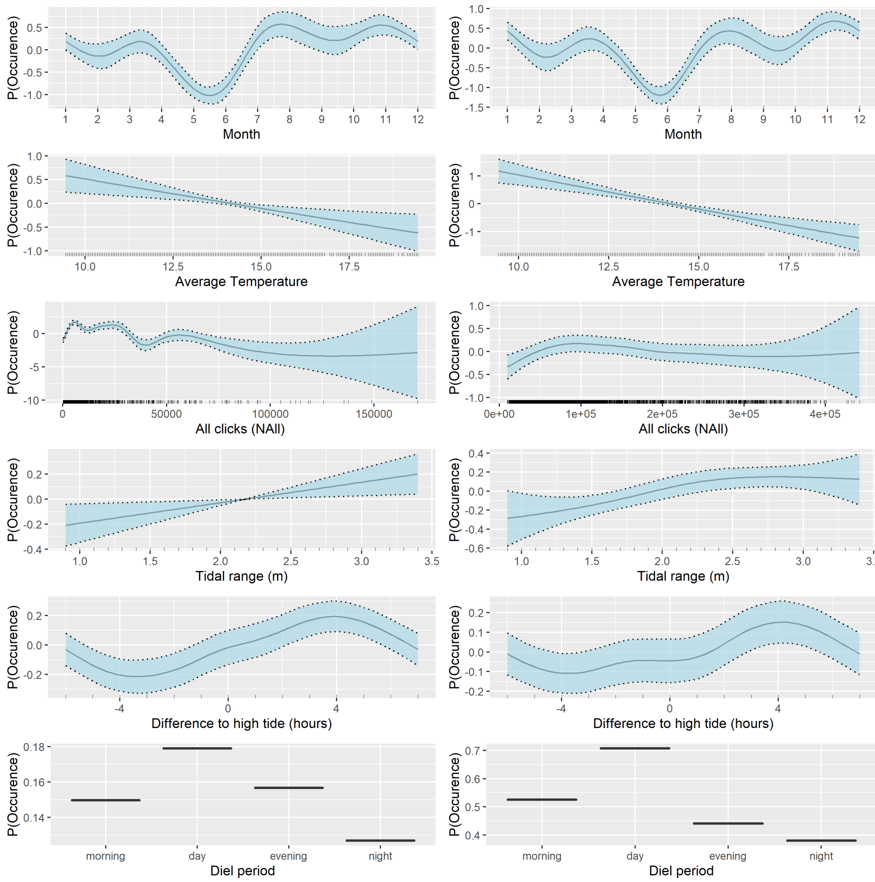
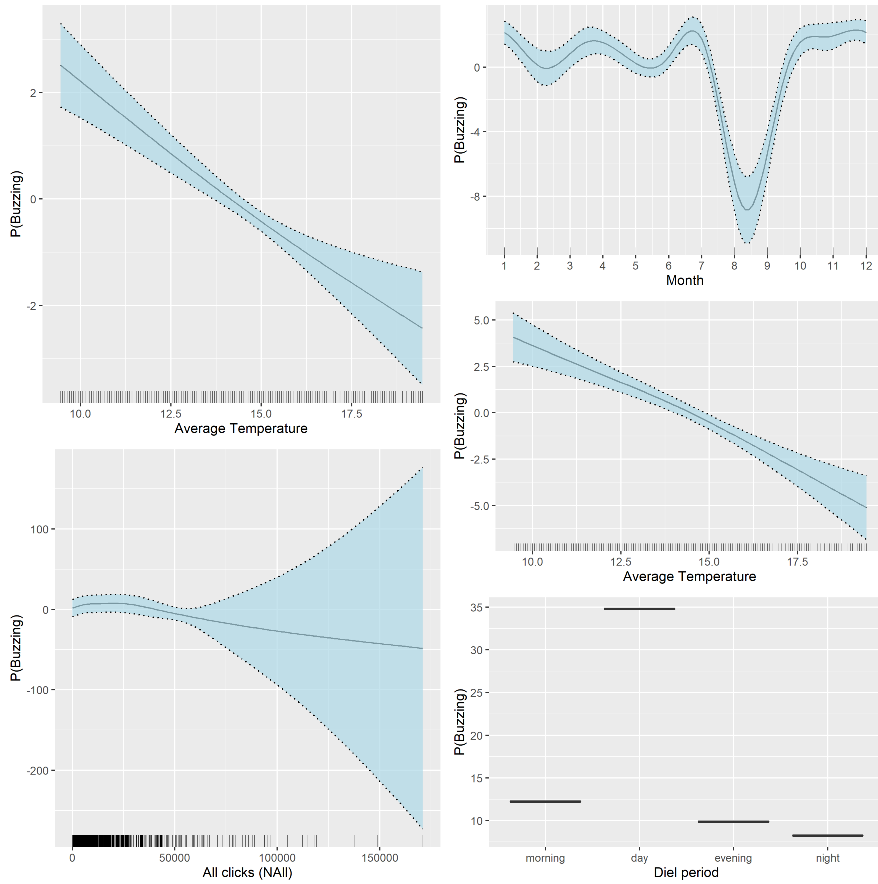
F



P(Occurence)
Month
1 2 3 4 5 6 7 8 9 10 11 12
Average Temperature
10.0 12.5 15.0 17.5
All clicks (NAll)
0 50000 100000 150000
0e+00 1e+05 2e+05 3e+05 4e+05
Tidal range (m)
1.0 1.5 2.0 2.5 3.0 3.5
Difference to high tide (hours)
-4 0 4
Diel period
morning day evening night


P(Buzzing)
Average Temperature
Month
All clicks (NAll)
Diel period
morning
day
evening
night