Energinet LOT1: Passive Acoustic Monitoring of harbour porpoises in the Danish North Sea

CPOD and FPOD comparison

Final report

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Energinet LOT1: Passive Acoustic Monitoring of harbour porpoises in the Danish North Sea– CPOD and FPOD comparison

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1 INTRODUCTION

The harbour porpoise (*Phocoena phocoena* L., 1758) is the most common cetacean in the continental shelf waters of north-western Europe: An estimated 339,000 animals live in the North Sea, of which around 35,000 live in the Danish and German Bight (GILLES ET AL. 2023). To monitor their distribution and abundance, Passive Acoustic Monitoring is often used, as this species uses echolocation for orientation, foraging and intraspecific communication regardless of light conditions (KOSCHINSKI ET AL. 2008; VERFUß ET AL. 2009), and thus, they use their echolocation system almost continuously (AKAMATSU ET AL. 2007; WISNIEWSKA ET AL. 2016). Therefore, detection rates of harbour porpoises are assumed to be an approximate measure of harbour porpoise presence and relative abundance. Visual observations showed that there is a strong correlation between harbour porpoise detection rates and density (DIEDERICHS ET AL. 2002; KOSCHINSKI ET AL. 2003; CARSTENSEN ET AL. 2006; KYHN ET AL. 2012; WILLIAMSON ET AL. 2016; JACOBSON ET AL. 2017). In a study of wild harbour porpoises in Canada, 98 % of all visual observations were also recorded by acoustic data loggers within a distance of 150 m (KOSCHINSKI ET AL. 2003). In addition, harbour porpoises occur mainly solitary or in groups of two to three animals (SIEBERT ET AL. 2006).

Passive Acoustic Monitoring (PAM) based on CPODs is a cost-effective method of monitoring harbour porpoise populations compared to techniques such as aerial and ship-based surveys. These devices are user-friendly, relatively inexpensive and can be deployed for continuous monitoring periods of 2 to 4 months. A CPOD detects individual echolocation clicks between 20 and 160 kHz and has been a popular tool used to study odontocete ecology and behaviour worldwide (CARSTENSEN ET AL. 2006; DÄHNE ET AL. 2017; JARAMILLO-LEGORRETA ET AL. 2017; BRANDT ET AL. 2018; VOß ET AL. 2023). Thus, the CPOD has become an integral part of global monitoring programs for more than a decade, as it provides standardized measures of porpoise presence and relative abundance that can be compared across time and space. The idea of PODs is that the devices do not store waveform data (which requires a lot of energy), but instead store summarized information for each click, which then enables subsequent classification of the detected sounds via sequences, so-called click sequences. Based on the frequency, bandwidth and pattern of the click sequences, the data can be differentiated between ship sonar, dolphins and porpoises in terms of their probability of origin.

However, the phasing out of CPODs following the development of the new Full Waveform Capture POD (FPOD) with new electronics and software represents an important methodological change in data collection, particularly when introduced into existing monitoring programs.

The FPODs were developed to enhance and extend the data collected with the CPODs by recording more details about the detected clicks, including the location of the loudest cycle, frequency range and full waveform information (CHELONIA LTD. 2020a; b). These new features are expected to improve click train detection and provide greater sensitivity. In principle, comparability with CPODs is assumed, but the false-positive rate is said to be lower compared to CPODs (CHELONIA LTD. 2020a; b). Therefore, according to the manufacturer, the FPOD has a higher sensitivity, an improved train detection and a lower false positive rate.

Many studies currently using CPODs need to ensure the long-term comparability of their data for monitoring purposes, especially with regard to the question of possible changes due to

anthropogenic interventions, such as the construction of offshore wind farms. To ensure comparability of data from previous projects (with CPOD deployment) to data collected in the future (with FPOD deployment), CPODs and FPODs must be deployed simultaneously in different areas with varying detection rates and different behaviour of harbour porpoises (e. g. feeding buzzes, social calls). So far, however, comparisons between CPODs and FPODs are still very limited (TODD ET AL. 2023; RANSIJN ET AL. 2024; GAUGER & TAUPP 2025). Therefore, within this study, nine stations were deployed in the Danish North Sea between April 2023 and April 2025, equipped with a CPOD-FPOD pair. Within the scope of this report, detection rates of CPODs and FPODs were compared on different detection metrics.

2 METHODS

2.1 Study design

Of the total of 43 stations equipped with Passive Acoustic Monitoring devices for harbour porpoises in the study area in the Danish North Sea (Figure 2.1), 9 stations were equipped with a pair of a CPOD and an FPOD. Table 2.1 shows the coordinates and deployment periods of these POD stations. The devices have been deployed until April 2025.

The present report covers POD deployment between the 16th of April 2023 and the recovery on the 4th of April 2025.

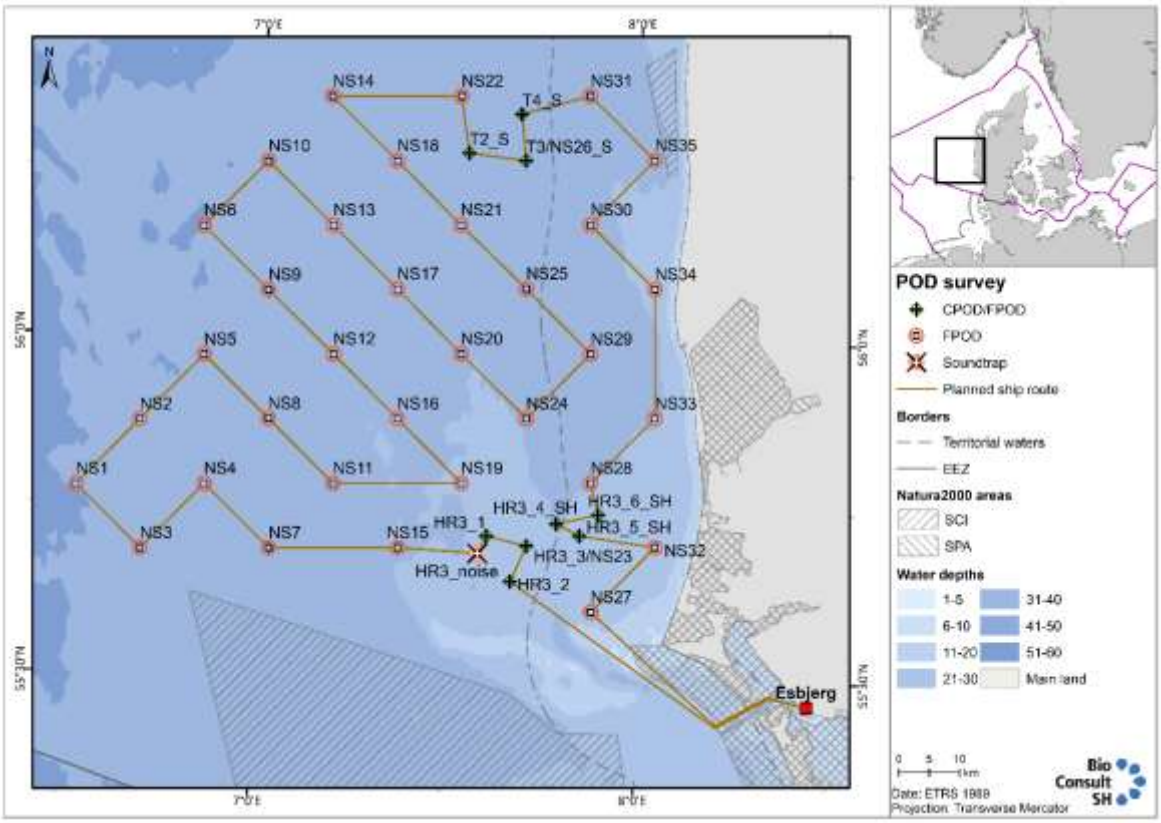

Figure 2.1 Study design in the Danish North Sea: At 43 stations, FPODs were deployed from April 2023 until April 2025. At 9 of these 43 stations, CPODs were additionally deployed.

Table 2.1 Geographical positions and deployment periods of the deployed FPODs and CPODs, water depth (m), and type of mooring. PODs were deployed from April 2023 until April 2025.

Station ID	Lati-tude (°N)	Lon-gitude (°E)	Total water depth at sta-tion (m)	Mooring	Deployment	Recovery
HR3_1	55.7148	7.6081	-17	Acoustic release	22.04.2023	04.04.2025
HR3_2	55.6485	7.6725	-12	Acoustic release	17.04.2023	04.04.2025
HR3_3/ NS23	55.7012	7.7141	-19	Acoustic release	17.04.2023	04.04.2025
HR3_4	55.7348	7.7908	-18	Large surface bouy → changed to Normal surface bouy	17.04.2023	04.04.2025
HR3_5	55.7173	7.8519	-16	Large surface bouy → changed to Normal surface bouy	16.04.2023	04.04.2025
HR3_6	55.7487	7.9010	-18	Large surface bouy → changed to Normal surface bouy	16.04.2023	04.04.2025
T2	56.2799	7.5437	-32	Normal surface bouy	21.04.2023	01.04.2025
T3/ NS26	56.2706	7.6946	-31	Normal surface bouy	21.04.2023	22.01.2025
T4	56.3391	7.6816	-29	Normal surface bouy	21.04.2023	22.01.2025

2.2 Harbour porpoise detection devices

The Porpoise Detector (FPOD and CPOD)

FPODs and CPODs (**C**etacean **Po**rpoise **D**etector) are devices that have a hydrophone and store information about impulsive sound events that have passed certain filter settings. This allows the high-frequency echolocation signals of harbour porpoises to be detected at a distance of up to a maximum of appr. 400 m (Figure 2.2; TODD ET AL. 2025). The FPOD is the successor model of the CPOD with new electronics and software. The differences between the two devices are listed in Table 2.2.

CPODs are autonomous recording devices that record these high-frequency echolocation sounds of harbour porpoises using a built-in underwater microphone (hydrophone). In detail, a CPOD consists of a hydrophone, amplifier, frequency filters, two battery units (each with four or five 1.5 volt D batteries) and a digital memory card (SD card with usually 4 GB memory), which are housed in a 54 or 66 cm long (depending on the number of batteries) and pressure-resistant plastic housing. The hydrophone is located under a white plastic cap at one end of the housing and records all sound events omnidirectionally with a click characteristic in a frequency range of 20 to 145 kHz or 160 kHz (depending on the CPOD version). This covers the typical frequency range of porpoises from 100 to 140 kHz.

The FPOD is the successor model to the CPOD. All the above points also apply to the FPOD with the following exceptions: An FPOD consists of a hydrophone, amplifier, frequency filters, two battery units (each with five 1.5 volt D batteries) and a digital memory card (mini SD card with 32 GB memory), which are housed in a 71 cm long and pressure-resistant plastic housing. The hydrophone records all sound events omnidirectionally with a click characteristic in a frequency range from 20 to 160 kHz.

Both the CPOD and the FPOD are tared so that the device rises vertically under water with the hydrophone pointing upwards. A gravity sensor switches on the data recording as soon as the angle falls below a pre-set value. The position angle of the POD in the water is also recorded during data recording, which can be used later to detect possible interference events. After setting various filters, the POD captures the physical characteristics of the recorded sound events.

The recorded information are later automatically searched for porpoise-specific signals using special software.

The clicking sounds of harbour porpoises are strongly forward directed. They are emitted within a sound beam with a horizontal beam width of 13° and a vertical beam width of 11° (KOBLITZ ET AL. 2012). This means that PODs will only be able to detect harbour porpoise presence if these animals (1) emit click sounds, (2) have their head pointed towards the hydrophone, and (3) are located at a suitable distance from the device. Even though the theoretical distance to which these data loggers can record information on clicks of harbour porpoises is up to a range of 400 m (TODD ET AL. 2025), the effective detection radius is therefore smaller. For example, in a field study with the predecessor model, the T-POD, only clicks up to a distance between 22 and 104 m were effectively recorded (KYHN ET AL. 2012), while in another field study a detection range of about 170 m was observed (KOSCHINSKI ET AL. 2003). The respective detection radius depends on the POD type, POD sensitivity, train classification settings, source level of the emitted sound and duration of snapshots, as well as sea state, wind, current speed and sediment type which affect the background noise level.

The recording of harbour porpoise clicks is therefore highly influenced by the animals' activity as well as distance from and angle of approach towards the POD. Applying different pre-set filters, the POD converts the sound waves into digital data, which are stored on an SD card. A number of different specific click characteristics is additionally saved. The CPODs were set to a scan limit of 4,096 clicks/min. In contrast, FPODs do not have a scan limit, but change their sensitivity depending on the background noise level.

Figure 2.2 Porpoise detection devices – an FPOD on the left and a CPOD on the right. FPODs have longer hydrophones than CPODs.

Table 2.2 Differences between CPODs and FPODs in hardware and software.

	CPOD	FPOD
Hard-ware	Electronics	Modified electronics (no further information available)
Soft-ware	Manual scan limit	Automatic change in threshold in case of high back-ground noise levels
	KERNO classifier	Modified KERNO classifier
	Hel1 classifier	No Hel1 classifier so far (not planned either)

POD calibration

All deployed devices were calibrated by the manufacturer (Chelonia Ltd., UK) to the main frequency of porpoise clicks (130 kHz) and set to the same hearing threshold (± 3 dB). Calibration is carried out in a specifically designed test tank in a standardized acoustic environment indicating possible differences in the sensitivity of the devices. The sensitivity of the units had been standardized when built by rotating the complete instrument in a sound field and adjusted to achieve a radially averaged, temperature corrected, maximum source pressure level (SPL) reading within 5% of the standard at 130 kHz (60.5 dB). The radial values were taken at 5 degree intervals. The calibration and standardization process are described in detail on the manufacturer's website (www.chelonia.co.uk).

POD deployment

Three of the 9 stations with CPOD and FPOD were deployed with acoustic release systems (Figure 2.3), 3 of the 9 stations were deployed with normal surface buoys (Figure 2.4) and 3 of the 9 stations were initially deployed with large surface buoys and changed to normal surface buoys during the first year of the project.

Compared to CPODs, FPODs have an internal clock. This internal clock runs continuously regardless of whether the POD is switched on or not and is calibrated to the sea temperature. However, due to different temperatures between the sea and the storage basement, the length of one recording minute can vary. To minimize the difference between actual time and recorded time, all FPODs were touched at an exact time a few hours before deployment. This time served as a reference: The time at which the FPOD was touched was compared to the time at which the FPOD recorded the touch; the FPOD data set was adjusted to this time.

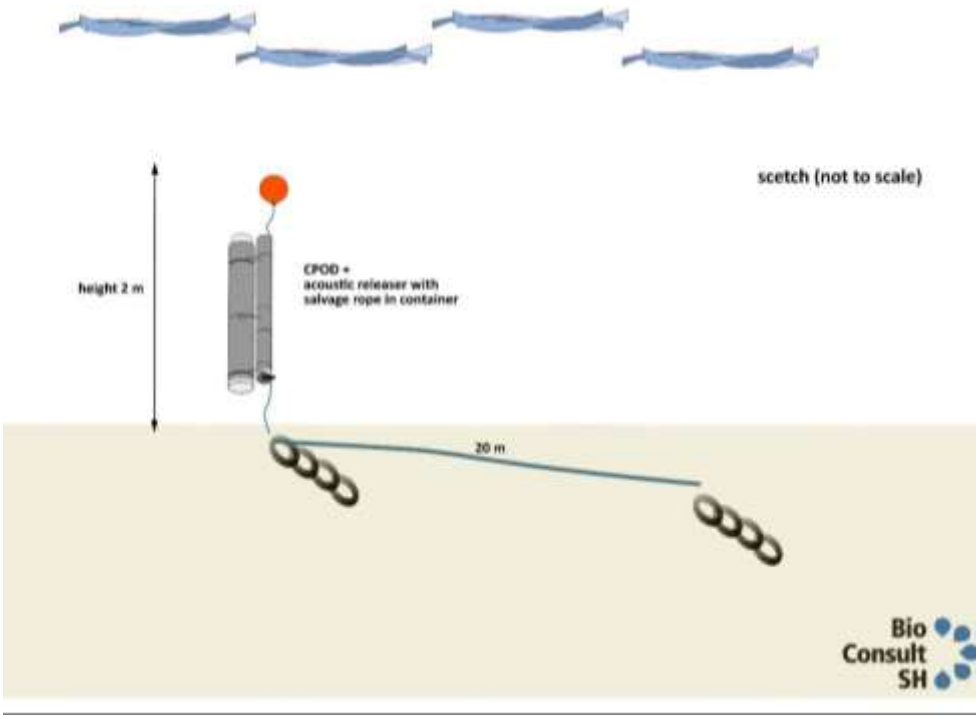

Figure 2.3 POD anchoring system with Acoustic Release System.

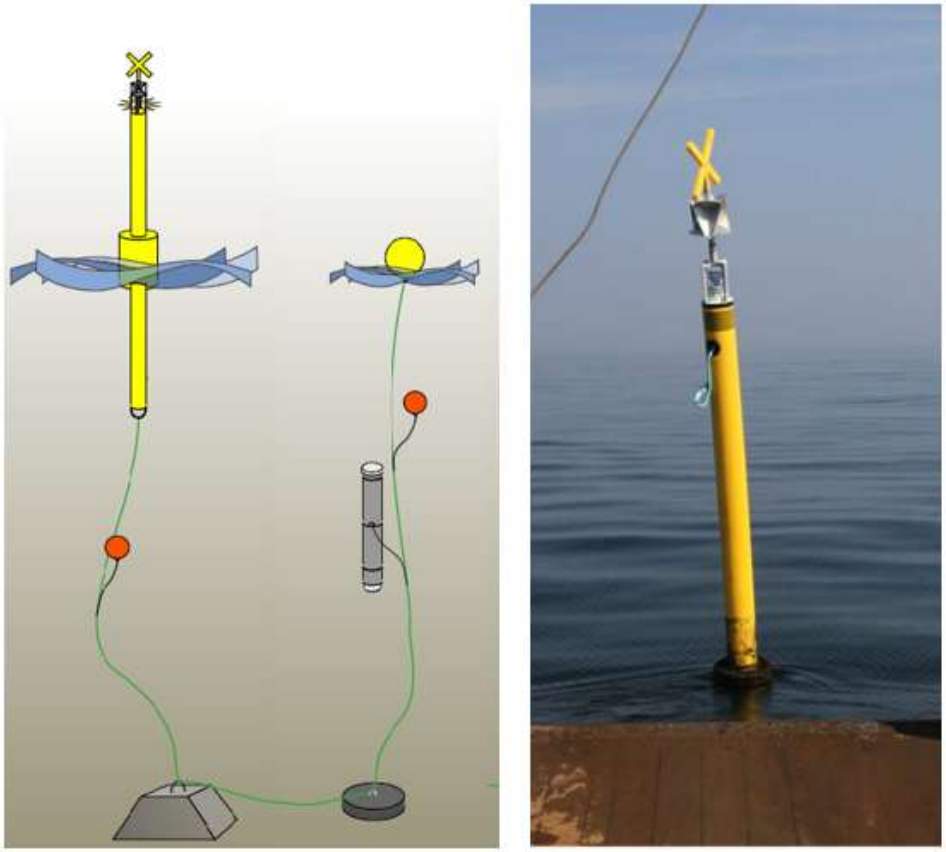

Figure 2.4 POD anchoring system with normal spare buoys.

2.3 POD software

Raw data of the PODs are processed using the associated software FPOD.exe respectively CPOD.exe (Chelonia Ltd., UK). Each software is available as a free download under http://www.chelonia.co.uk. For this final report, CPOD.exe software v2.045 and FPOD.exe software v1.0 were used.

PODs record signals in real time allowing to identify click trains due to the temporal resolution. Harbour porpoise click trains are extracted from the raw data by means of an algorithm of the FPOD.exe respectively CPOD.exe software. Besides, signals are classified by the KERNO classifier into different categories according to the probable source: harbour porpoise, dolphin, boat sonar or unknown source. The software assigns each click train to one of these classes and gives an estimate of the quality of this classification. Four quality classes are available:

- “high”: these click trains are highly probable harbour porpoise signals.
- “moderate”: short click trains, which are probably harbour porpoise signals.
- “low”: click trains with sound patterns which may be harbour porpoise signals but deviate from the ideal and may therefore originate from other sources.
- “doubtful”: series of click trains, which are due to the length or the temporal pattern of rather technical origin. These may still contain harbour porpoise click trains, which were only partly recorded by the hydrophone or from a larger distance or at an unfavourable angle.

For the present analysis, standard filtering for CPOD was applied according to Chelonia Ltd., including only the two highest quality classes (“high” and “moderate”) to decrease the number of incorrectly classified harbour porpoise click trains. For FPODs, filtering was applied including the two highest quality classes (“high” and “moderate”; see chapter 3.1) as well as only including the highest quality class (“high”; see chapter 3.2). Due to high number of detections and the high susceptibility to subjective assessments and therefore low comparability, a visual inspection of the raw data was not carried out.

2.4 Data recording

9 stations with simultaneous deployment of CPODs and FPODs were set up in the project area in April 2023. The devices were replaced approx. every three months to extract data and change the batteries. The stations were recovered latest in April 2025. Longer-term data loss occurred either due to loss of devices or technical problems (Figure 2.5). A total of 802 of 6,300 possible FPOD days (13 %) and 948 of 6,202 possible CPOD days (15 %) could not be included in the evaluation due to loss of devices (Table 2.3). 3 additional FPOD days (0 %) and 119 additional CPOD days (2 %) could not be included in the evaluation due to technical problems.

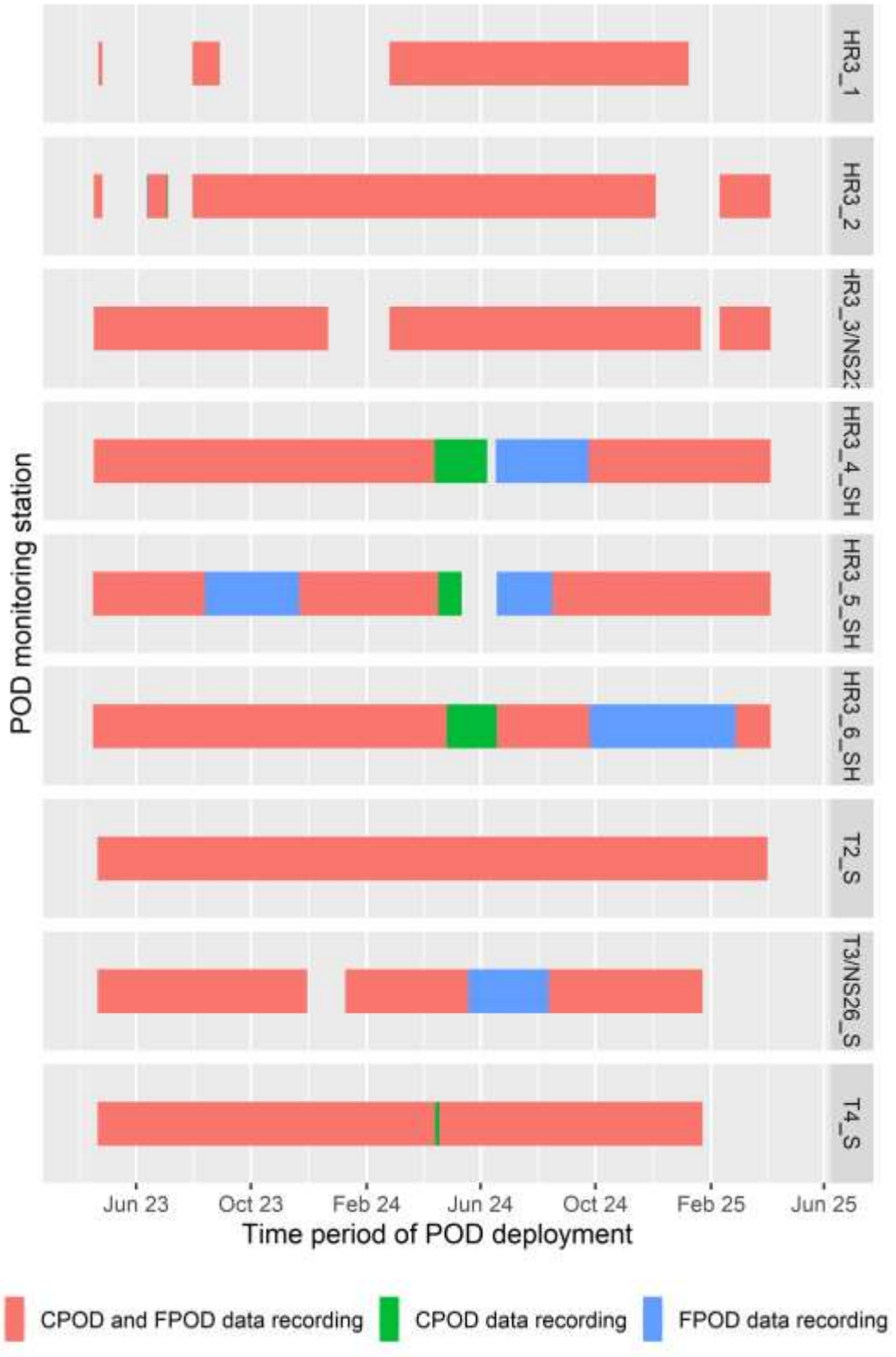

Figure 2.5 *Bar chart, indicating the duration of deployment of PODs for the survey period (April 2023 to April 2025). Red: CPOD and FPOD both recorded data; green: only CPOD recorded data; blue: only FPOD recorded data, grey: no data. The x-axis shows the date, the y-axis the POD station.*

Table 2.3 FPOD data analysis: All possible days, days with data deployment, days with data recording, days after quality check and whole days with records of 1,440 minutes.

Dataset	Number of FPOD days	Number of CPOD days
All possible days	6,300 (100 %)	6,202 (100 %)
Days with data deployment (Days with losses of devices are excluded)	5,498 (87 %)	5,254 (84 %)
Days with data recording (Days with technical problems are excluded)	5,495 (87 %)	5,135 (83 %)
Days after quality check (Days with a lot of background noise are excluded)	4,125 (65 %)	4,504 (73 %)
Whole days with records of 1,440 minutes (Incomplete records due to e. g. exchanges of PODs are excluded)	4,048 (64 %)	4,428 (71 %)

2.5 Clicks of unknown origin

To avoid possible masking effects of too many clicks of unknown sources on the registration of harbour porpoise clicks, the quality of POD records was checked. In addition to echolocation sounds of harbour porpoises, PODs record all impulse sound events in a frequency band of between 20 kHz and 160 kHz. Among these are the sounds of boat sonars (which can be recognised by the algorithm), breaking waves, boat propeller and sediment movement (grains of sand hitting the housing of the hydrophone). If a CPOD is deployed in a noisy environment, the pre-set click limit of 4,096 clicks per minute will quickly be exceeded and the CPOD will then record no further data for the rest of this minute. In such a case, harbour porpoise clicks may be missed. FPODs do not have a scan limit but according to the manufacturer change their sensitivity depending on the background noise level, which could possibly lead to larger differences in the detection probability between C- and FPOD.

But also, if the CPOD scan limit is not reached it cannot be excluded that porpoise clicks may be missed due to masking. A dual criterion was defined in order to prevent a data bias, due to too many clicks of unknown origin in the further analysis: The two criteria were defined based on CPOD experience gained in the analysis of different projects in the North Sea and Baltic Sea (ROSE ET AL. 2019). All complete days with POD recordings that registered either more than three million clicks (the maximum possible number is > 5.89 million clicks) or had more than 200 minutes reaching the

CPOD click limit of 4,096 clicks were removed. Even though FPODs do not have a scan limit, these two criteria were also applied to FPOD data to make the data sets comparable. Overall, 1,370 FPOD days (22 %) and 631 CPOD day (10 %) exceeded the dual criterion and were thus excluded from further analyses (Table 2.3).

Furthermore, only whole days with records of 1,440 minutes were included in the evaluation. Duplicate or incomplete records due to e. g. exchanges of PODs were excluded. 77 FPOD days (1 %) and 76 CPOD days (1 %) recorded data for less than 1,440 minutes and were therefore discarded (Table 2.3).

2.6 Data analysis

Comparisons between CPOD and FPOD were generated based on harbour porpoise detection rates using the software R (version 4.3.2; R CORE TEAM 2017). For comparing detection rates between CPODs and FPODs, only days when both devices recorded data at the same station were evaluated.

Detection rates can be analysed at different temporal scales: Harbour porpoise-positive time units are pre-defined periods (e.g., days/hours/10 minutes or minutes), which are checked for the occurrence of harbour porpoise click trains. In case the chosen time unit contains at least one harbour porpoise signal, this time unit is rated to be harbour porpoise positive. As the number of recorded clicks largely depends on the behaviour of the animals and is very sensitive to possible minor differences in sensitivity between the devices, the parameter "positive time unit" is an indication for harbour porpoise presence, which is independent of the context of the animals' sound emission. Different studies were able to show a clear relation between absolute harbour porpoise density (determined in aerial surveys) and the detection rate within the same period and area in form of harbour porpoise positive time units (SIEBERT & RYE 2008; KYHN ET AL. 2012; WILLIAMSON ET AL. 2016; JACOBSON ET AL. 2017; SCHUBERT ET AL. 2019). It can therefore be assumed that the higher the detection rate, the more harbour porpoises will have been present in the respective range of the POD in the particular time unit (e.g. day) although it cannot be completely excluded that in case of a high detection rate only few animals stayed in the area covered by a POD for a longer period of time. This parameter therefore only serves as a rough indicator for harbour porpoise density (see formula 1, x_t = number of clicks for this time unit).

Formula 1:

$$\text{Harbour porpoise positive time per time unit } [\%] = \frac{\text{N time units with clicks } (x_t > 0)}{\text{N total time unit}} * 100$$

%DPD/time unit (% detection-positive days per time unit) gives the percentage of survey days per pre-defined time unit (e. g., month/year/study period, etc.) with at least one harbour porpoise signal. Applying this parameter, no difference is made if only one click train was recorded that day or if every minute hundreds of click trains occurred. This coarse resolution parameter is especially suited for data sets with few harbour porpoise detections. The parameter is standardized to values

between 0 and 100 as %DPD/month, taking the number of recording days per month as 100 %. In areas with low porpoise abundance, i.e., great parts of the eastern Baltic Sea, the daily presence of harbour porpoises has more explanatory power than the daily or even hourly frequency of occurrences (see **%DP10M/day**). That is because analyses based on an hourly or even minute-by-minute basis have a high susceptibility to randomness due to the very infrequent recording and thus only have a low informative value. To meet highest explanatory goals for areas with low porpoise abundance, the reduced temporal resolution is considered an acceptable limitation in data analysis.

%DPH/time unit (% detection-positive hour per time unit) gives the percentage of survey hours per pre-defined time unit (e. g., day/month/study period, etc.) with at least one harbour porpoise signal. This parameter is usually used in a resolution per day where it describes within how many of the usually available 24 hours at least one harbour porpoise signal was recorded. Thus, it is the most appropriate measure in areas with low or moderate porpoise abundance. This parameter can be used to check for any temporal differences in the presence of porpoises during the course of a year.

%DP10M/time unit (% detection-positive 10 minutes per time unit): This parameter gives percentages of the number of 10-minute units per pre-defined time unit (e.g., day/month/study period, etc.) with at least one harbour porpoise signal. This parameter is usually used in a resolution per day where it describes within how many of the usually available 144 10-minute units of a 24-hour day at least one harbour porpoise signal was recorded. Thus, it is the most appropriate measure in areas with moderate or high porpoise abundance. This parameter can be used to check for any temporal differences in the presence of porpoises during the course of a 24-hour day. Since the instruments are deployed close to the seabed, regular differences in detections during a day can give valuable information about the habitat use.

%DPM/time unit (% detection-positive minute per time unit) gives the percentage of survey minutes per pre-defined time unit (e. g., 10-minute block/day/month/study period, etc.) with at least one harbour porpoise signal. This parameter is usually used in a resolution per day where it describes within how many of the usually available 1440 minutes per day at least one harbour porpoise signal was recorded. Thus, it is the most appropriate measure in areas with high porpoise abundance.

Time units (from minutes up to months) were chosen depending on the specific question and harbour porpoise presence in the study area. For generally comparing detection rates of CPODs and FPODs (methodology in chapter 2.6.1), all temporal scales were analysed.

For comparing detection rates of CPODs and FPODs at specific stations (methodology in chapter 2.6.2), data were only analysed in %DP10M/d due to the generally high density of harbour porpoises in the study area. With this parameter, 10-minute unit on which at least one click train was recorded is considered a “detection positive 10-minute unit” (DP10M). By this procedure, a 10-minute unit with few click train recordings is treated equal to a 10-minute unit on which almost continuous (i. e. many) porpoise click trains are recorded. The use of this parameter was considered a good compromise between the finest possible temporal resolution and adequate size of the detection rate, i. e. with coarser temporal resolution the values on the Y-axis would have been very large and with finer temporal resolution the values on the Y-axis would have been very small, both of which would have led to less pronounced curve shapes.

Besides, even though the internal clock of the FPOD was checked for every deployment (see chapter 2.2), there might still be a minor time difference between CPODs and FPODs. When comparing the detections of the two devices and analysing data in %DP10M/d, the time difference of a few seconds can be ignored.

2.6.1 Comparison of detection rates

Boxplots were created for every month showing the detection rates of CPODs and FPODs in all temporal scales and containing the data of all stations. In addition, the detections of CPODs and FPODs were plotted against each other, and a curve was drawn through the data points (see methodology of generalised log-logistic model in chapter 2.6.5).

A correlation test using the methodology "Pearson" was conducted to analyse whether the detection rates correlate significantly. Correlation tests can only be used when the covariation is linear and the data from each of the two variables (i.e. detection rate of CPOD and detection rate of FPOD) are normally distributed – this was therefore checked.

Furthermore, a paired samples t-test was used to compare the detection rates of CPODs and FPODs for the different temporal scales. In this case, you have two values (i.e., pair of values) for the same samples. Paired t-tests can only be used when the difference d is normally distributed – this was therefore checked using a Shapiro-Wilk test.

2.6.2 Comparison of detection rates between the individual stations

The phenology for each station was represented by the parameter %DP10M/d. Also, the detections of CPODs and FPODs were plotted against each other for each station, and a curve was drawn through the data points (see methodology of generalised log-logistic model in chapter 2.6.5).

A paired samples t-test was used to compare the detection rates of CPODs and FPODs for each station. In this case, you have two values (i.e., pair of values) for the same samples. Paired t-tests can only be used when the difference d is normally distributed – this was checked before using a Shapiro-Wilk test.

2.6.3 Comparison of detection rates between the two monitoring years

Data were divided between the 1st year of monitoring (April 2023 – March 2024) and 2nd year of monitoring (April 2024 – April 2025) in order to analyse the amount of data needed for significant results as well as in order to analyse the potential need for further data collection. As described in chapter 2.6.1, (1) a correlation test using the methodology "Pearson" was conducted to analyse

whether the detection rates correlate significantly, and (2) a paired samples t-test was used to compare the detection rates of CPODs and FPODs for the different temporal scales.

2.6.4 Potential reasons for differences in detection rates

In order to analyse the potential reasons of the differences between the detection rates such as background noise levels as described in the publication from Todd et al. (2023), a GAM for CPOD data and a GAM for FPOD data was created (see chapter 2.6.6). It was examined which variables explain the recorded detections by CPODs and FPODs, respectively.

2.6.5 Generalised log-logistic model

As visual inspection uncovered that the difference in detection rates was stronger at intermediate detection rates than at very low or high rates, a nonlinear model had to be chosen. We considered log-logistic dose-response models as being most promising for this purpose. Those were made available by the R package drc (RITZ & STREIBIG 2007a). The theory is explained by RITZ & STREIBIG (RITZ & STREIBIG 2007b) and RITZ ET AL. (2015). We decided for a Generalised log-logistic model with log(ED50) as one of five parameters (model LL2.5 in drc), which proved to show a very good fit with all types of detection rates mentioned above. The respective model formula is given here:

Formula 2:

$$x = c+((d-c)/(1+\exp(b*(\log(y)-e)))^{f})$$

with x representing the detection rate using FPODs, y the detection rate using CPODs, and b, c, d, e, and *f* the parameters to be delivered by the respective model for each type of detection (details to the latter five parameters are given by RITZ & STREIBIG 2007b). As the model required values between 0 and 1 (e. g. DP10M/d)., model building was conducted based on rates rather than the normally shown percentage values (e g. %DP10M/d).

2.6.6 Generalized Additive Model (GAM)

A Generalised Additive Model (GAM) was chosen because GAMs do not require a normal distribution of data points compared to e. g. Generalised Linear Models (GLM) and also because no parametric form of the function has to be specified (WOOD 2017). Since the data sets were large, the bam() function of the R package "mgcv" was used (WOOD 2015).

The response variable was "Harbour_porpoise_detection", which was binary and indicated the presence-absence response on the respective temporal basis (Table 2.4).

Besides, ddifferent explanatory variables were available (Table 2.4): The longitude and latitude of the station (tensor product of the variables “Lon” and “Lat”), the depth (variable “depth”), the distance to the closest shipping lane (variable “dist_ship”), the hour of the day (variable “hourofday”), the day of the year (variable “dayofyear”), and the number of total clicks recorded within this time unit (variable “Nall.m”).

Collinearity between variables can greatly distort model estimates and predictions at correlation coefficients above 0.7 (DORMANN ET AL. 2013). Consequently, in order not to include variables with a strong correlation into the models, the correlation between all possible variables except factors was investigated at the beginning. The variables “depth” and ”dist_shipping” had a correlation coefficient above 0.7 and thus, the variable “dist_shipping” was excluded as background noise is already partly included in the variable “Nall.m”.

Besides collinearity, GAMs must also be tested for multicollinearity as multicollinearity can negatively affect the estimated coefficients in multiple regression analyses (MANSFIELD & HELMS 1982). Namely, smooth functions are used in GAMs, so it must be investigated whether the smooth function of one variable can be created by combining the smoothings of the other variables in the model, and thus leading to concurvity (AMODIO ET AL. 2015). Although GAMs have some degree of built-in amplification against multicollinearity, it should still be tested whether the data are affected by multicollinearity and therefore concurvity in the GAM occurs.

Multicollinearity can be estimated by computing the so-called variance inflation factor (or VIF), which measures how much the variance of a regression coefficient is expanded due to multicollinearity in the model (MANSFIELD & HELMS 1982). None of the parameters included in the model after correlation analysis had a VIF greater than 0.01. Various rules of thumb indicate severe multicollinearity starting from a VIF of 4, 10, 20 or 40, even if these rules of thumb for the VIF alone cannot actually make clear statements about severe multicollinearity (O’BRIEN 2007). Therefore, other indicators of multicollinearity such as very high standard errors for regression coefficients or an overall significant model with no single significant coefficient were also examined. Overall, none of the analyses indicated a serious effect of multicollinearity in the GAM. Furthermore, this study aimed to make only estimates and predictions, but not to interpret individual regression coefficients, so that multicollinearity needs less consideration (MURRAY ET AL. 2012).

Also, a random effect was included into the model: The ID of the POD device (variable “podident”). In this way, it was corrected for effect differences due to factors like kind of device and POD sensitivity. Since a GAM is often faster and more reliable when the number of random effects is modest (WOOD 2017), only one random effect per GAM was used.

GAMs assume that errors (residuals) are identical and independently distributed (i. i. d.). This assumption does not apply to time-series regression because current time series values are often strongly correlated with past values, so that model errors are also correlated (so-called temporal autocorrelation) (PINHEIRO & BATES 2000). In order to reduce autocorrelation, the observations up to a certain previous time step or the observation at a previous time step should be included as a variable. In this analysis, the variable “Harbour_porpoise_detection_t”, which describes the harbour porpoise detection in the previous time unit, was added to the model as a proxy for autocorrelation.

In order to deal with overfitting, a specification for the smoothing factor was defined. Usually, an unmodified smoothness selection will not take off smoothness from a model (WOOD 2017). In order to reduce the chance of overfitting in this analysis, the smooths were modified to shrink to the zero function and thus to filter out of the model. There are two ways to do this: shrinkage smoothers, and the double penalty approach. The second approach is considered to work slightly better (MARRA & WOOD 2011) and was accordingly activated in this analysis by using the select argument. The gamma value was set to 1.4 as recommended (WOOD 2017).

To find the best explanatory GAM, the Akaike Information Criterion (AIC) was used: At the beginning, a GAM was created using all parameters that were not highly correlated. Then, the parameter with the highest p-value was removed from the analysis step by step. The AIC value of the new model was compared with the AIC value of the previous model. If the AIC value of the new model was lower, the parameter with the highest p-value in the new model was removed. This process was repeated until the AIC value of the new model was higher than that of the previous model. The model with the lowest AIC value was considered to be the best explanatory model (WOOD 2017).

However, if the AIC values of two models differ by less than 2, the model with the higher AIC value can also be considered to be substantially supported (BURNHAM & ANDERSON 2002). If this case occurred in this study, the model with fewer variables was considered the best, even though it may have had a slightly higher AIC value. In other words, the inclusion of additional parameters had to result in an AIC difference of more than 2, otherwise the inclusion was considered poorly justified.

Table 2.4 List of all variables considered for the Generalised Additive Model.

Variable	Type	Description
harbour_porpoise_detection	binary	Detection Positive time unit (0 = no detection, 1 = detection)
harbour_porpoise_detection_t	factor	Detection Positive unit (0 = no detection, 1 = detection) in the previous time unit
Lon	continuous	Longitude of POD station
Lat	continuous	Latitude of POD station
depth	continuous	Water depth at the POD station
dist_shipping	continuous	Distance to next shipping lane
hourofday	circular integer	Hour of the day
dayofyear	circular integer	Day of the year
Nall.m		Number of all clicks within a time unit; these could originate from different noise sources (e. g. waves, sediment movement, ships, porpoises)
podident	factor (as many levels as used POD devices)	ID of POD device

3 RESULTS

3.1 Comparison of CPOD data (quality classes “high” and “moderate”) and FPOD data (quality classes “high” and “moderate”)

3.1.1 Comparison of detection rates

CPODs and FPODs were continuously deployed at 9 monitoring stations between April 2023 and April 2025 to compare the different types of Passive Acoustic Monitoring devices. These stations were located in specific areas within Danish waters which have been allocated for offshore wind build-out.

During the study period, an average of 492 CPOD days per station and 450 FPOD days per station were successfully surveyed during the two-year period of monitoring. When analysing data from CPODs and FPODs for comparison between the two devices, only the KERNO classifier was used. Therefore, in this chapter, all comparisons are based on data generated using the KERNO classifier as well as the two highest quality classes for CPODs (“high” and “moderate”), and using the KERNO classifier as well as the two highest quality classes for FPODs (“high” and “moderate”).

In general, harbour porpoise detection rates of CPODs and FPODs were similar – irrespectively if harbour porpoise detection rates are calculated on a daily (%DPD/m; Figure 3.1), hourly (%DPH/d; Figure 3.2), 10-minute block (%DP10M/d; Figure 3.3) or minutely basis (%DPM/d; Figure 3.4). However, the FPOD generally recorded more detections than the CPOD – again irrespectively of the temporal scale.

Both the CPOD and FPOD recorded detections on nearly every day: With the CPOD, an average detection rate of 99.2 %DPD/m was calculated, whereas with the FPOD, an average detection rate of 99.5 %DPD/m was calculated (Table 3.1). The correlation test showed that the CPOD detection rate and the FPOD detection rate correlated significantly when using the temporal scale %DPD/m (Table 3.2). Furthermore, the t-test showed no significant difference between the two detection rates (Figure 3.5, Table 3.1).

Regarding the hourly scale, an average detection rate of 47.4 %DPH/d was recorded with the CPOD, whereas an average detection rate of 49.2 %DPH/d was recorded with the FPOD (Table 3.1). The correlation test showed that the CPOD detection rate and the FPOD detection rate correlated significantly when using the temporal scale %DPH/d (Table 3.2). However, the t-test showed a significant difference in detection rates between the two devices (Figure 3.6, Table 3.1).

Furthermore, with the CPOD, an average detection rate of 18.7 %DP10M/d was calculated, whereas with the FPOD, an average detection rate of 20.1 %DP10M/d was calculated (Table 3.1). The correlation test showed that the CPOD detection rate and the FPOD detection rate correlated significantly when using the temporal scale %DP10M/d (Table 3.2). However, the t-test showed a significant difference between the two detection rates (Figure 3.7, Table 3.1).

When analysing the data on a minutely basis, an average detection rate of 5.6 %DPM/d was recorded with the CPOD, whereas an average detection rate of 6.6 %DPM/d was recorded with the

FPOD (Table 3.1). The correlation test showed that the CPOD detection rate and the FPOD detection rate correlated significantly when using the temporal scale %DPM/d (Table 3.2). However, the t-test showed a significant difference between the two devices (Figure 3.8, Table 3.1).

In summary, when analysing data in different resolutions (%DPD/d, %DPH/d, %DP10M/d, %DPM/d) and using the two highest quality classes for FPODs ("high" and "moderate"), detection rates of CPODs and FPODs always correlated significantly, with the FPOD always recording more detections than the CPOD irrespectively of the temporal scale. This difference was statistically significant for the temporal scales %DPH/d, %DP10M/d, and %DPM/d.

Table 3.1 *Comparing the detection rates using different temporal scales averaged over all stations in the Danish North Sea: Results of the t-test; signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; FPOD quality classes "high" and "moderate".*

	Average CPOD detection rate	Average FPOD detection rate	t	df	p-value
%DPD/m	99.17	99.45	-0.85	319	0.4
%DPH/d	47.37	49.16	-3.5	7484	5e-04 ***
%DP10M/d	18.73	20.06	-4.2	7488	3e-05 ***
%DPM/d	5.550	6.625	-7.6	7156	4e-14 ***

Table 3.2 *Comparing the detection rates using different temporal scales averaged over all stations in the Danish North Sea: Results of the correlation test; signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; FPOD quality classes "high" and "moderate".*

	Sample estimate: cor	t	df	p-value
%DPD/m	0.6471	11	183	<2e-16 ***
%DPH/d	0.9202	144	3743	<2e-16 ***
%DP10M/d	0.9408	170	3743	<2e-16 ***
%DPM/d	0.92	157	3611	<2e-16 ***

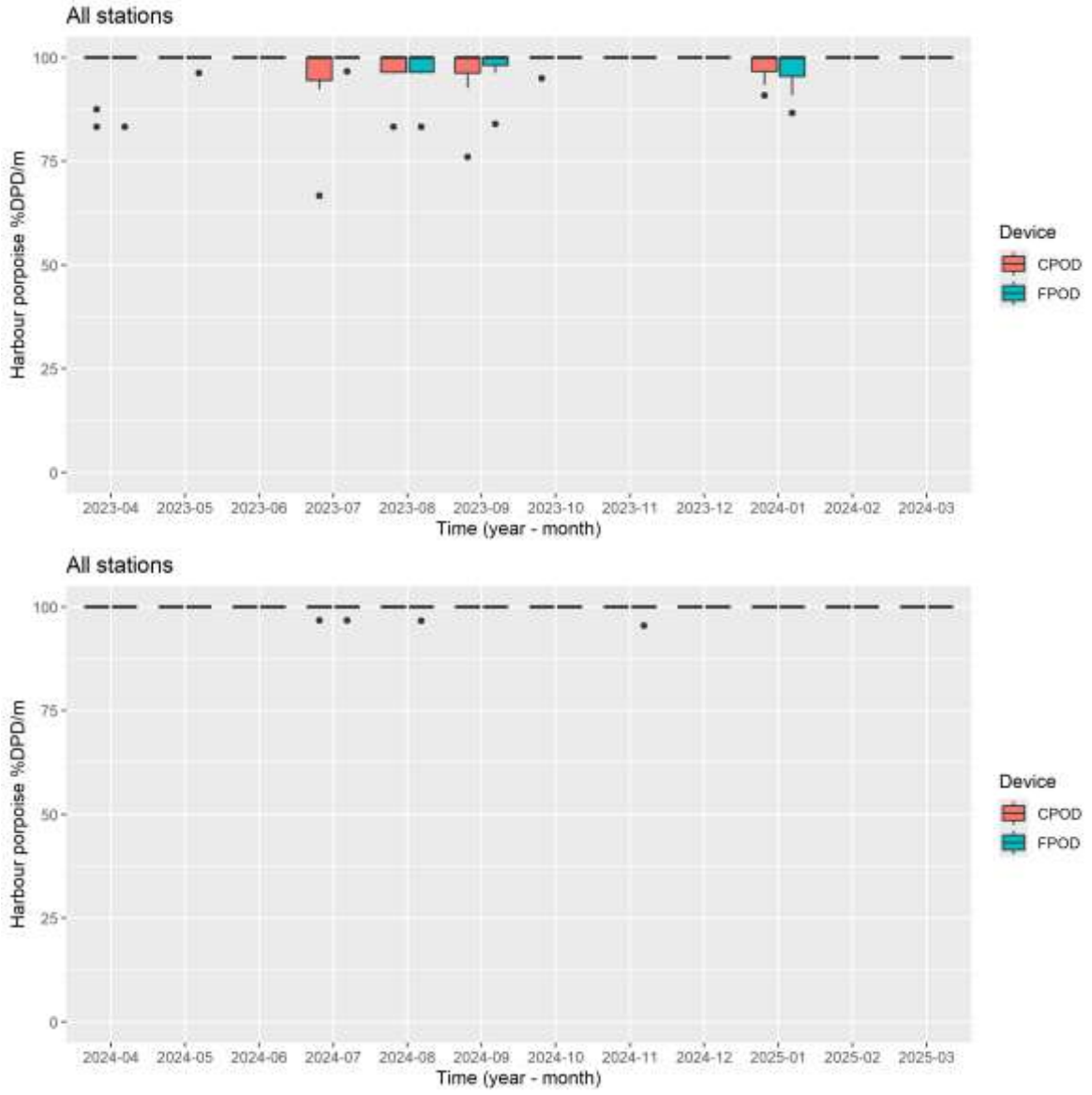

Figure 3.1 *Harbour porpoise detection rates using the temporal scale %DPD/m from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025; first year of monitoring = upper graph and second year of monitoring = lower graph) averaged over all stations in the Danish North Sea; data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality classes "high" and "moderate".*

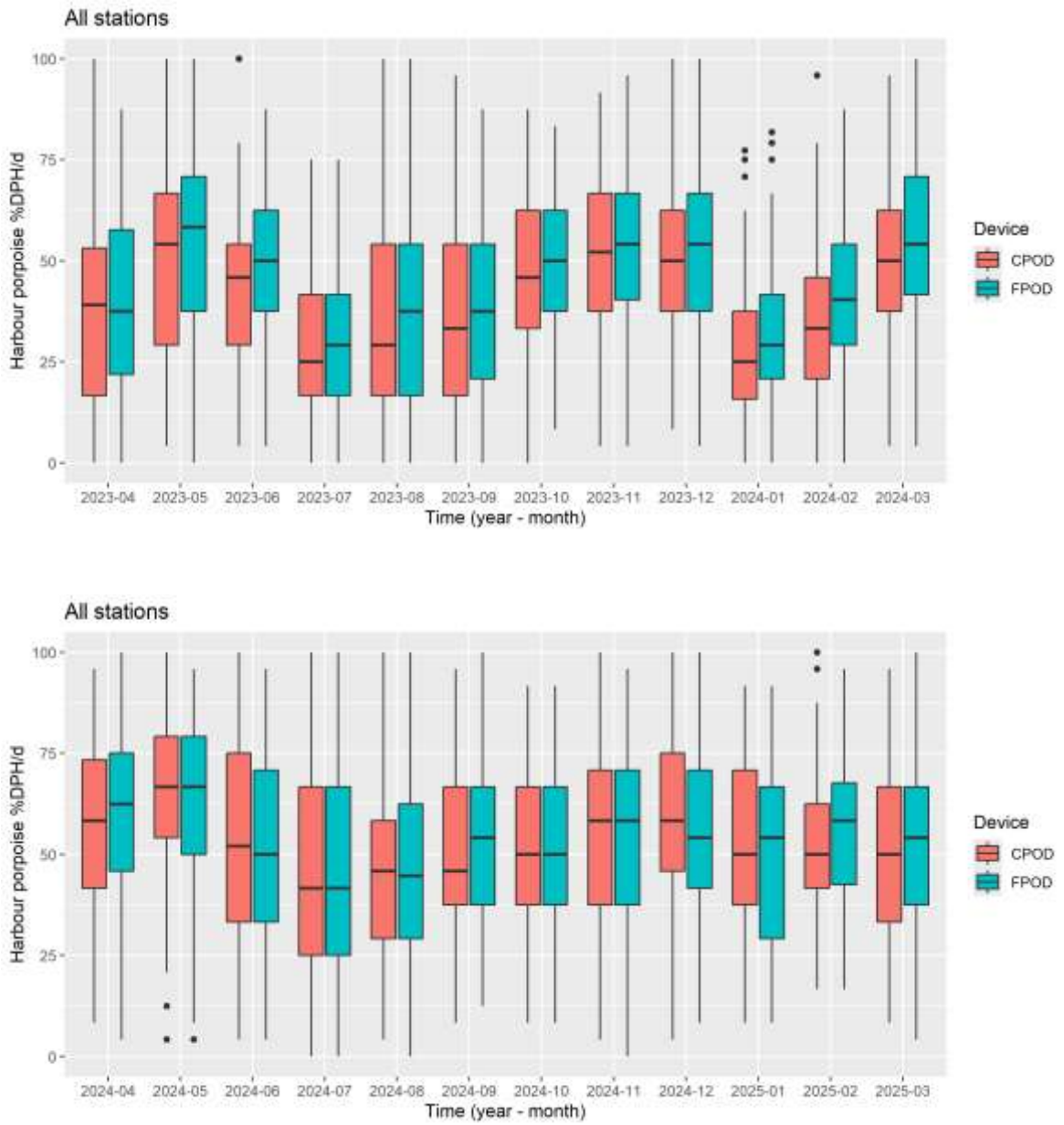

Figure 3.2 *Harbour porpoise detection rates using the temporal scale %DPH/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025; first year of monitoring = upper graph and second year of monitoring = lower graph) averaged over all stations in the Danish North Sea; data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality classes "high" and "moderate".*

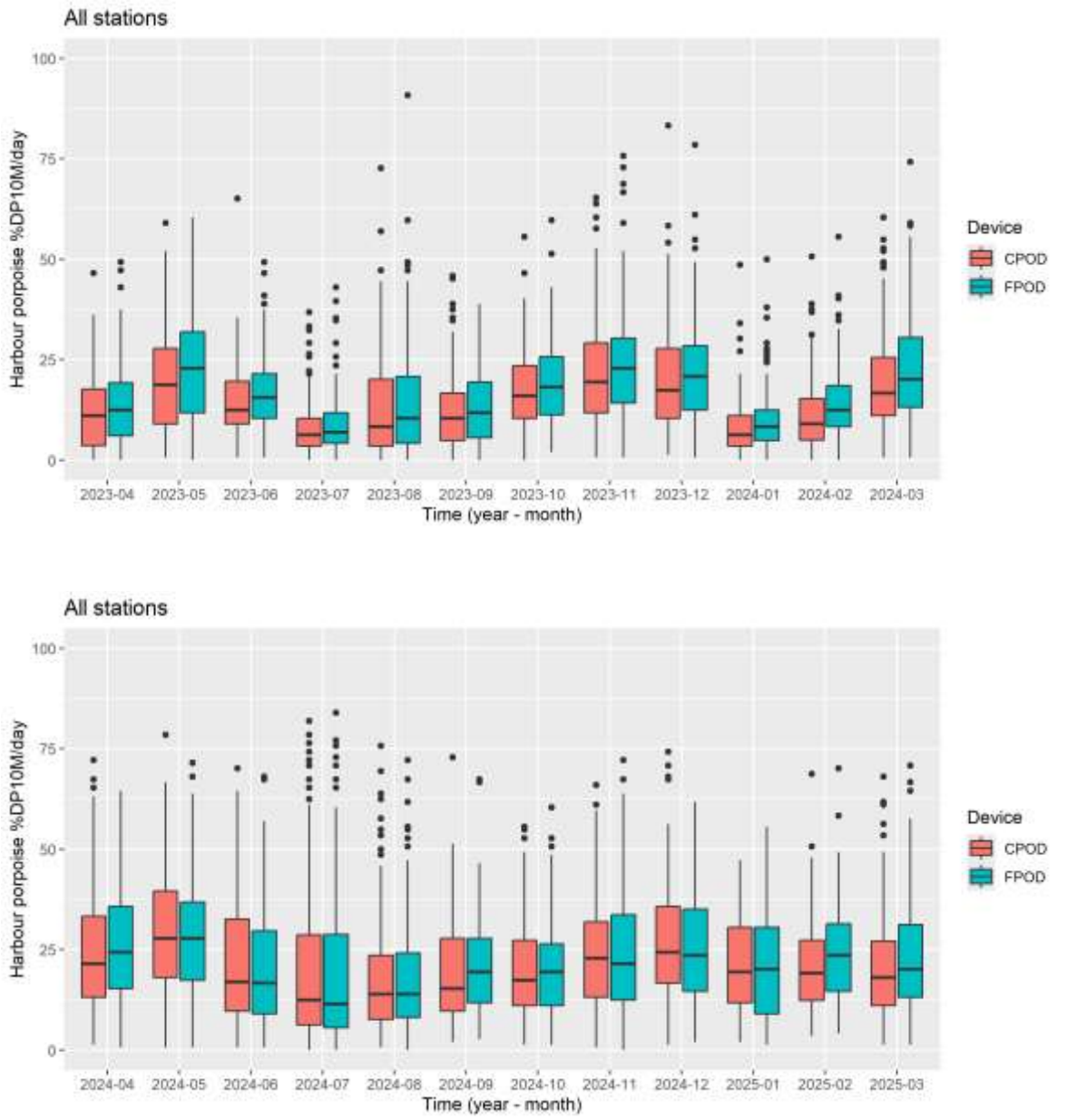

Figure 3.3 *Harbour porpoise detection rates using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025; first year of monitoring = upper graph and second year of monitoring = lower graph) averaged over all stations in the Danish North Sea; data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality classes "high" and "moderate".*

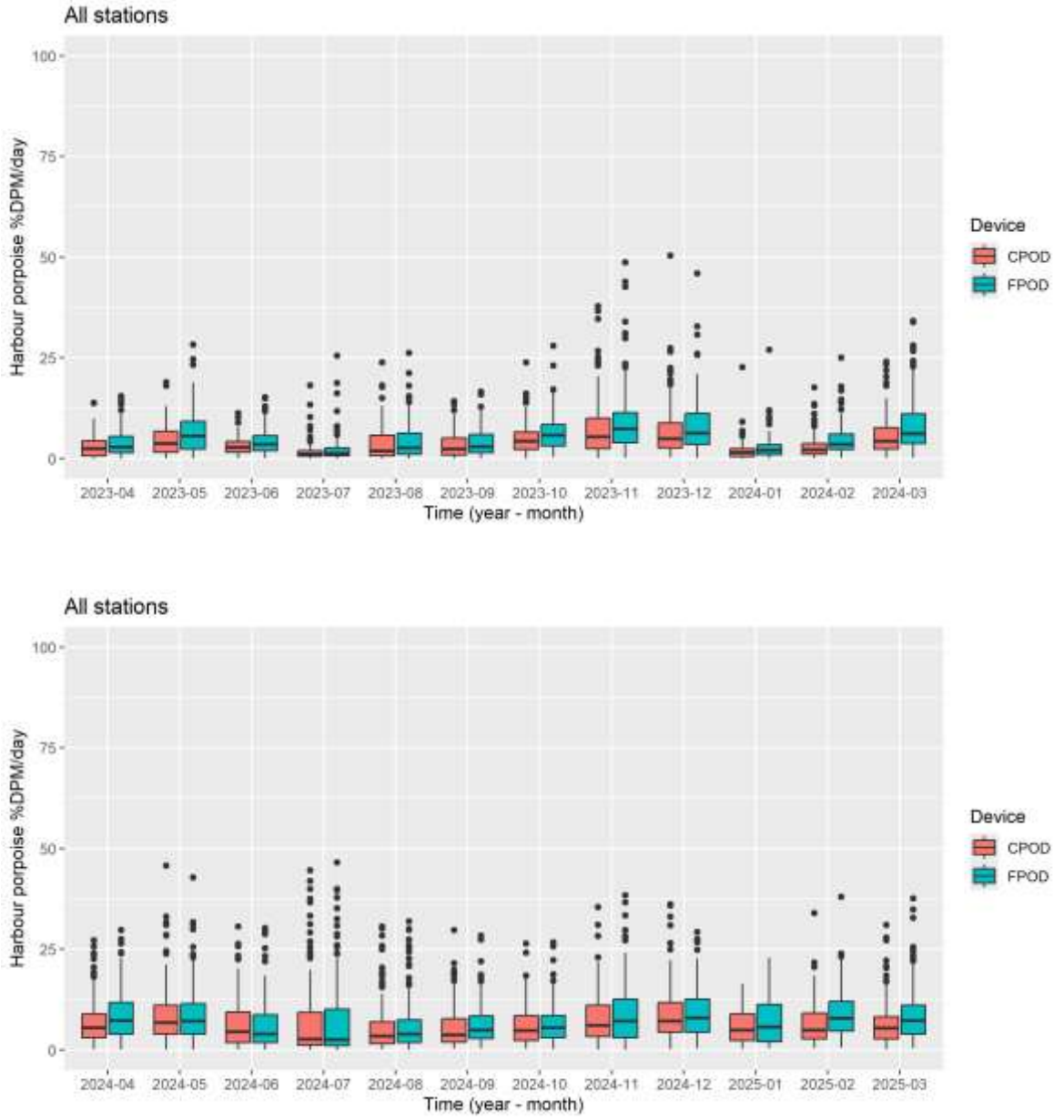

Figure 3.4 *Harbour porpoise detection rates using the temporal scale %DPM/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025; first year of monitoring = upper graph and second year of monitoring = lower graph) averaged over all stations in the Danish North Sea; data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality classes "high" and "moderate".*

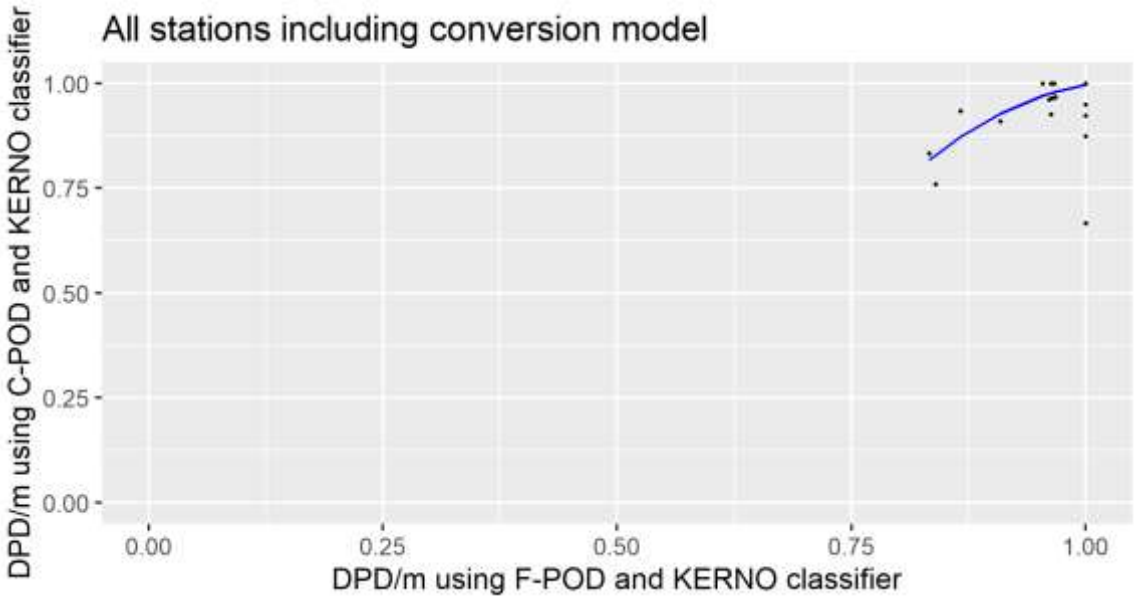

Figure 3.5 *Comparing harbour porpoise detection rates using the temporal scale %DPD/m from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025) averaged over all stations in the Danish North Sea; the blue line is a curve fitting using a generalised log-logistic model; FPOD quality classes "high" and "moderate".*

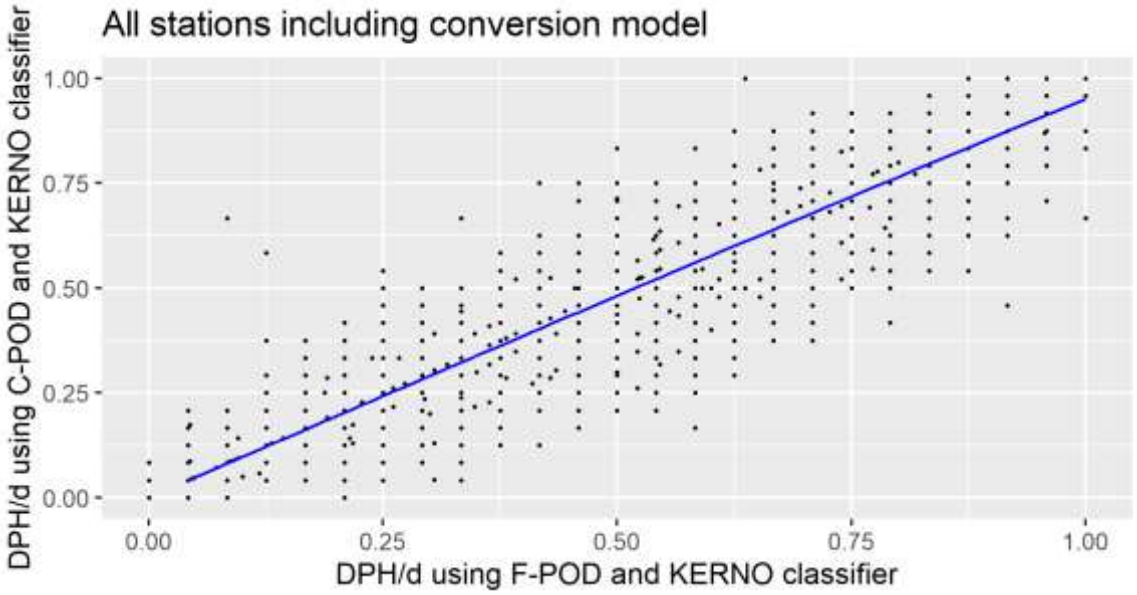

Figure 3.6 *Comparing harbour porpoise detection rates using the temporal scale %DPH/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025) averaged over all stations in the Danish North Sea; the blue line is a curve fitting using a generalised log-logistic model; FPOD quality classes "high" and "moderate".*

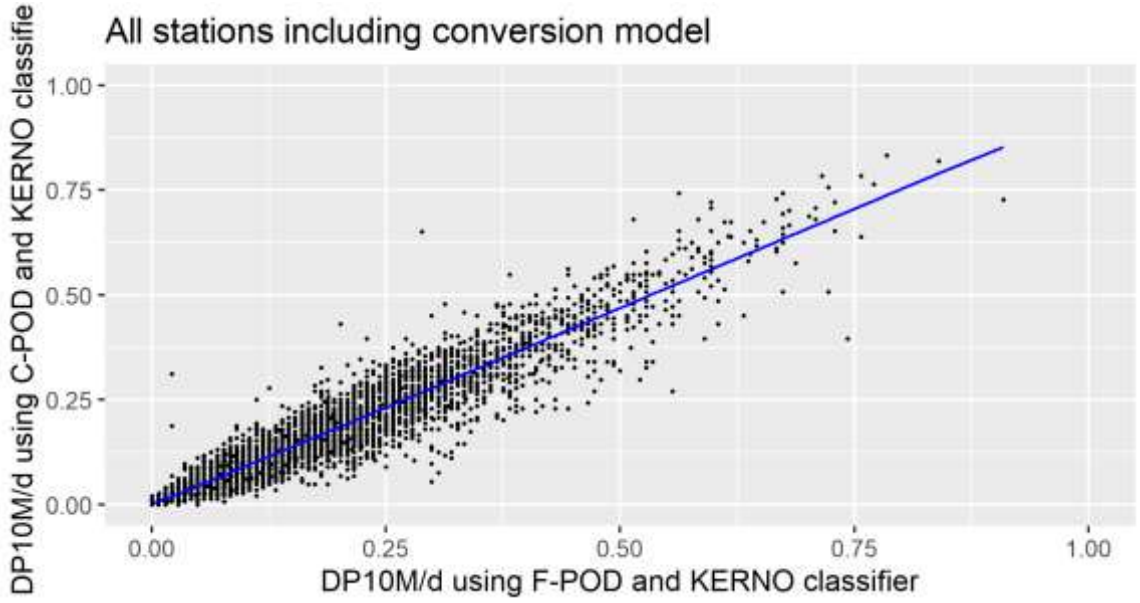

Figure 3.7 *Comparing harbour porpoise detection rates using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025) averaged over all stations in the Danish North Sea; the blue line is a curve fitting using a generalised log-logistic model; FPOD quality classes "high" and "moderate".*

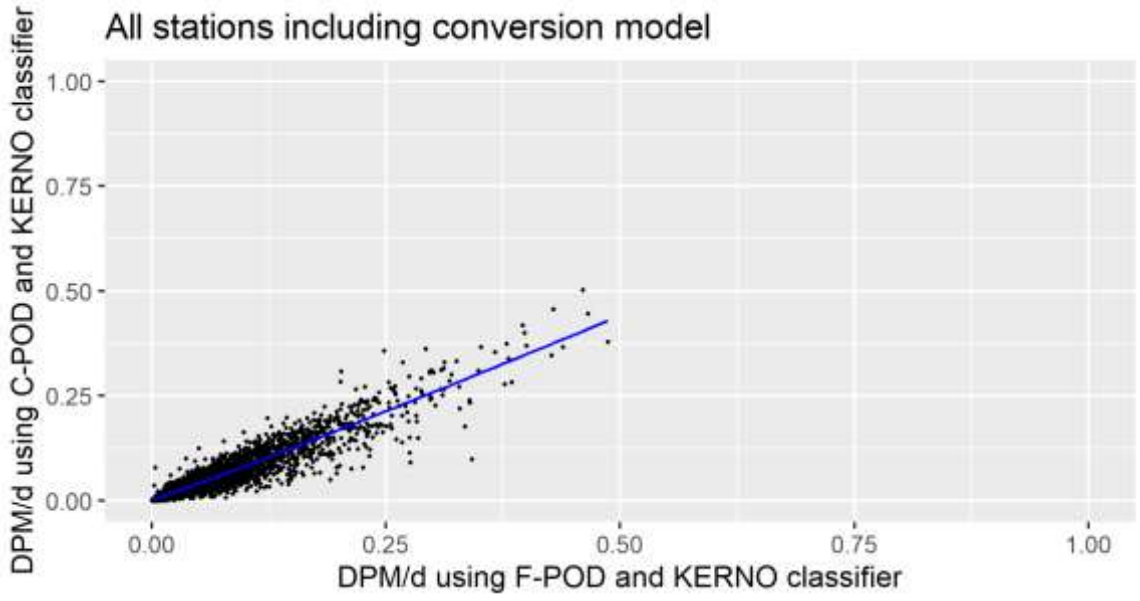

Figure 3.8 *Comparing harbour porpoise detection rates using the temporal scale %DPM/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025) averaged over all stations in the Danish North Sea; the blue line is a curve fitting using a generalised log-logistic model; FPOD quality classes "high" and "moderate".*

3.1.2 Comparison of detection rates between the individual stations

Both devices reported detections at the same time and only the number of detections varied (Figure 3.9 – Figure 3.26). Therefore, both devices seem to detect harbour porpoises in a similar way, making the different data sets comparable.

The differences between the two detection rates, however, varied (Table 3.3). At 7 out of 9 stations, the detection rates of FPODs were higher than the detection rates of CPODs. At station HR3_1, however, 32.3 %DP10M/d were recorded on average when using a CPOD and 32.2 %DP10M/d were recorded on average when using an FPOD; at station HR3_2, 22.3 %DP10M/d were recorded on average when using a CPOD and 21.1 %DP10M/d were recorded on average when using an FPOD.

Besides, the detection rates of CPODs and FPODs differed significantly at 4 stations (all of them with higher FPOD detection rates than CPOD detection rates) and did not differ significantly at 5 stations.

Accordingly, the average difference between the detection rates of CPODs and FPODs from chapter 3.1.1 does not mean that the FPOD records this percentage of detections more than the CPOD. Instead, even at stations such as those in this study, which are all located in a similar study area, there are differences in the extent to which CPODs and FPODs have similar detection rates.

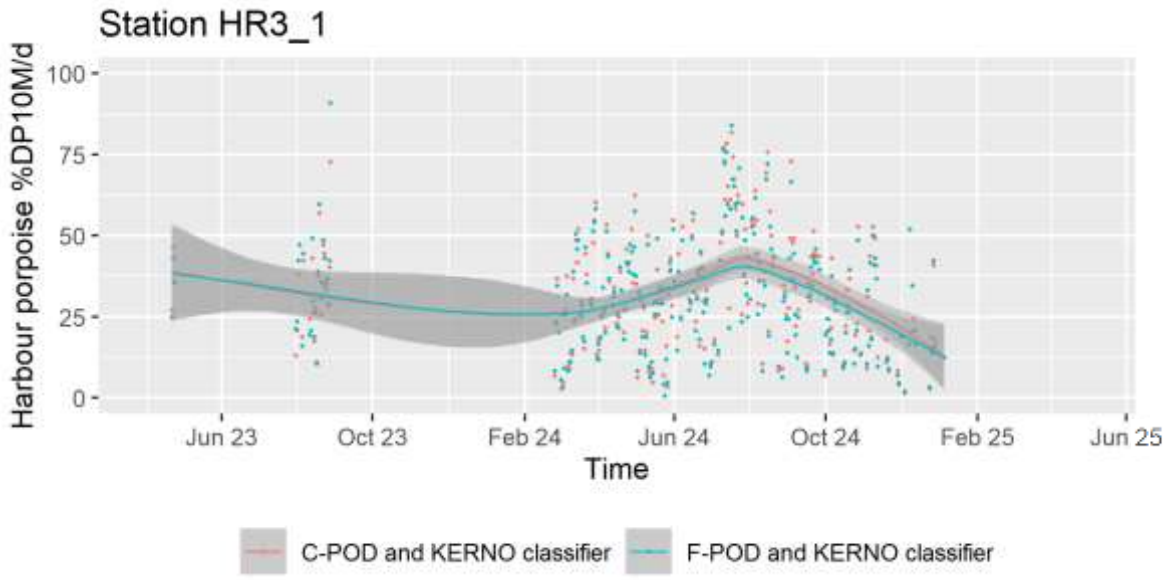

Figure 3.9 *Harbour porpoise detection rates at the station HR3_1 using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality classes "high" and "moderate".*

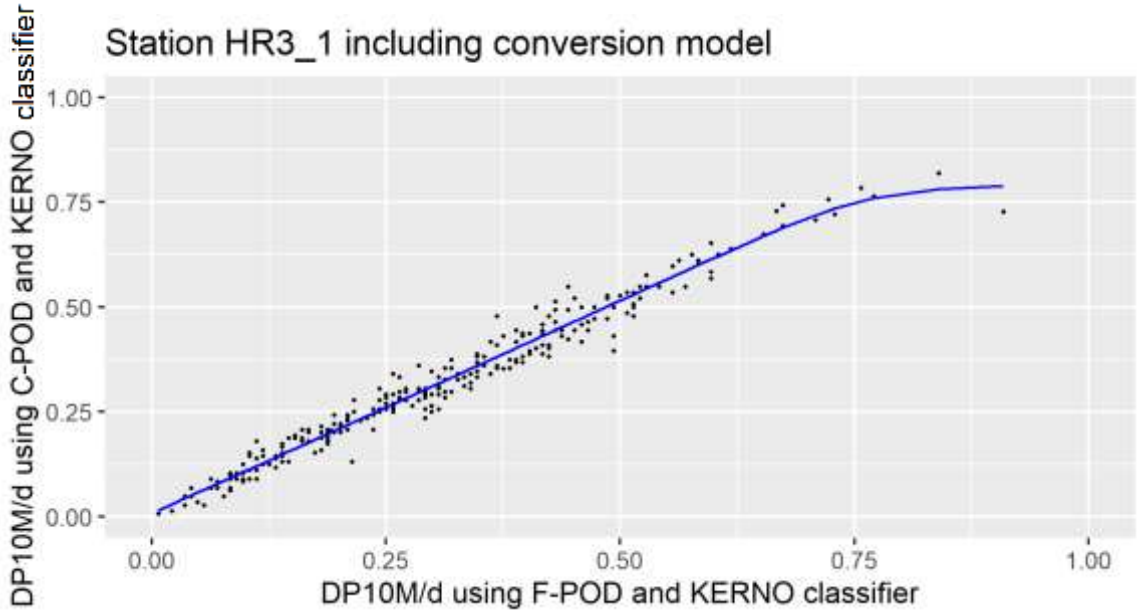

Figure 3.10 *Comparing harbour porpoise detection rates at the station HR3_1 using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality classes "high" and "moderate".*

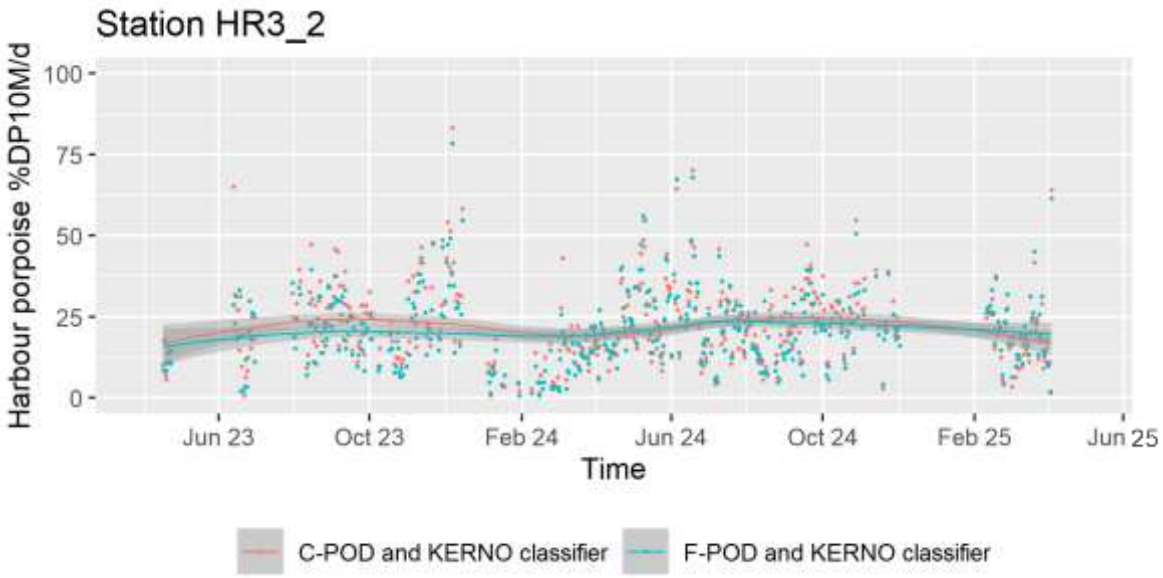

Figure 3.11 *Harbour porpoise detection rates at the station HR3_2 using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality classes "high" and "moderate".*

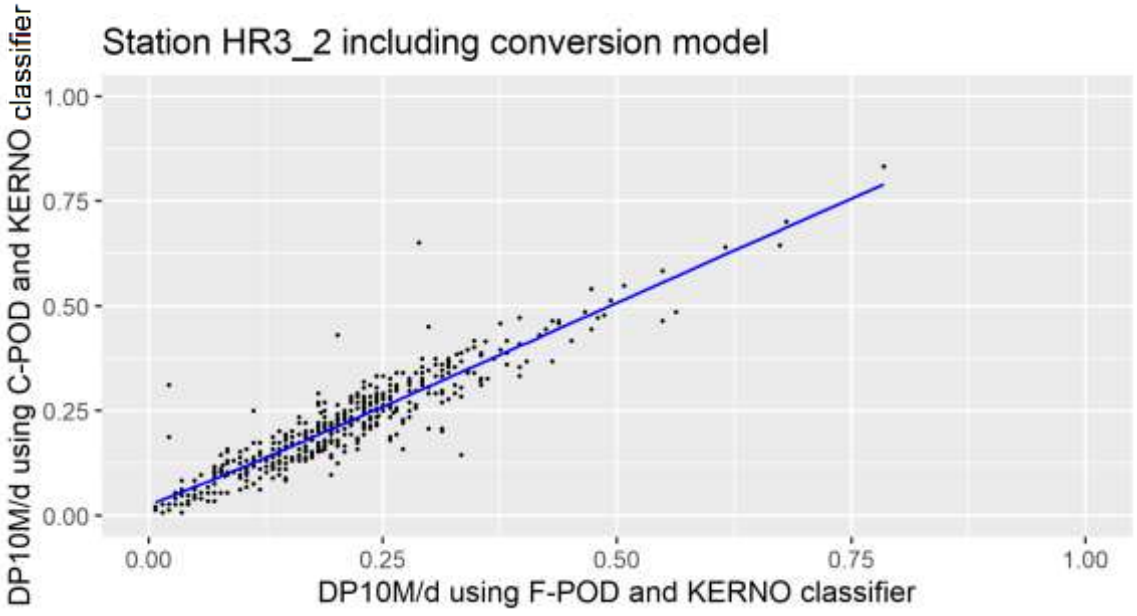

Figure 3.12 *Comparing harbour porpoise detection rates at the station HR3_2 using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality classes "high" and "moderate".*

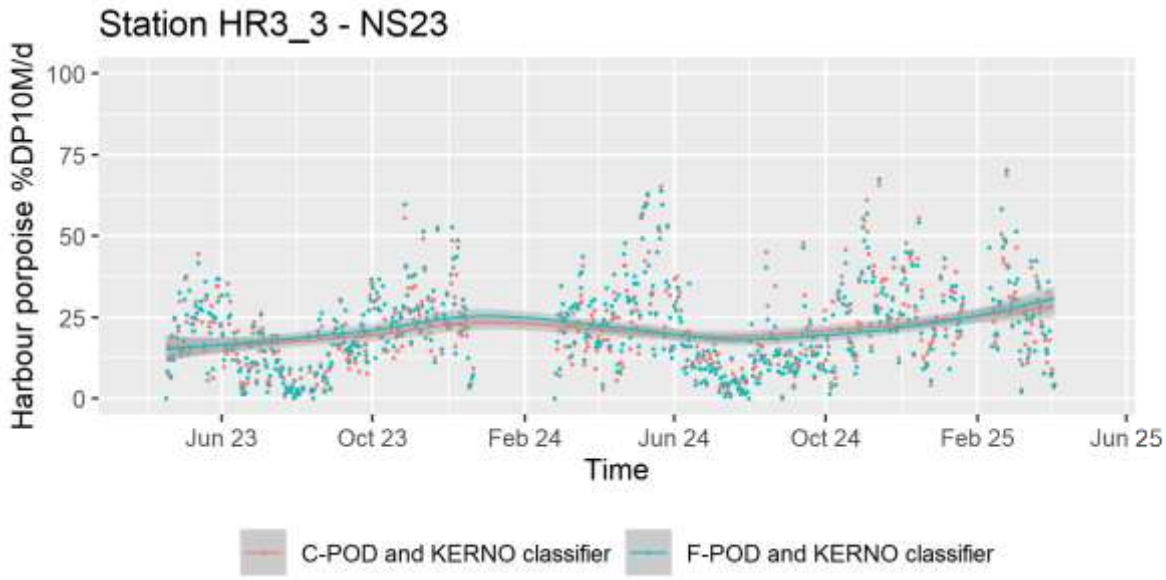

Figure 3.13 *Harbour porpoise detection rates at the station HR3_3/NS23 using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality classes "high" and "moderate".*

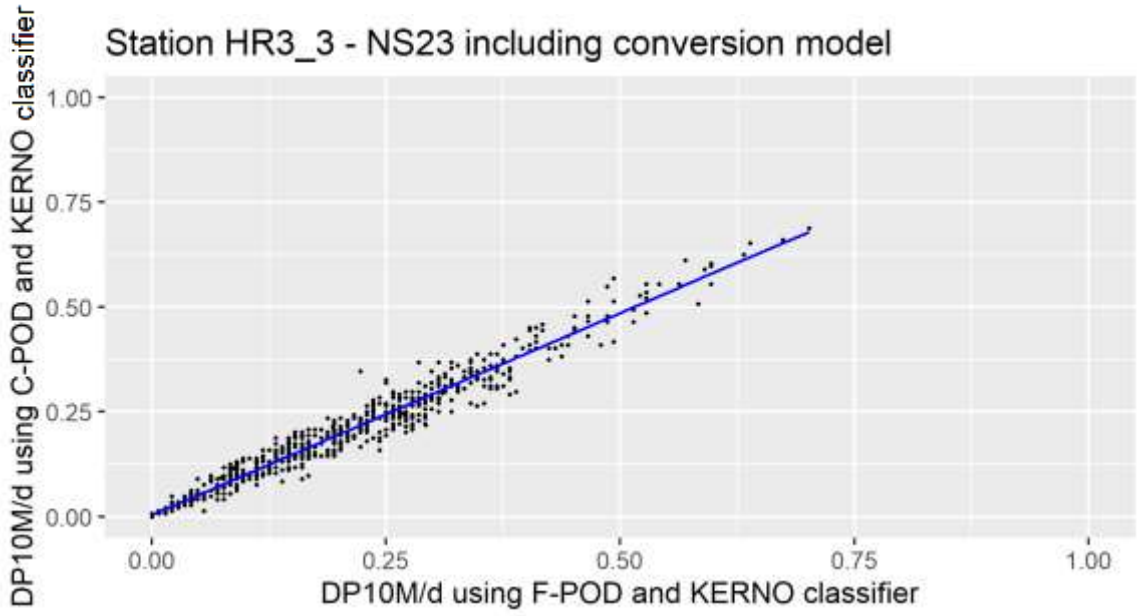

Figure 3.14 *Comparing harbour porpoise detection rates at the station HR3_3/NS23 using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality classes "high" and "moderate".*

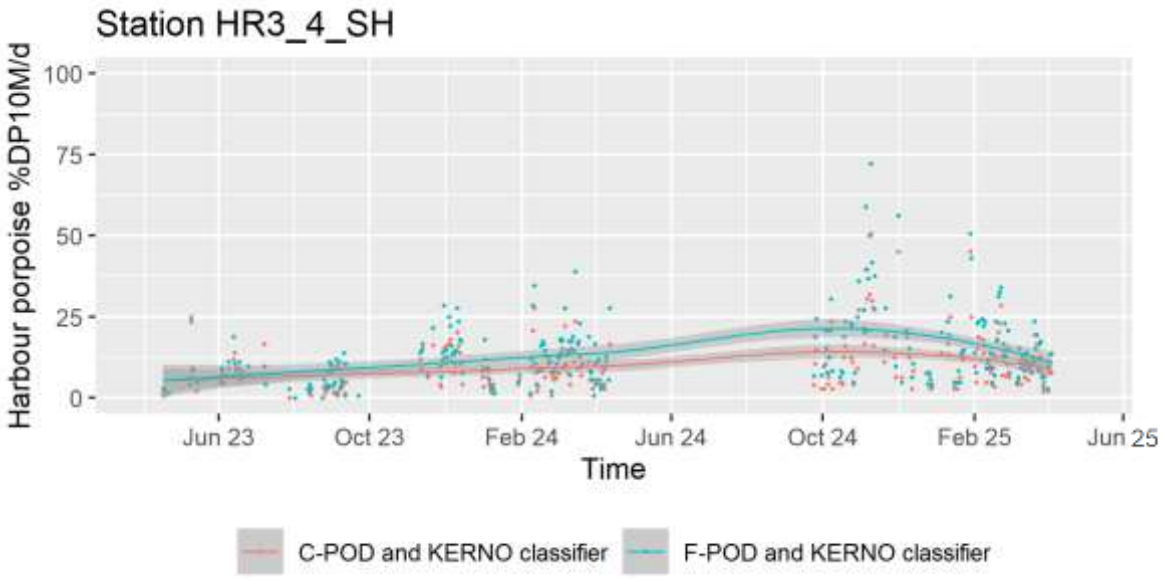

Figure 3.15 *Harbour porpoise detection rates at the station HR3_4_SH using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality classes "high" and "moderate".*

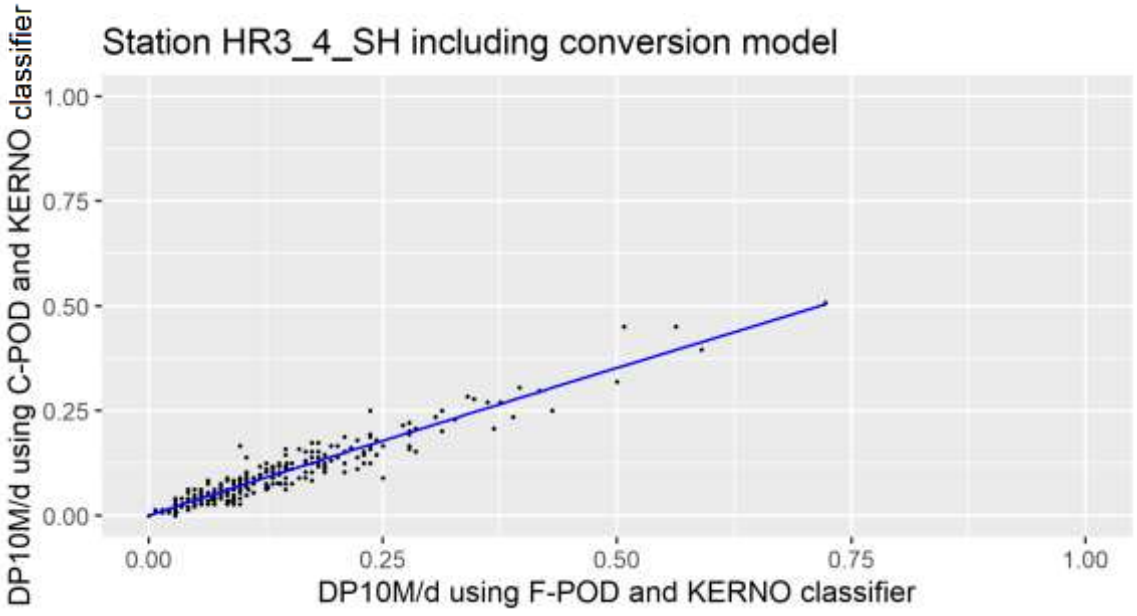

Figure 3.16 *Comparing harbour porpoise detection rates at the station HR3_3/NS23 using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality classes "high" and "moderate".*

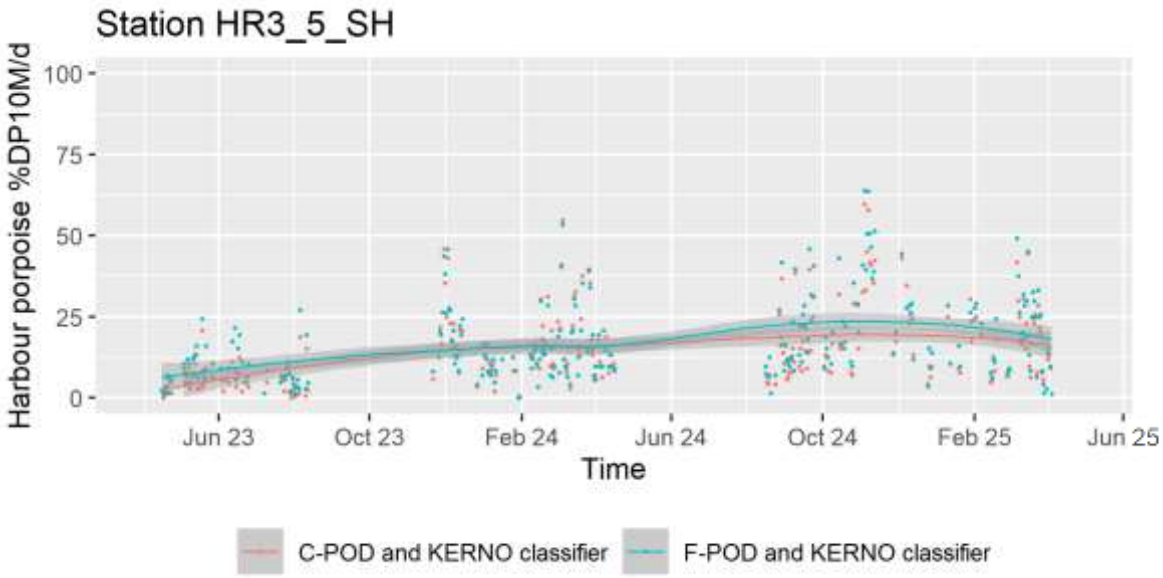

Figure 3.17 *Harbour porpoise detection rates at the station HR3_5_SH using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality classes "high" and "moderate".*

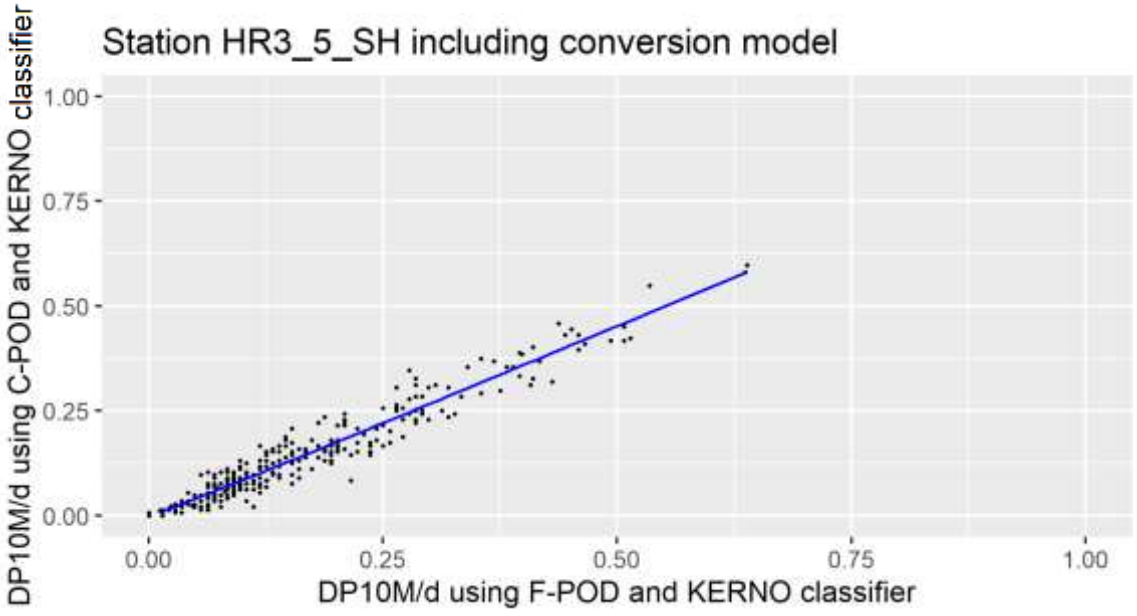

Figure 3.18 *Comparing harbour porpoise detection rates at the station HR3_5_SH using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality classes "high" and "moderate".*

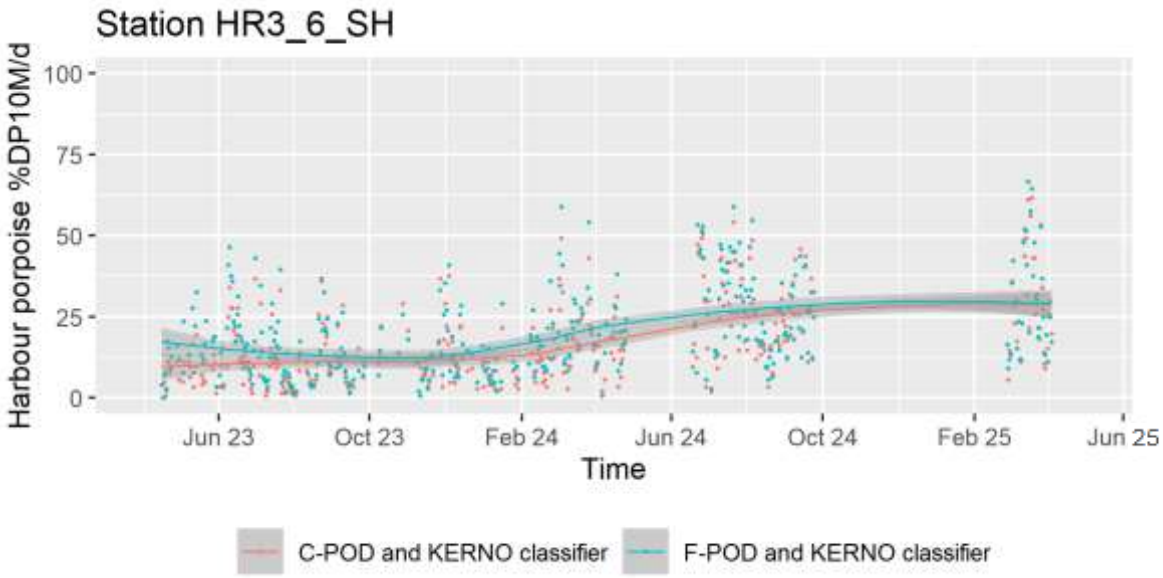

Figure 3.19 *Harbour porpoise detection rates at the station HR3_6_SH using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality classes "high" and "moderate".*

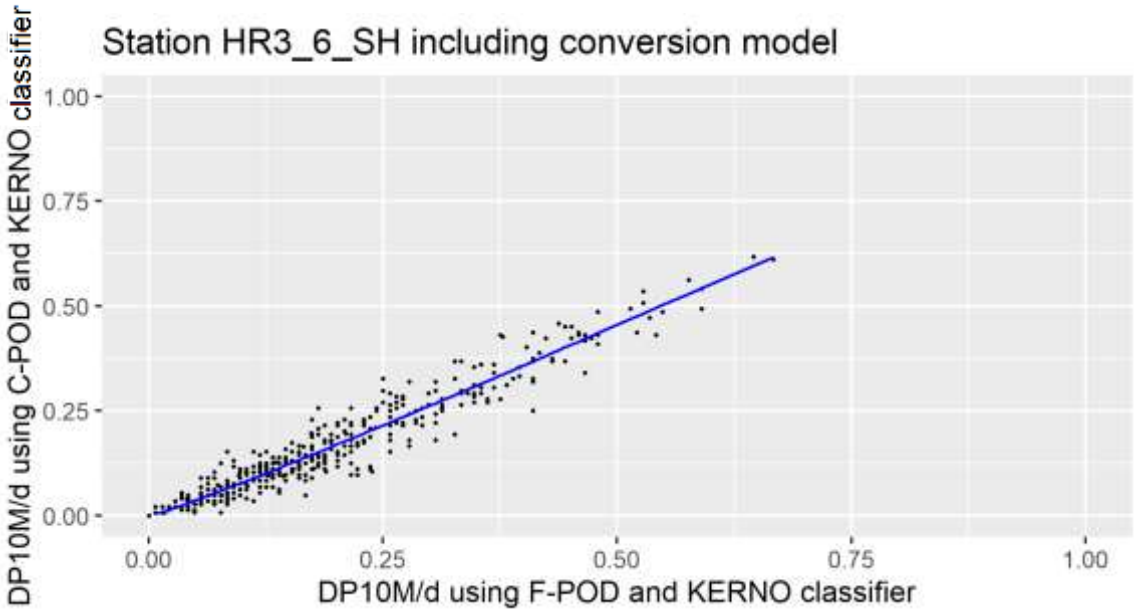

Figure 3.20 *Comparing harbour porpoise detection rates at the station HR3_6_SH using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality classes "high" and "moderate".*

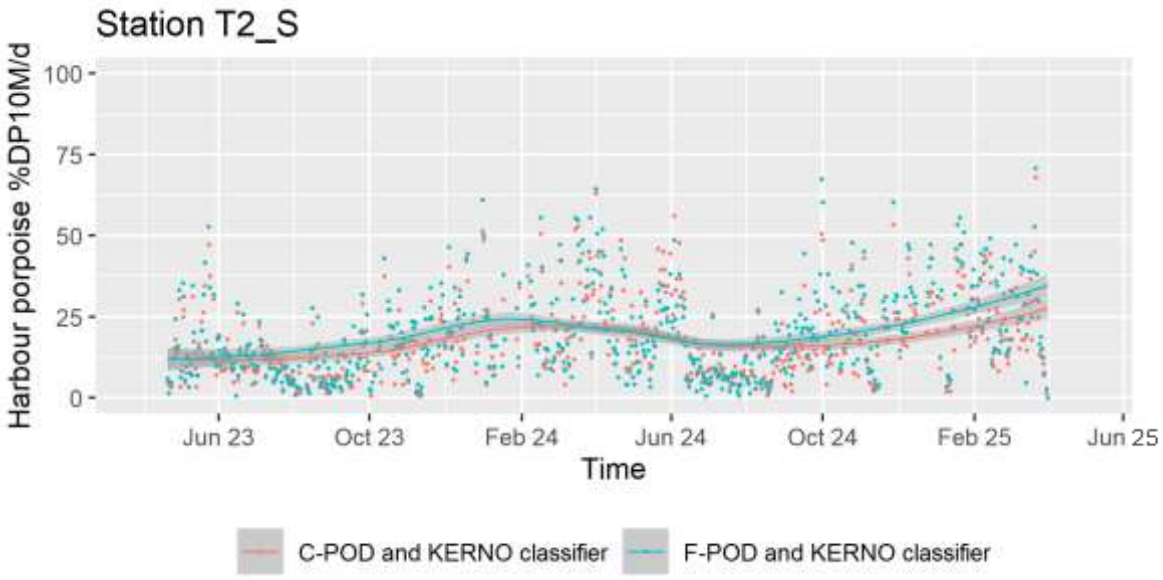

Figure 3.21 *Harbour porpoise detection rates at the station T2_S using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality classes "high" and "moderate".*

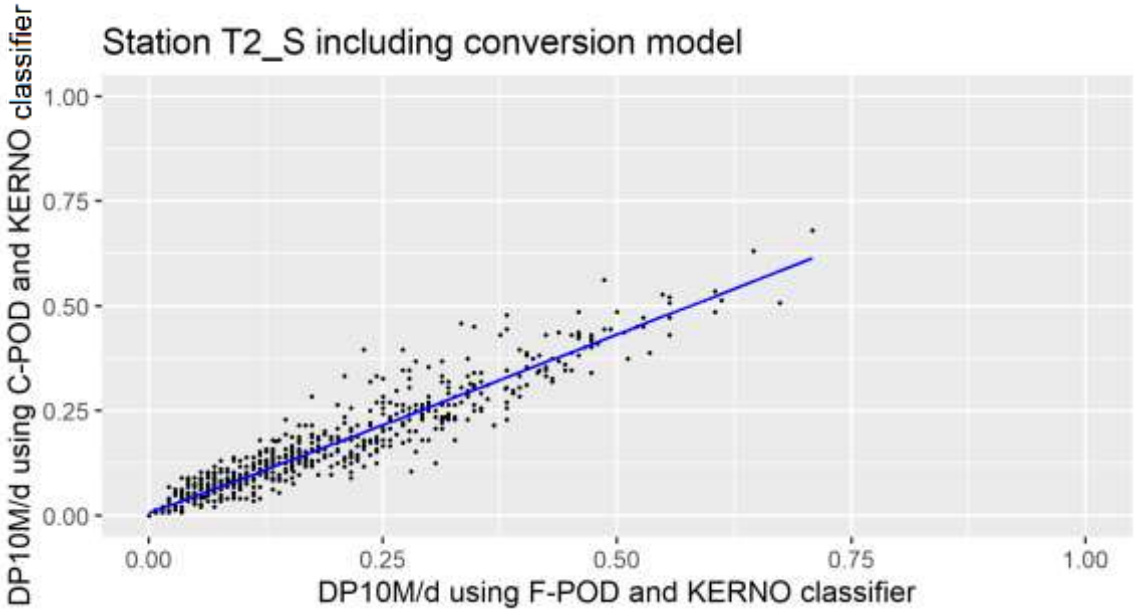

Figure 3.22 *Comparing harbour porpoise detection rates at the station T2_S using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality classes "high" and "moderate".*

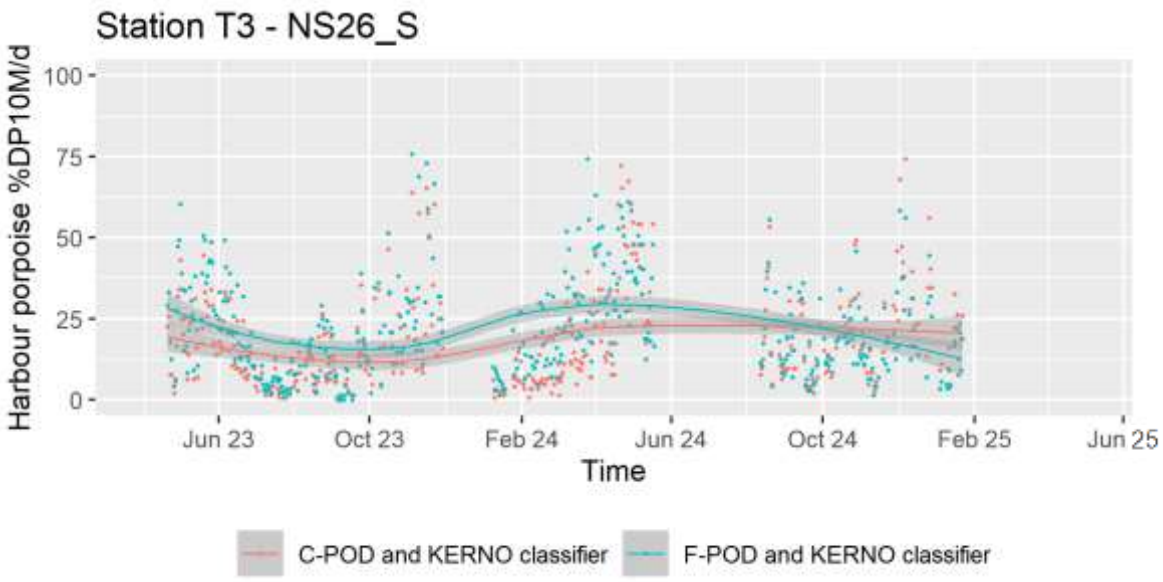

Figure 3.23 *Harbour porpoise detection rates at the station T3/NS26_S using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality classes "high" and "moderate".*

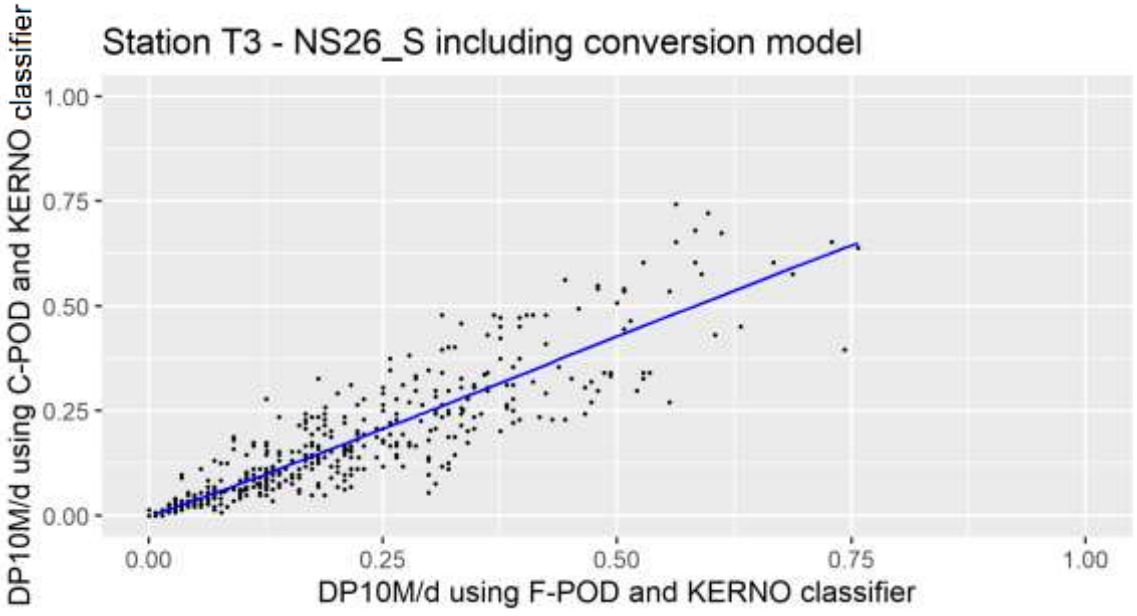

Figure 3.24 *Comparing harbour porpoise detection rates at the station T3/NS26_S using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality classes "high" and "moderate".*

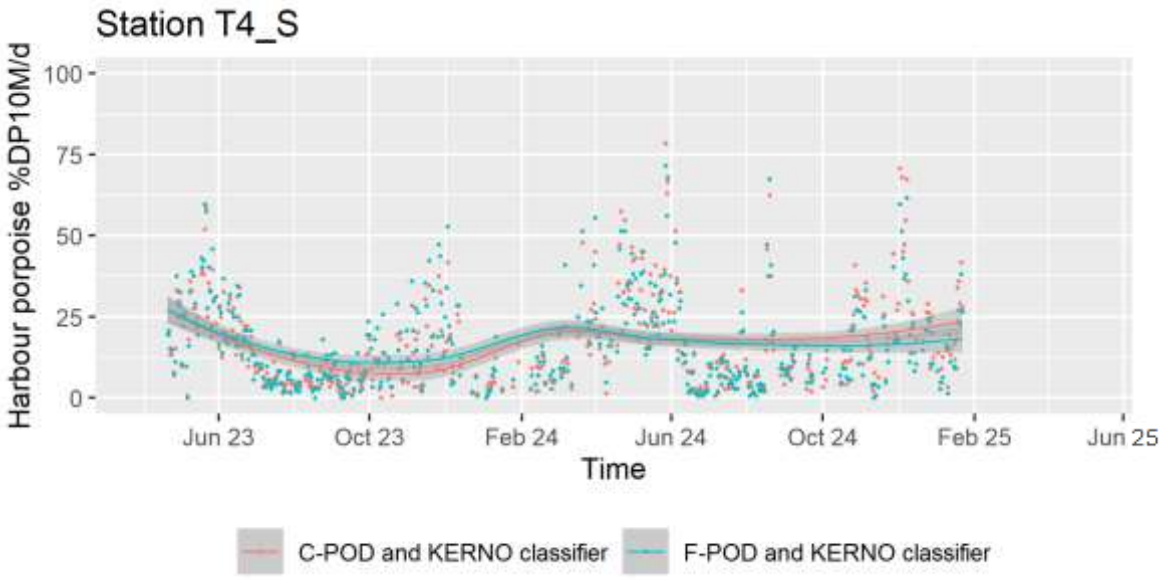

Figure 3.25 *Harbour porpoise detection rates at the station T4_S using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); only complete recording days and only the two highest data quality classes used; FPOD quality classes "high" and "moderate".*

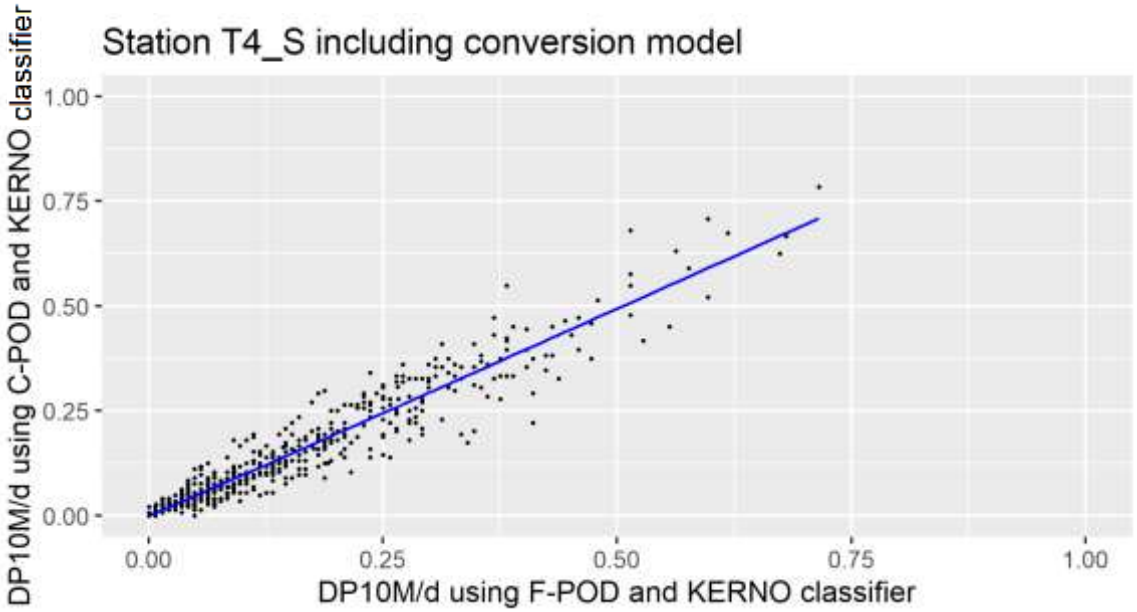

Figure 3.26 *Comparing harbour porpoise detection rates at the station T4_S using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality classes "high" and "moderate".*

*Table 3.3 Comparing the detection rates for each station using %DP10M/D: Results of the t-test; signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; FPOD quality classes "high" and "moderate".*

	Average CPOD detection rate	Average FPOD detection rate	t	df	p-value
HR3_1	32.32	31.23	0.72	512	0.5
HR3_2	22.32	21.06	1.6	897	0.1
HR3_3/NS23	20.78	21.08	-0.4	1215	0.7
HR3_4	10.03	13.78	-4.5	466	7e-06 ***
HR3_5	14.80	16.83	-2	538	0.05 .
HR3_6	17.23	19.97	-2.9	741	0.004 **
T2	17.15	19.54	-3.3	1227	0.001 **
T3/ NS26	18.11	21.69	-3.5	855	5e-04 ***
T4	16.06	16.32	-0.29	957	0.8

3.1.3 Comparison of detection rates between the two monitoring years

In general, higher detection rates were observed during the second year of monitoring (April 2024 – April 2025; Table 3.5) compared to the first year of monitoring (April 2023 – March 2024; Table 3.4) – irrespectively of the temporal scale.

In both years of monitoring, detection rates of CPODs and FPODs always correlated significantly – irrespectively of the temporal scale (Table 3.6, Table 3.7). As a reminder, this was also the case when data of both monitoring years were combined (see chapter 3.1.1, Table 3.2).

Furthermore, in both years of monitoring, the FPOD generally recorded more detections than the CPOD, regardless of the temporal scale – except for the second year of monitoring with the temporal scale %DPD/m (Table 3.4, Table 3.5). However, this difference was only significant in the first year of monitoring using the temporal scales %DPH/d, %DP10M/d and %DPM/d (Table 3.4), and in the second year of monitoring using the temporal scale %DPM/d (Table 3.5). As a reminder, when data of both monitoring year were combined, the FPOD also recorded more detections and this difference was significant using the temporal scales %DPH/d, %DP10M/d and %DPM/d (see chapter 3.1.1, Table 3.1).

*Table 3.4 Comparing the detection rates using different temporal scales averaged over all stations in the Danish North Sea (1st year of monitoring): Results of the t-test; signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; FPOD quality classes "high" and "moderate".*

	Average CPOD detection rate	Average FPOD detection rate	t	df	p-value
%DPD/m	98.39	99.03	-1	158	0.3
%DPH/d	41.95	45.17	-4.5	3647	7e-06 ***
%DP10M/d	15.28	17.44	-5.3	3633	9e-08 ***
%DPM/d	4.197	5.542	-7.8	3380	9e-15 ***

*Table 3.5 Comparing the detection rates using different temporal scales averaged over all stations in the Danish North Sea (2nd year of monitoring): Results of the t-test; signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; FPOD quality classes "high" and "moderate".*

	Average CPOD detection rate	Average FPOD detection rate	t	df	p-value
%DPD/m	99.96	99.88	1.1	134	0.3
%DPH/d	52.52	52.96	-0.61	3838	0.5
%DP10M/d	22.01	22.55	-1.2	3838	0.2
%DPM/d	6.829	7.649	-3.8	3698	1e-04 ***

*Table 3.6 Comparing the detection rates using different temporal scales averaged over all stations in the Danish North Sea (1st year of monitoring): Results of the correlation test; signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; FPOD quality classes "high" and "moderate".*

	Sample estimate: cor	t	df	p-value
%DPD/m	0.6417	8	91	4e-12 ***
%DPH/d	0.9091	93	1823	<2e-16 ***
%DP10M/d	0.9291	107	1823	<2e-16 ***
%DPM/d	0.9259	103	1754	<2e-16 ***

*Table 3.7 Comparing the detection rates using different temporal scales averaged over all stations in the Danish North Sea (2nd year of monitoring): Results of the correlation test; signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; FPOD quality classes "high" and "moderate".*

	Sample estimate: cor	t	df	p-value
%DPD/m	0.4886	5.3	90	8e-07 ***
%DPH/d	0.927	108	1918	<2e-16 ***
%DP10M/d	0.9479	130	1918	<2e-16 ***
%DPM/d	0.9408	119	1855	<2e-16 ***

3.1.4 Potential reasons for differences in detection rates

According to the best explanatory Generalised Additive Model, the detection rates of both CPODs (Table 3.8, Figure 3.27) and FPODs (Table 3.9, Figure 3.28) were significantly affected by temporal patterns: The model showed daily patterns (variable “hourofday”) and seasonal patterns (variable “dayofyear”). Besides, the detection rates were significantly affected by spatial patterns (tensor product of the variables “Lon” and “Lat”), and by whether or not a harbour porpoise was detected within the previous 10 minutes (variable “harbour_porpoise_detection_t”). Furthermore, significantly fewer harbor porpoises were detected when PODs recorded many signals and thus presumably high background noise levels occurred (variable “Nall.m”). In contrast, in both models, the variable “depth” did not significantly affect the detection rates.

In the CPOD model, the deviance explained by the GAM was 38.2%, whereas in the FPOD model, the deviance explained by the GAM was 28.8%. Therefore, other factors that were not considered in this modeling may also have a significant impact on the detection rates.

Table 3.8 *Generalised Additive Model for CPOD data to analyse which variables affect the detection rates most. For the best explanatory model, the values for all variables and additionally the indices of the model were given. Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; FPOD quality classes "high" and "moderate".*

Variable	Edf/ Estimate	Ref.df/ Std. Error	Chi.sq/ z value	p-value/ Pr(>|z|)
harbour_porpoise_detection_t	2.182070	0.009764	223.5	<2e-16 ***
Tensor product: Lon – Lat	7.988	8.00	13378.34	<2e-16 ***
depth	excluded from the best explanatory model			
hourofday	5.610	8.00	71.72	<2e-16 ***
dayofyear	7.911	8.00	48036.06	<2e-16 ***
Nall.m	16.579	18.72	62271.27	<2e-16 ***
podident	22.729	23.00	4213.56	<2e-16 ***
N (number of 10-minute blocks analysed)	**535155**			
R-squared (adjusted)	**0.412**			
Deviance explained	**38.2%**			

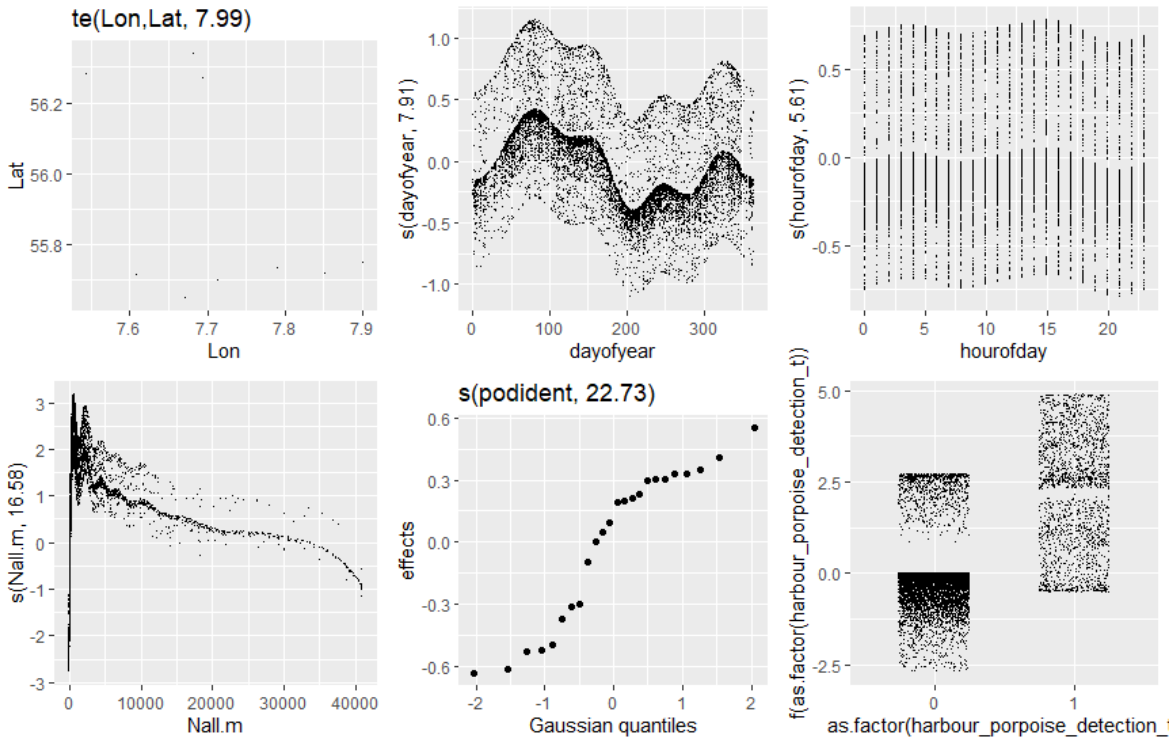

Figure 3.27 *Generalised Additive Model for CPOD data to analyse which variables affect the detection rates most. For the best explanatory model, the relationship between the variables and the detection rate was shown. The plots indicate the effect of the individual variable on the detection rate. Positive values on the y-axis indicate an increase in detection rates; negative values indicate a decrease in detection rates; FPOD quality classes "high" and "moderate".*

Table 3.9 *Generalised Additive Model for FPOD data to analyse which variables affect the detection rates most. For the best explanatory model, the values for all variables and additionally the indices of the model were given. Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; FPOD quality classes "high" and "moderate".*

Variable	Edf/ Estimate	Ref.df/ Std. Error	Chi.sq/ z value	p-value/ Pr(>|z|)
harbour_porpoise_detection_t	2.364691	0.008652	273.30	<2e-16 ***
Tensor product: Lon – Lat	7.904	7.983	887.1	<2e-16 ***
depth	excluded from the best explanatory model			
hourofday	5.977	8.000	110.5	<2e-16 ***
dayofyear	7.936	8.000	66207.2	<2e-16 ***
Nall.m	13.890	15.540	33465.3	<2e-16 ***
podident	41.946	44.000	6150.5	<2e-16 ***
N (number of 10-minute blocks analysed)	**535152**			
R-squared (adjusted)	**0.326**			
Deviance explained	**28.8%**			

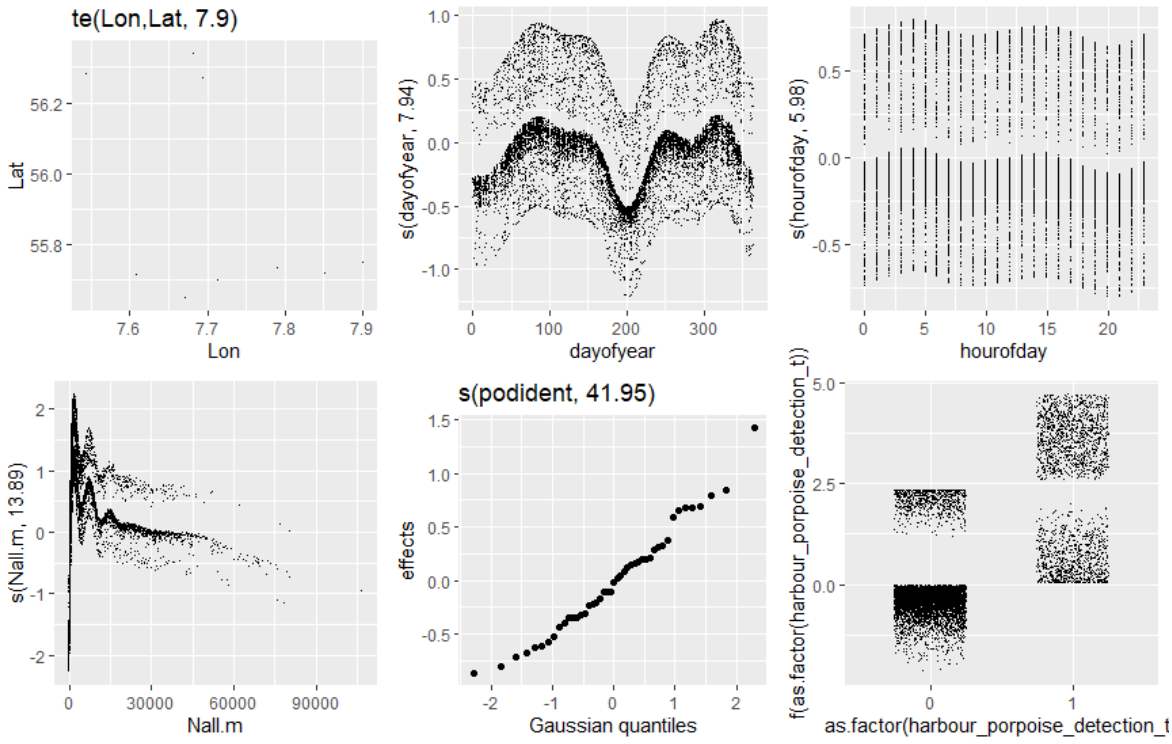

Figure 3.28 *Generalised Additive Model for FPOD data to analyse which variables affect the detection rates most. For the best explanatory model, the relationship between the variables and the detection rate was shown. The plots indicate the effect of the individual variable on the detection rate. Positive values on the y-axis indicate an increase in detection rates; negative values indicate a decrease in detection rates; FPOD quality classes "high" and "moderate".*

3.2 Comparison of CPOD data (quality classes “high” and “moderate”) and FPOD data (quality class “high”)

3.2.1 Comparison of detection rates

In this chapter, all comparisons are based on data generated using the KERNO classifier as well as the two highest quality classes for CPODs (“high” and “moderate”), and using the KERNO classifier as well as the highest quality class for FPODs (“high”).

In general, harbour porpoise detection rates of CPODs and FPODs were similar – irrespectively of if harbour porpoise detection rates are calculated on a daily (%DPD/m; Figure 3.29), hourly (%DPH/d; Figure 3.30), 10-minute block (%DP10M/d; Figure 3.31) or minutely basis (%DPM/d; Figure 3.32). However, the CPOD generally recorded more detections than the FPOD – again irrespectively of the temporal scale. In contrast, when using the two highest quality classes for FPODs (“high” and “moderate”), the FPOD recorded more detections than the CPOD (see chapter 3.1.1).

Both the CPOD and FPOD recorded detections on nearly every day: With the CPOD, an average detection rate of 99.2 %DPD/m was calculated, whereas with the FPOD, an average detection rate of 99.1 %DPD/m was calculated (Table 3.10). The correlation test showed that the CPOD detection rate and the FPOD detection rate correlated significantly when using the temporal scale %DPD/m (Table 3.11). Furthermore, the t-test showed no significant difference between the two detection rates (Figure 3.33, Table 3.10). The same statistical significances were observed when using the two highest quality classes for FPODs (“high” and “moderate”; see chapter 3.1.1).

Regarding the hourly scale, an average detection rate of 47.4 %DPH/d was recorded with the CPOD, whereas an average detection rate of 44.5 %DPH/d was recorded with the FPOD (Table 3.10). The correlation test showed that the CPOD detection rate and the FPOD detection rate correlated significantly when using the temporal scale %DPH/d (Table 3.11). However, the t-test showed a significant difference in detection rates between the two devices (Figure 3.34, Table 3.10). The same statistical significances were observed when using the two highest quality classes for FPODs (“high” and “moderate”; see chapter 3.1.1).

Furthermore, with the CPOD, an average detection rate of 18.7 %DP10M/d was calculated, whereas with the FPOD, an average detection rate of 17.3 %DP10M/d was calculated (Table 3.10). The correlation test showed that the CPOD detection rate and the FPOD detection rate correlated significantly when using the temporal scale %DP10M/d (Table 3.11). However, the t-test showed a significant difference between the two detection rates (Figure 3.35, Table 3.10). The same statistical significances were observed when using the two highest quality classes for FPODs (“high” and “moderate”; see chapter 3.1.1).

When analysing the data on a minutely basis, an average detection rate of 5.6 %DPM/d was recorded with the CPOD, whereas an average detection rate of 5.4 %DPM/d was recorded with the FPOD (Table 3.10). The correlation test showed that the CPOD detection rate and the FPOD detection rate correlated significantly when using the temporal scale %DPM/d (Table 3.11). The t-test showed no significant difference between the two devices (Figure 3.36, Table 3.10). In contrast, the t-test showed a significant difference between the two devices when using the two highest quality classes for FPODs (“high” and “moderate”; see chapter 3.1.1).

In summary, when analysing data in different resolutions (%DPD/d, %DPH/d, %DP10M/d, %DPM/d) and using the highest quality class for FPODs ("high"), detection rates of CPODs and FPODs always correlated significantly, with the CPOD always recording more detections than the FPOD irrespectively of the temporal scale. This difference was statistically significant for the temporal scales %DPH/d and %DP10M/d.

In contrast, when using the two highest quality classes for FPODs ("high" and "moderate"), detection rates of CPODs and FPODs also always correlated significantly, but the FPOD always recording more detections than the CPOD irrespectively of the temporal scale. This difference was statistically significant for the temporal scales %DPH/d, %DP10M/d, and %DPM/d (see chapter 3.1.1).

*Table 3.10 Comparing the detection rates using different temporal scales averaged over all stations in the Danish North Sea: Results of the t-test; signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; FPOD quality class "high".*

	Average CPOD detection rate	Average FPOD detection rate	t	df	p-value
%DPD/m	99.17	99.07	0.29	343	0.8
%DPH/d	47.37	44.48	5.6	7482	2e-08 ***
%DP10M/d	18.73	17.25	4.8	7438	2e-06 ***
%DPM/d	5.550	5.383	1.3	7206	0.2

*Table 3.11 Comparing the detection rates using different temporal scales averaged over all stations in the Danish North Sea: Results of the correlation test; signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; FPOD quality class "high".*

	Sample estimate: cor	t	df	p-value
%DPD/m	0.5526	9	183	4e-16 ***
%DPH/d	0.9198	143	3743	<2e-16 ***
%DP10M/d	0.9386	166	3743	<2e-16 ***
%DPM/d	0.9349	158	3611	<2e-16 ***

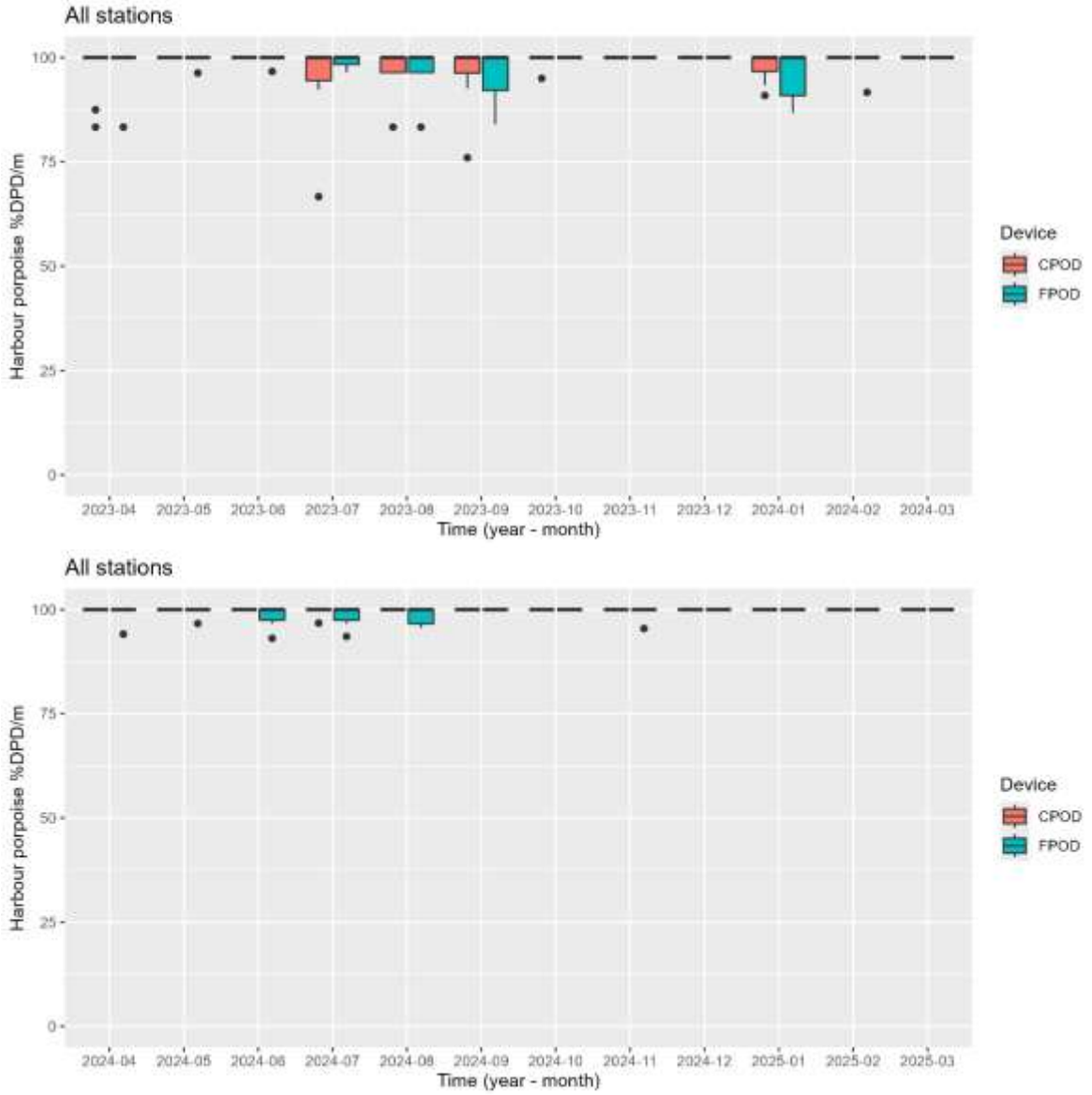

Figure 3.29 Harbour porpoise detection rates using the temporal scale %DPD/m from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025; first year of monitoring = upper graph and second year of monitoring = lower graph) averaged over all stations in the Danish North Sea; data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality class "high".

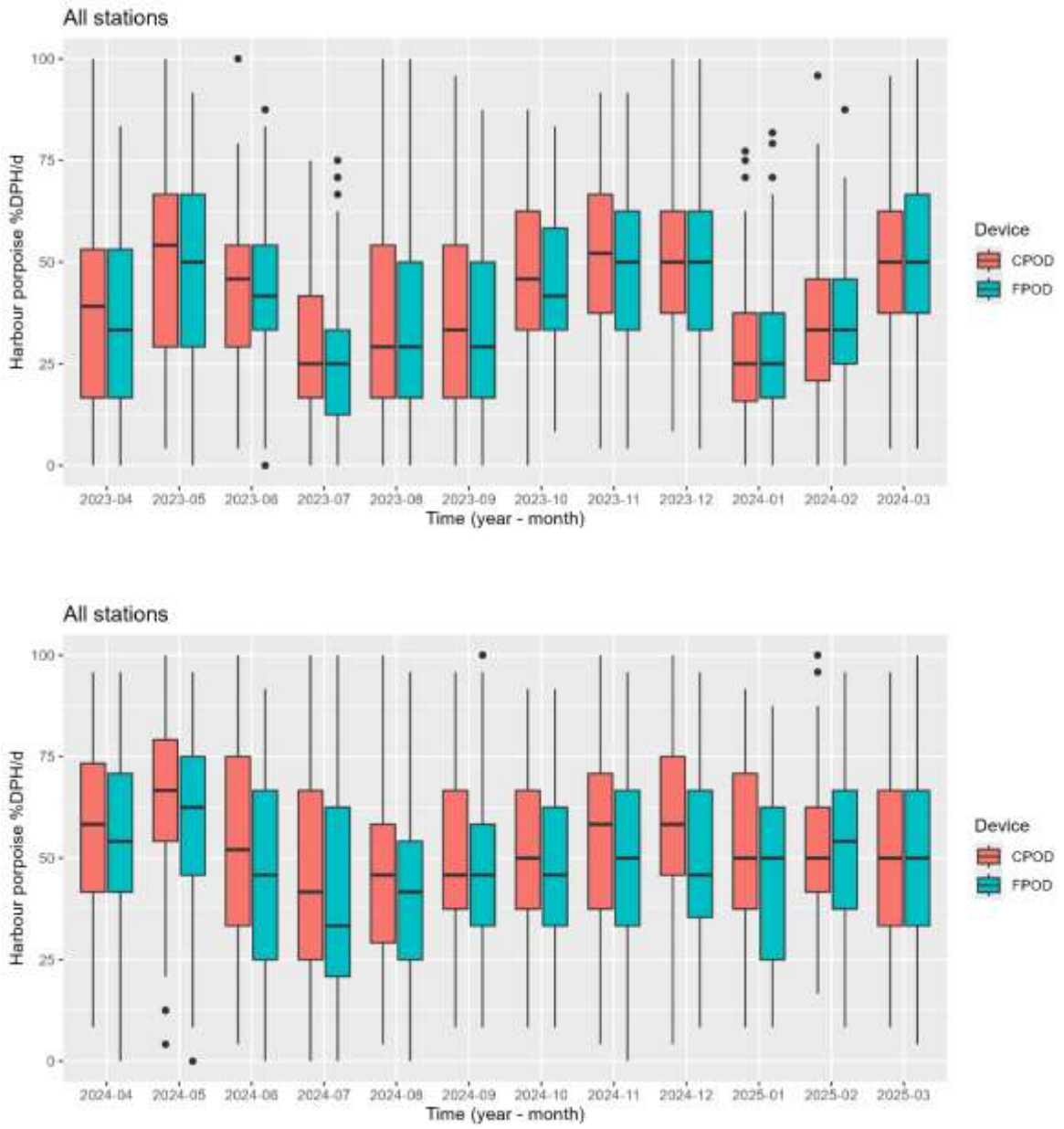

Figure 3.30 Harbour porpoise detection rates using the temporal scale %DPH/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025; first year of monitoring = upper graph and second year of monitoring = lower graph) averaged over all stations in the Danish North Sea; data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality class "high".

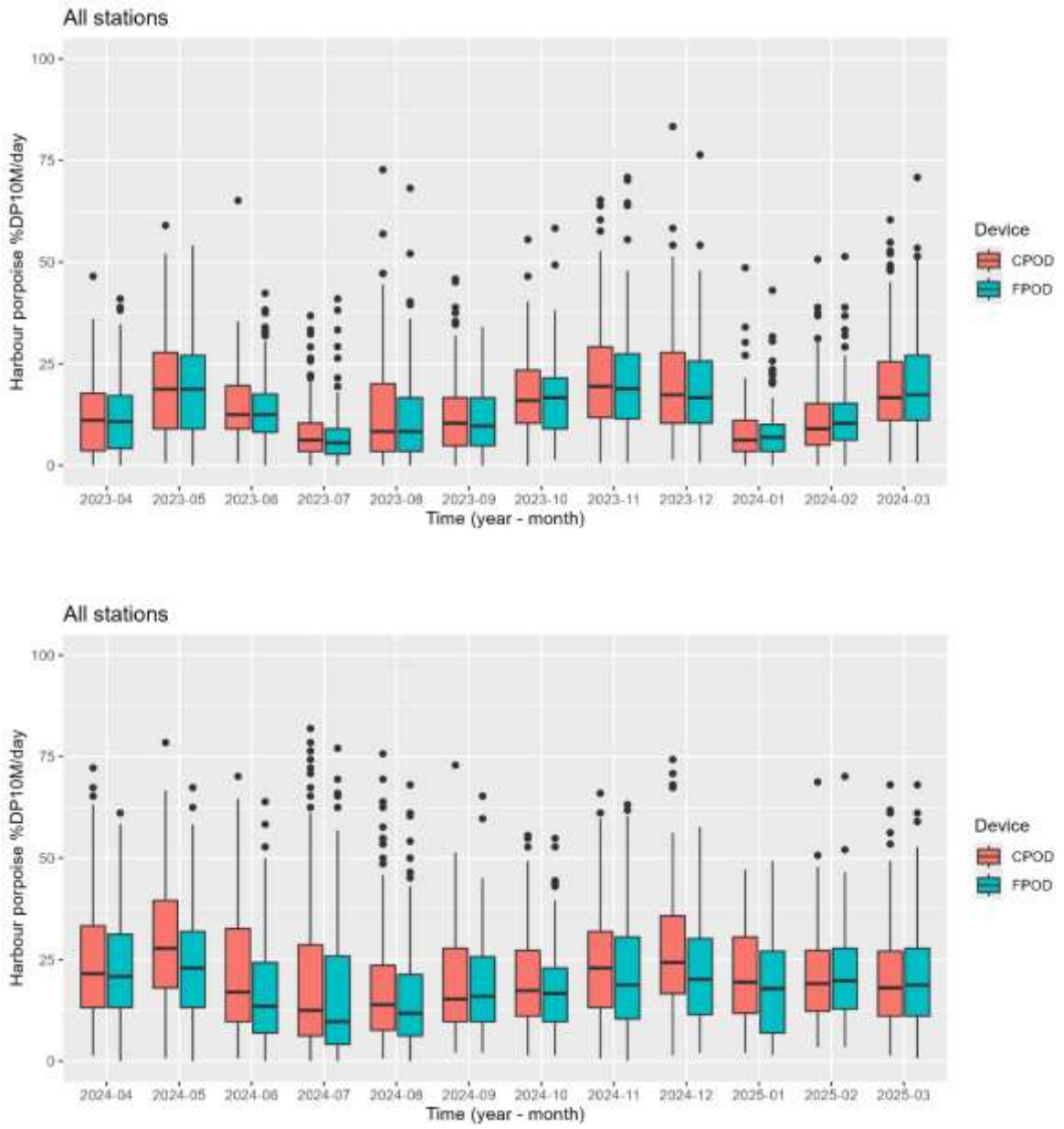

Figure 3.31 Harbour porpoise detection rates using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025; first year of monitoring = upper graph and second year of monitoring = lower graph) averaged over all stations in the Danish North Sea; data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality class "high".

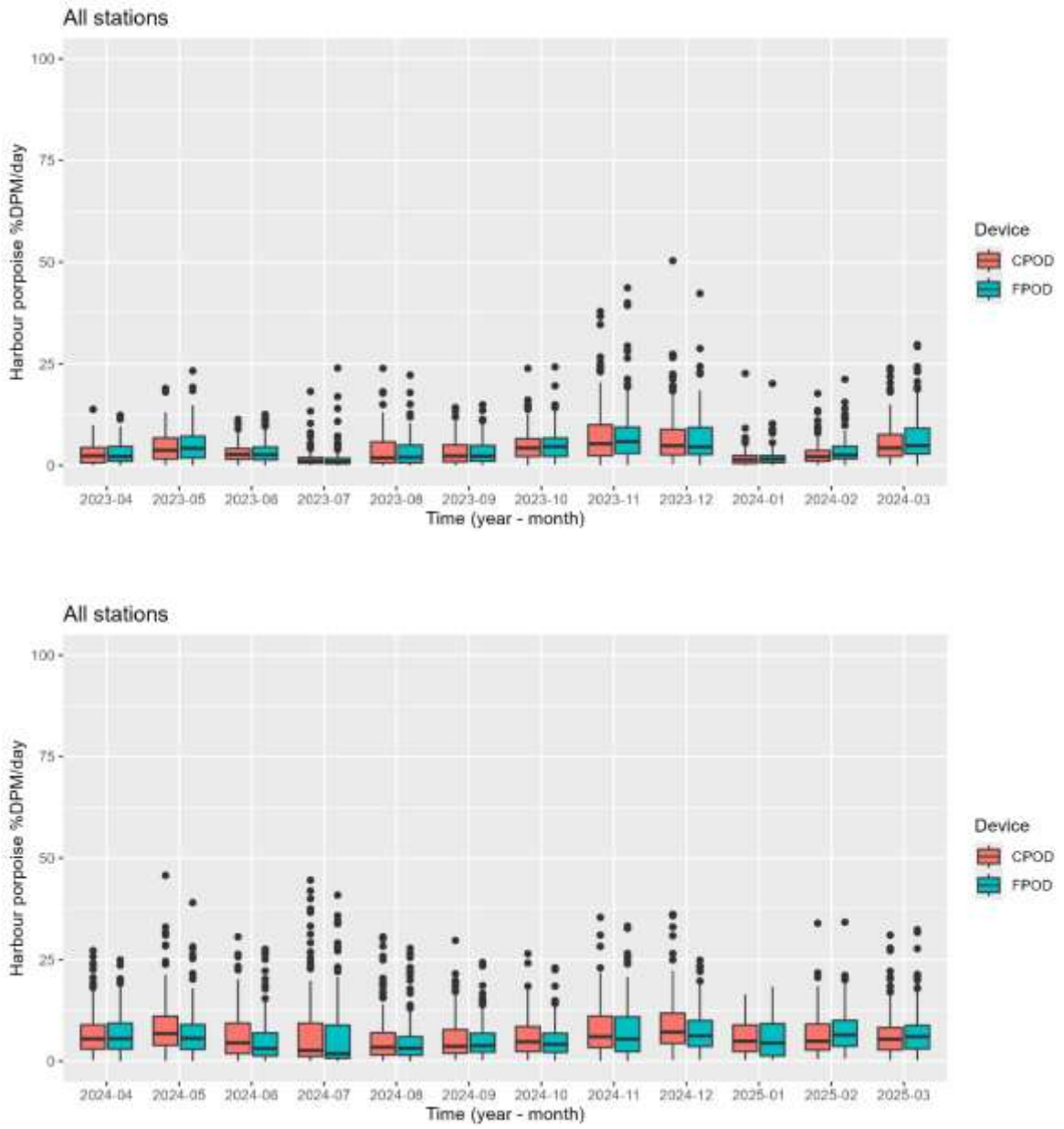

Figure 3.32 Harbour porpoise detection rates using the temporal scale %DPM/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025; first year of monitoring = upper graph and second year of monitoring = lower graph) averaged over all stations in the Danish North Sea; data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality class "high".

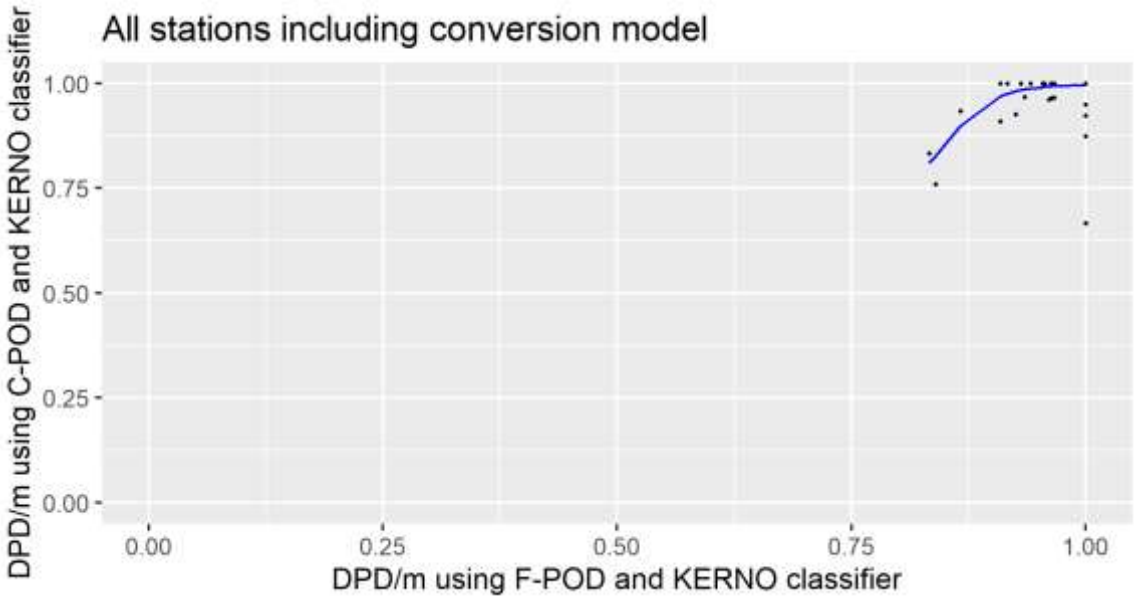

Figure 3.33 *Comparing harbour porpoise detection rates using the temporal scale %DPD/m from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025) averaged over all stations in the Danish North Sea; the blue line is a curve fitting using a generalised log-logistic model; FPOD quality class "high".*

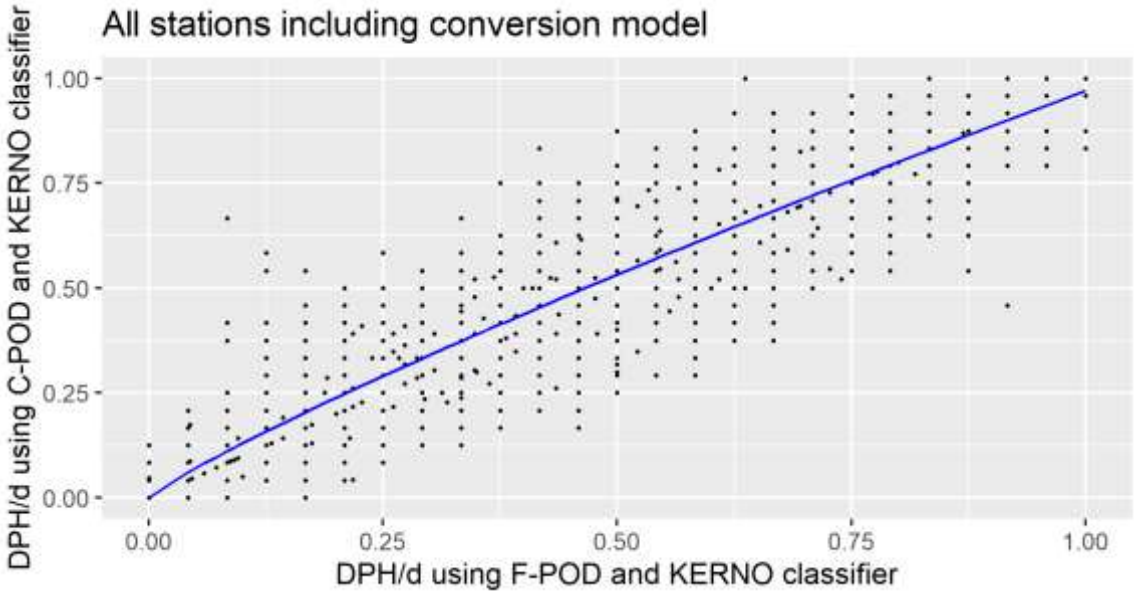

Figure 3.34 *Comparing harbour porpoise detection rates using the temporal scale %DPH/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025) averaged over all stations in the Danish North Sea; the blue line is a curve fitting using a generalised log-logistic model; FPOD quality class "high".*

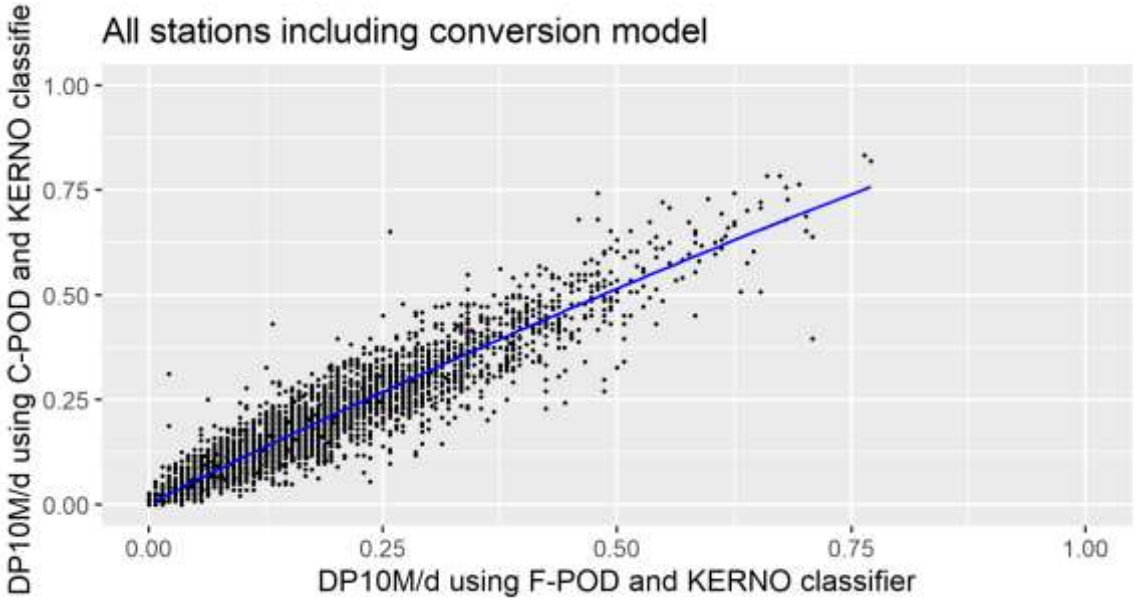

Figure 3.35 *Comparing harbour porpoise detection rates using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025) averaged over all stations in the Danish North Sea; the blue line is a curve fitting using a generalised log-logistic model; FPOD quality class "high".*

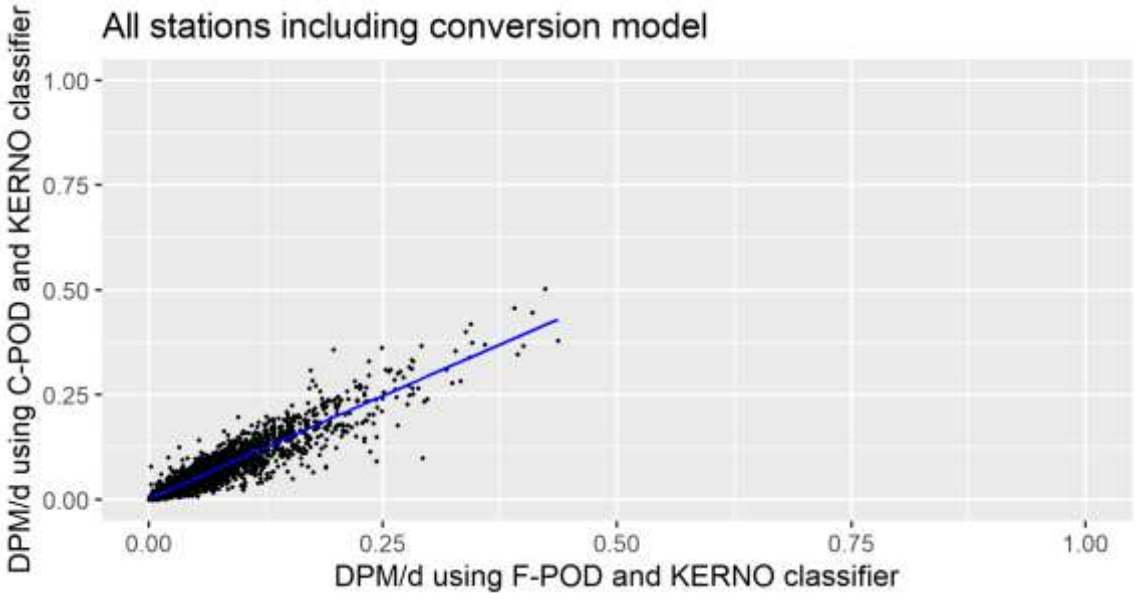

Figure 3.36 *Comparing harbour porpoise detection rates using the temporal scale %DPM/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025) averaged over all stations in the Danish North Sea; the blue line is a curve fitting using a generalised log-logistic model; FPOD quality class "high".*

3.2.2 Comparison of detection rates between the individual stations

Both devices reported detections at the same time and only the number of detections varied (Figure 3.37 – Figure 3.54). Therefore, both devices seem to detect harbour porpoises in a similar way, making the different data sets comparable.

The differences between the two detection rates, however, varied (Table 3.12). At 6 out of 9 stations, the detection rates of CPODs were higher than the detection rates of FPODs. Besides, the detection rates of CPODs and FPODs differed significantly at 4 stations (all of them with higher CPOD detection rates than CPOD detection rates) and did not differ significantly at 5 stations.

Accordingly, the average difference between the detection rates of CPODs and FPODs from chapter 3.2.1 does not mean that the FPOD records this percentage of detections more than the CPOD. Instead, even at stations such as those in this study, which are all located in a similar study area, there are differences in the extent to which CPODs and FPODs have similar detection rates.

In contrast, when using the two highest quality classes for FPODs (“high” and “moderate”), the FPOD recorded more detections than the CPOD at 7 out of 9 stations, and the detection rates of CPODs and FPODs differed significantly at 4 stations (all of them with higher FPOD detection rates than CPOD detection rates) (see chapter 3.2.2).

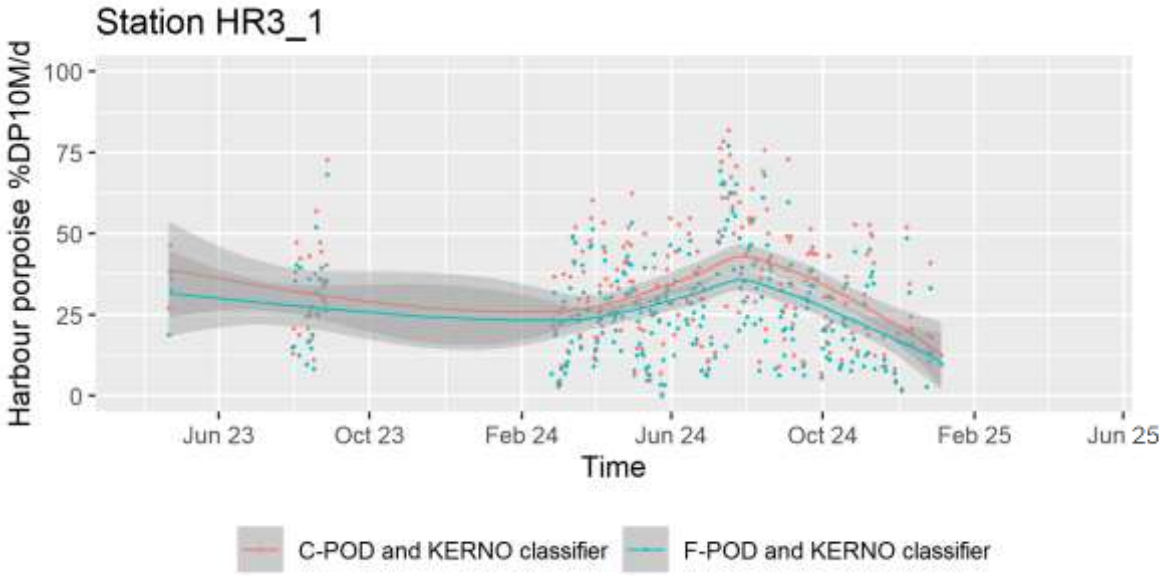

Figure 3.37 *Harbour porpoise detection rates at the station HR3_1 using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality class "high".*

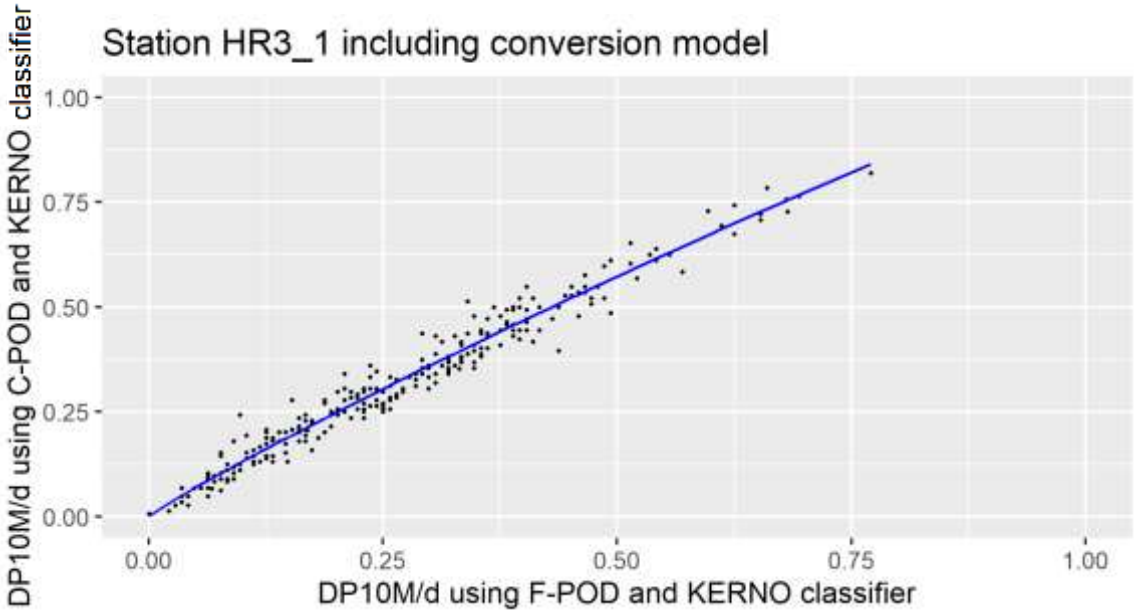

Figure 3.38 *Comparing harbour porpoise detection rates at the station HR3_1 using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality class "high".*

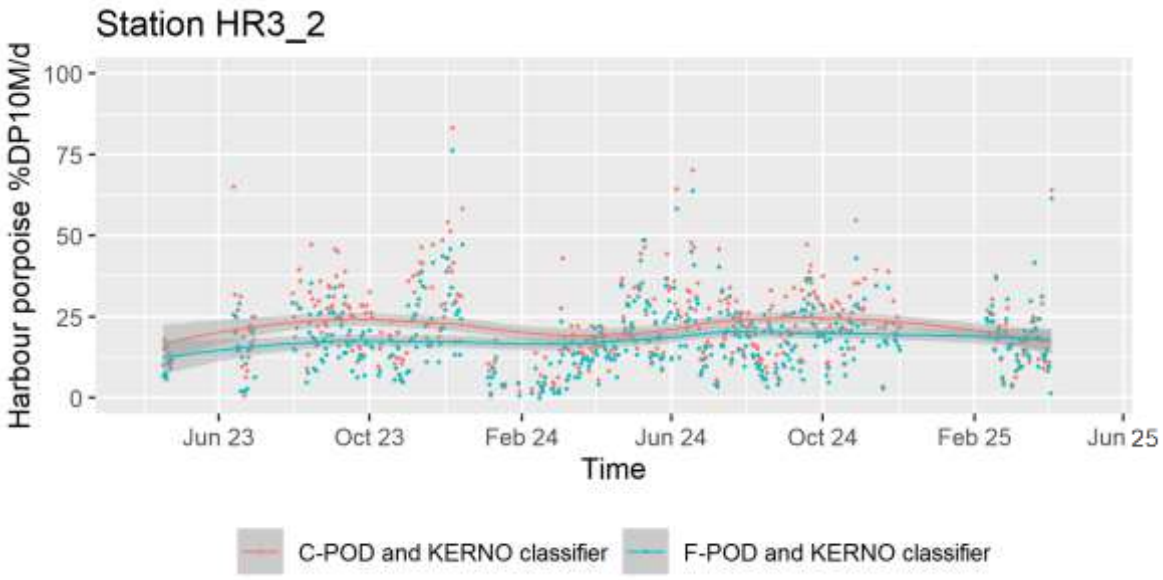

Figure 3.39 *Harbour porpoise detection rates at the station HR3_2 using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality class "high".*

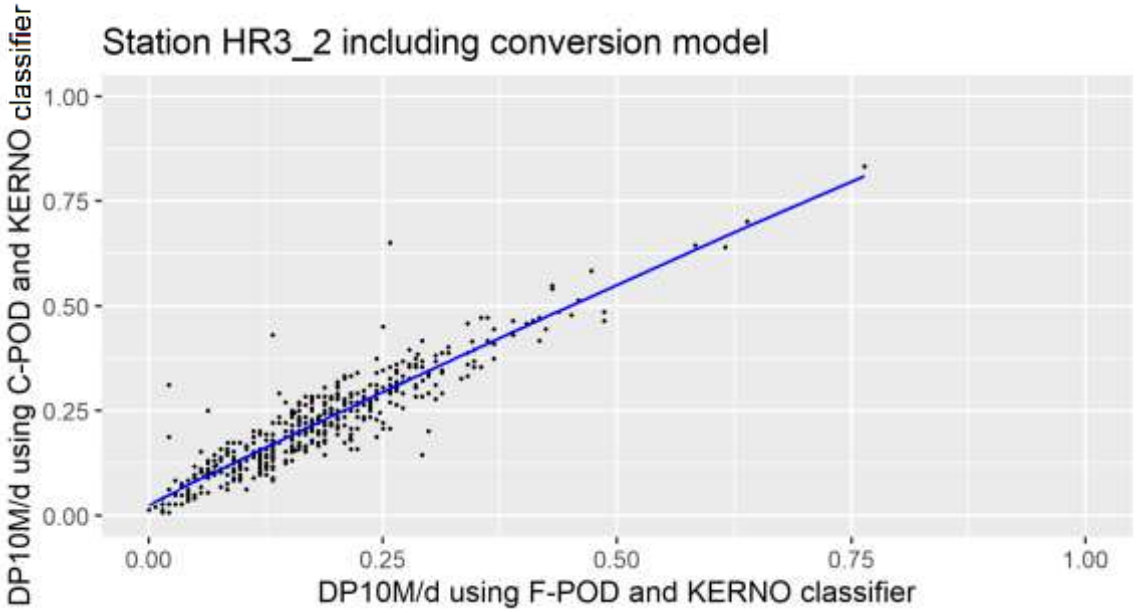

Figure 3.40 *Comparing harbour porpoise detection rates at the station HR3_2 using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality class "high".*

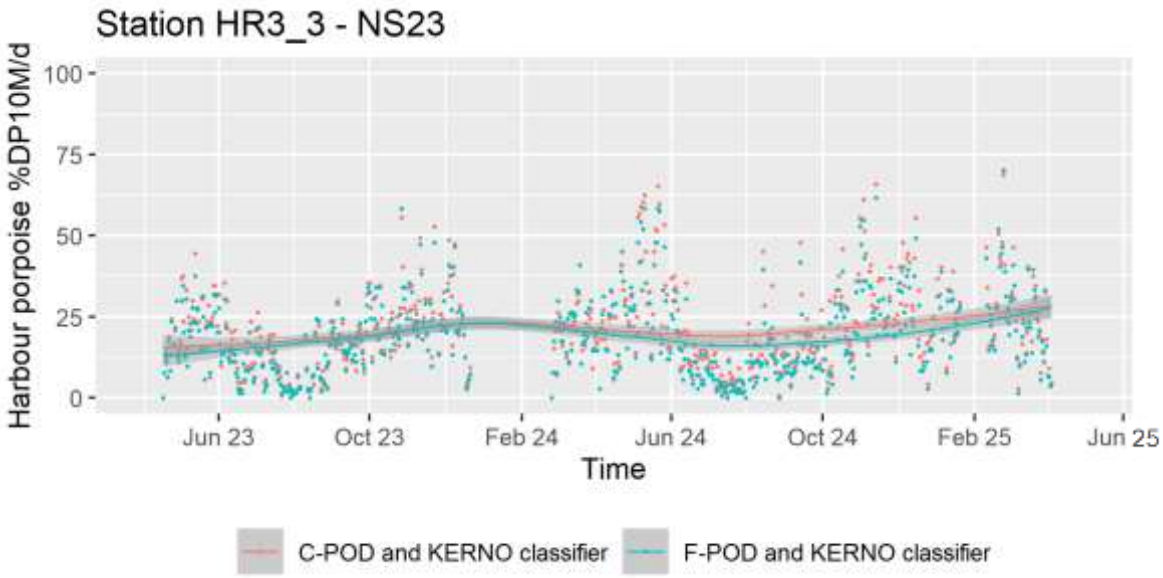

Figure 3.41 *Harbour porpoise detection rates at the station HR3_3/NS23 using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality class "high".*

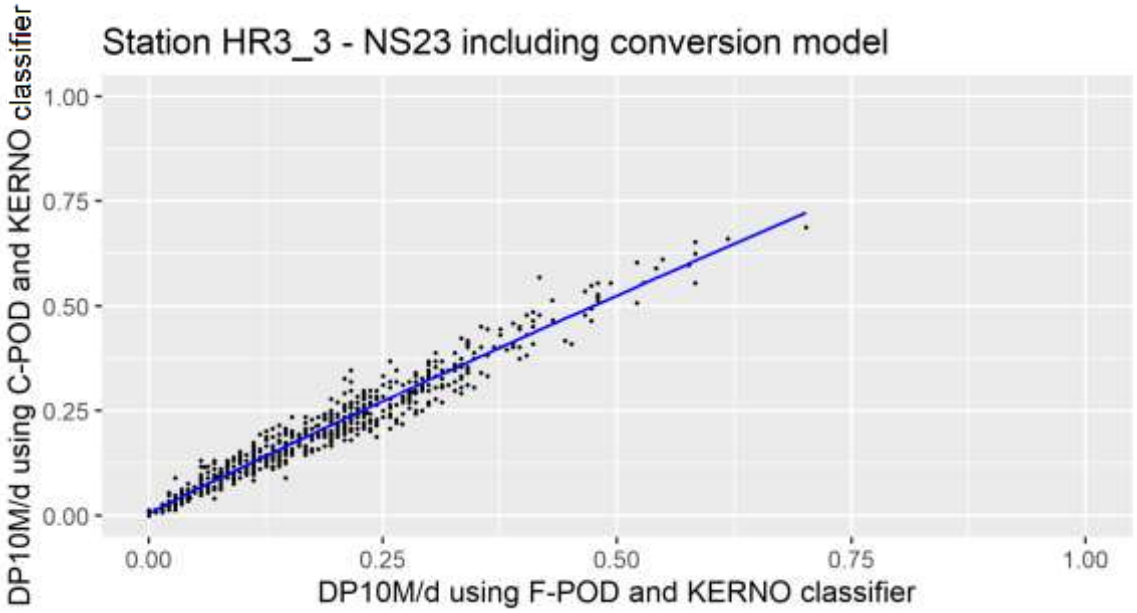

Figure 3.42 *Comparing harbour porpoise detection rates at the station HR3_3/NS23 using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality class "high".*

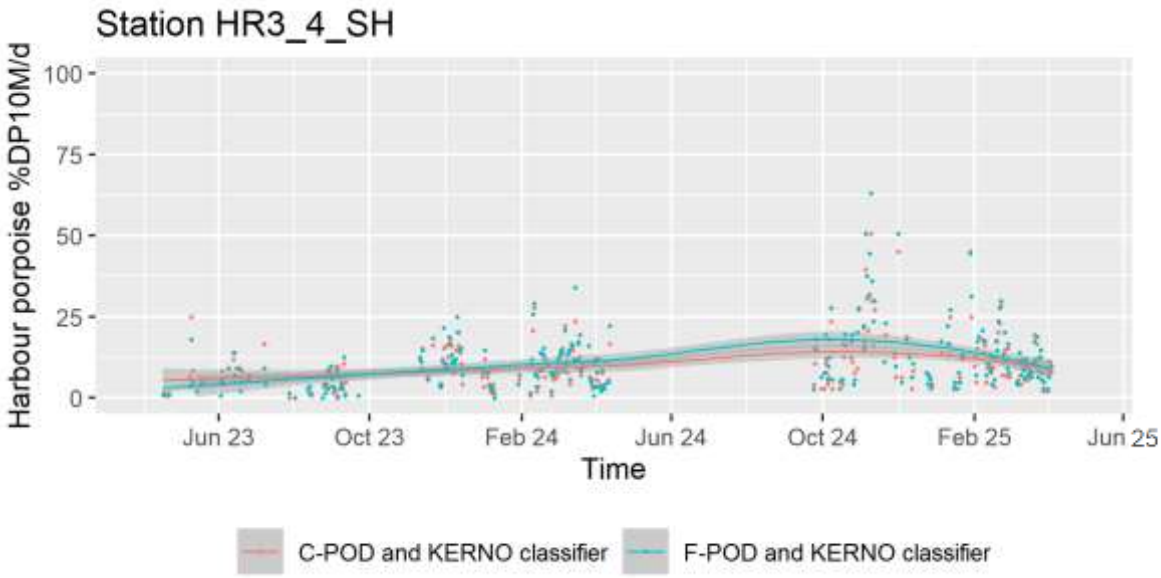

Figure 3.43 *Harbour porpoise detection rates at the station HR3_4_SH using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality class "high".*

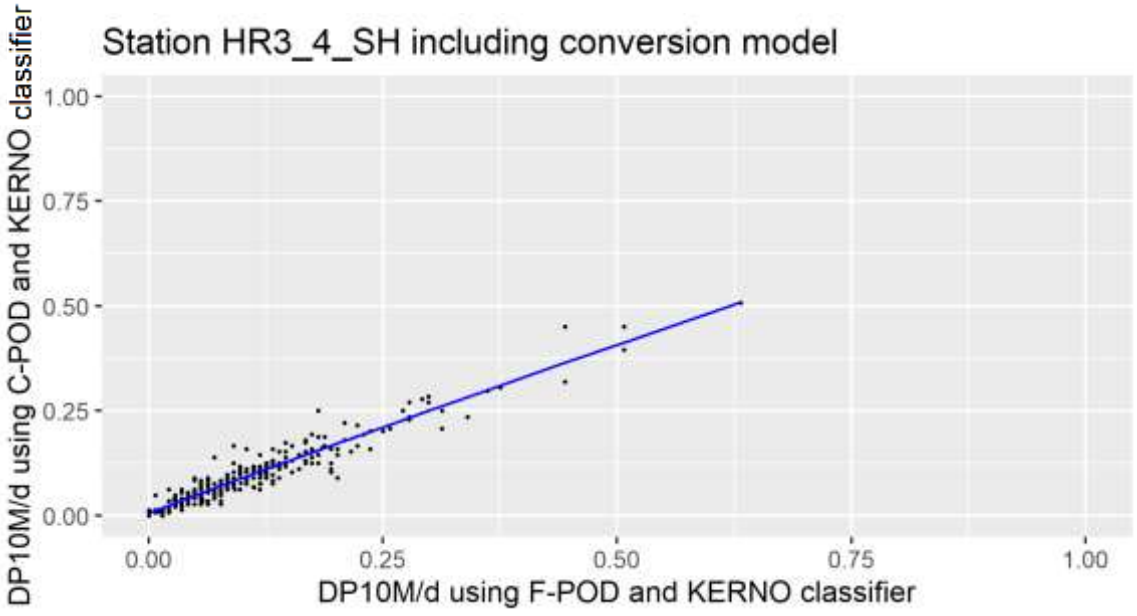

Figure 3.44 *Comparing harbour porpoise detection rates at the station HR3_3/NS23 using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality class "high".*

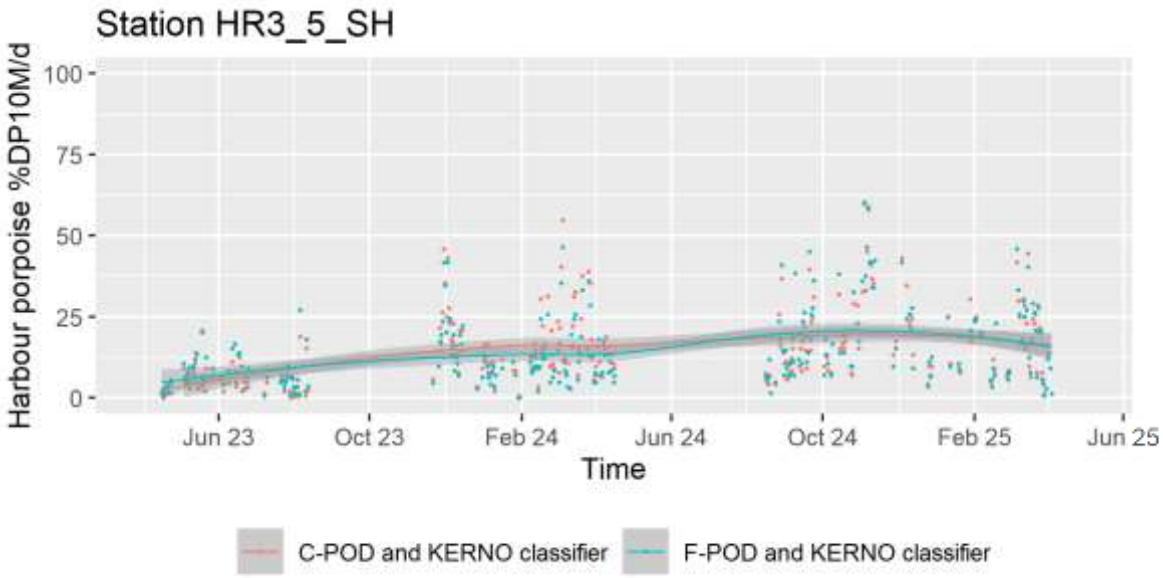

Figure 3.45 *Harbour porpoise detection rates at the station HR3_5_SH using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality class "high".*

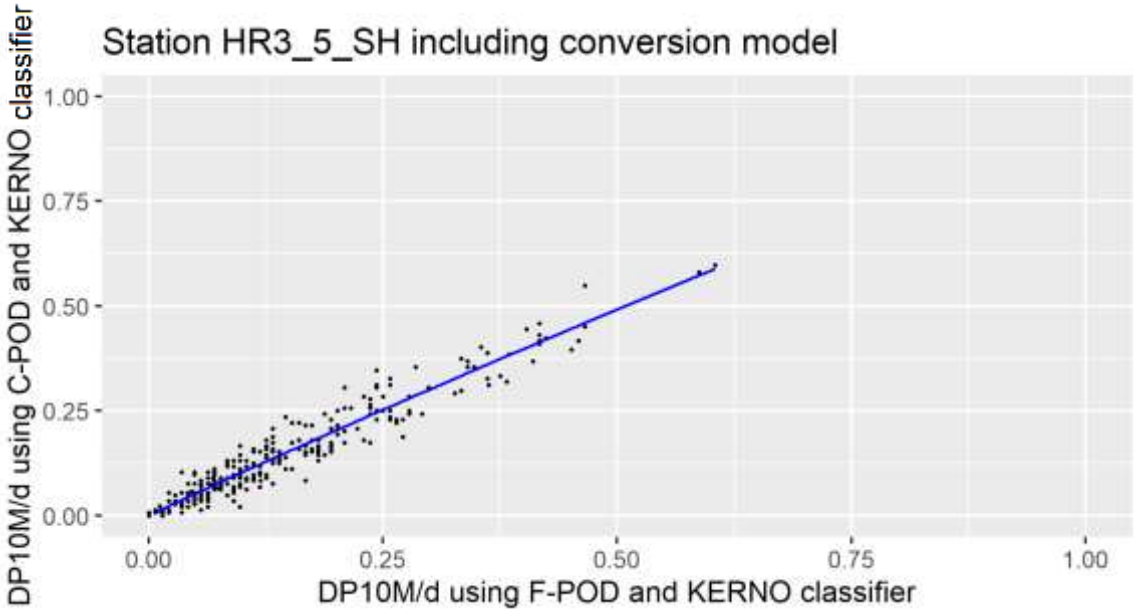

Figure 3.46 *Comparing harbour porpoise detection rates at the station HR3_5_SH using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality class "high".*

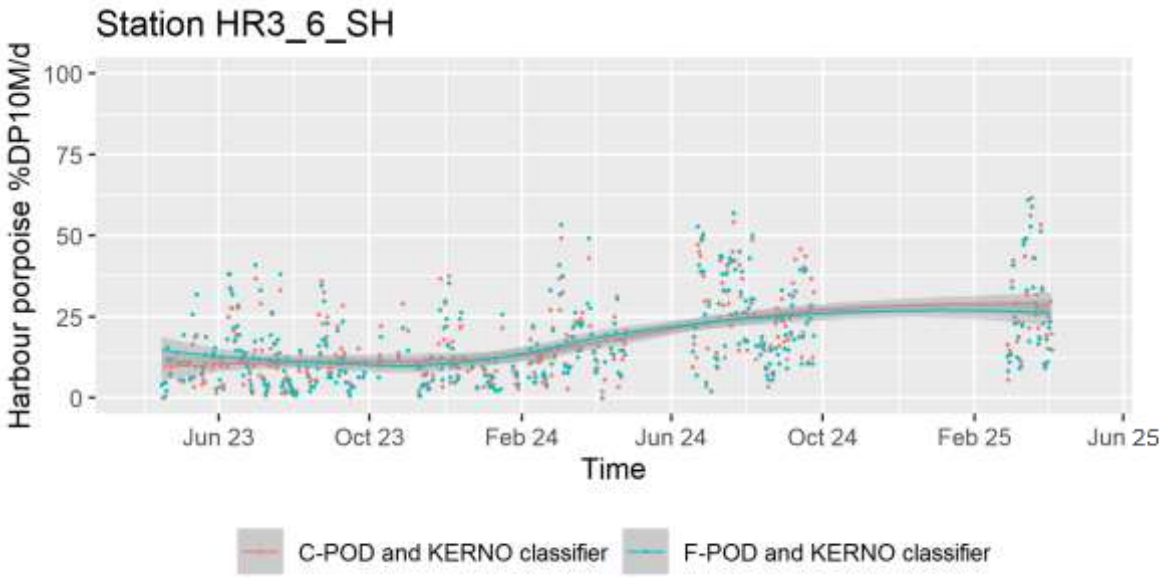

Figure 3.47 *Harbour porpoise detection rates at the station HR3_6_SH using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality class "high".*

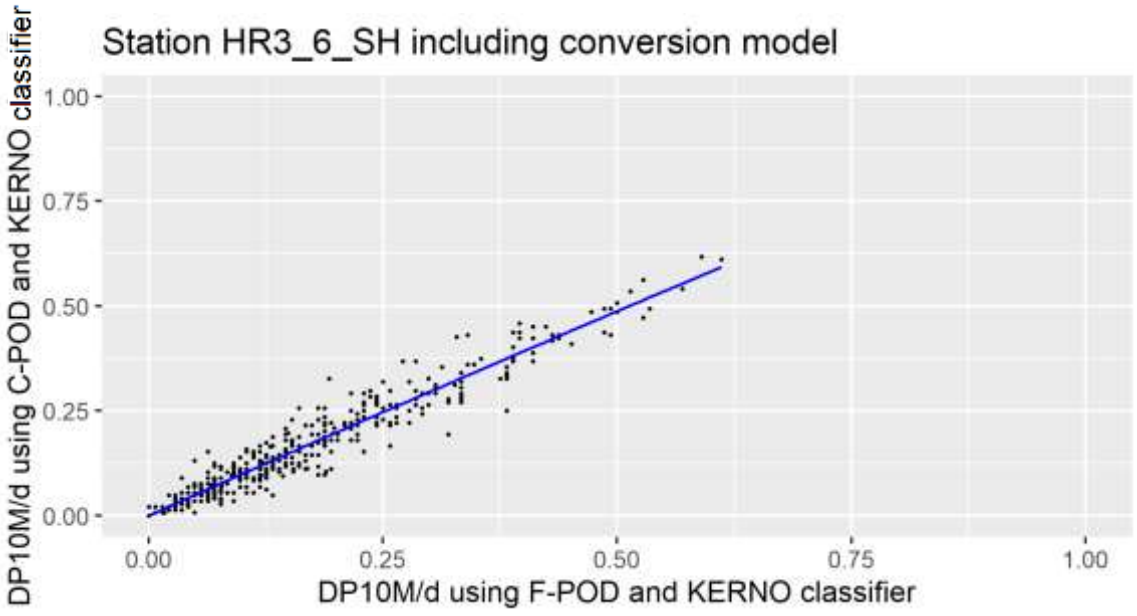

Figure 3.48 *Comparing harbour porpoise detection rates at the station HR3_6_SH using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality class "high".*

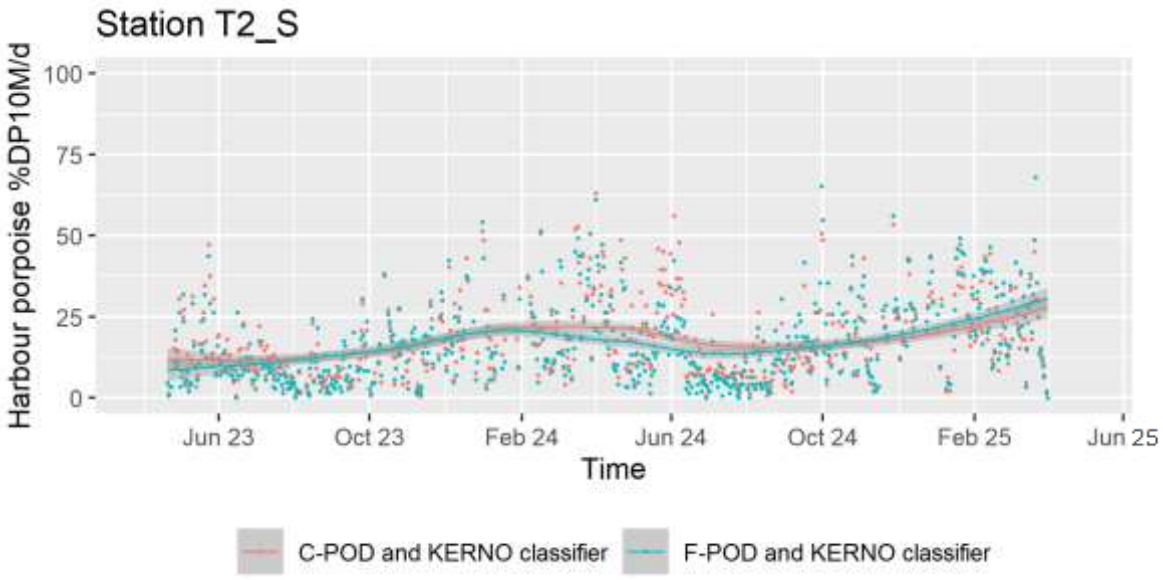

Figure 3.49 *Harbour porpoise detection rates at the station T2_S using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality class "high".*

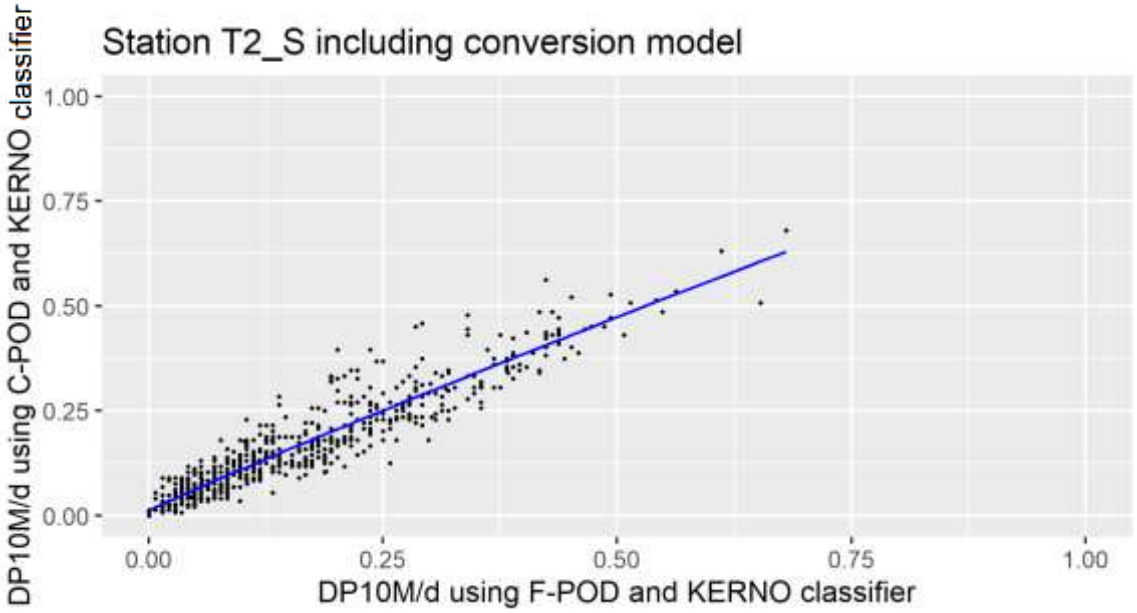

Figure 3.50 *Comparing harbour porpoise detection rates at the station T2_S using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality class "high".*

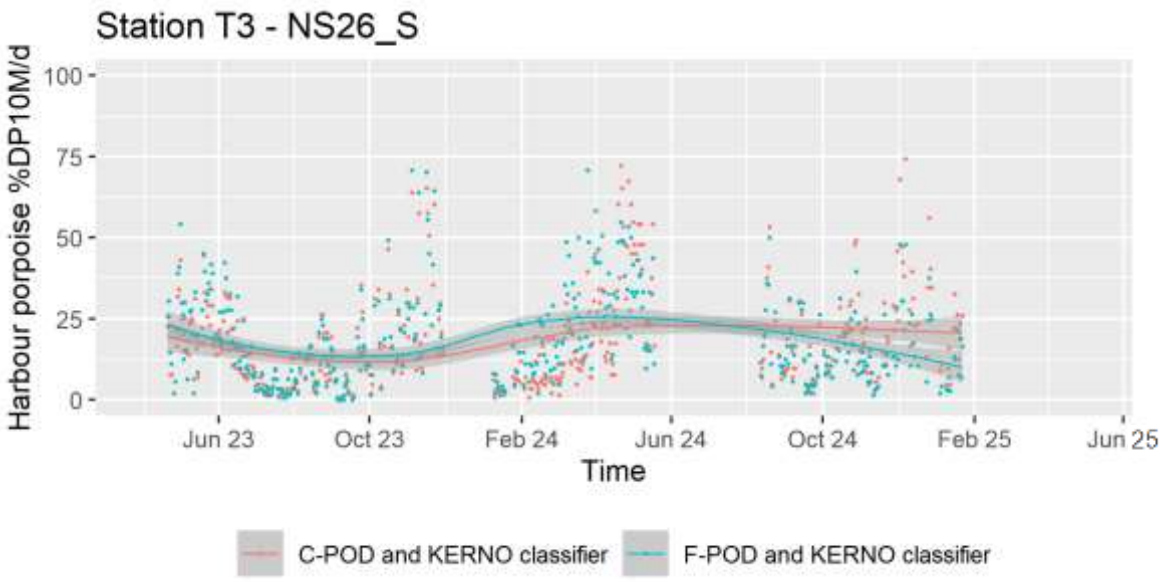

Figure 3.51 *Harbour porpoise detection rates at the station T3/NS26_S using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); data set adjusted for background noise; only complete recording days and only the two highest data quality classes used; FPOD quality class "high".*

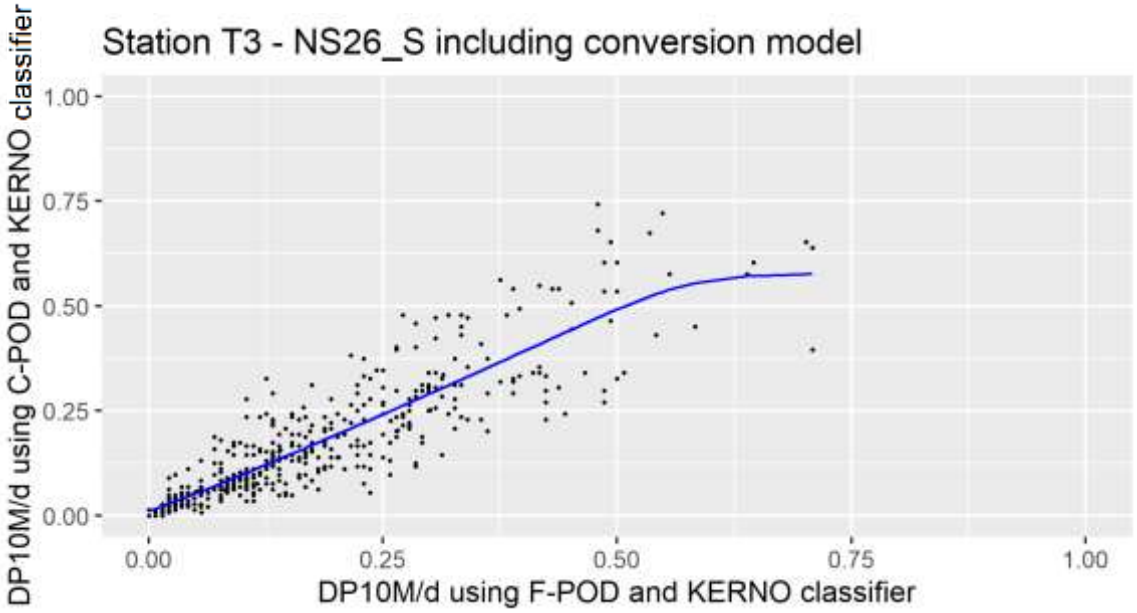

Figure 3.52 *Comparing harbour porpoise detection rates at the station T3/NS26_S using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality class "high".*

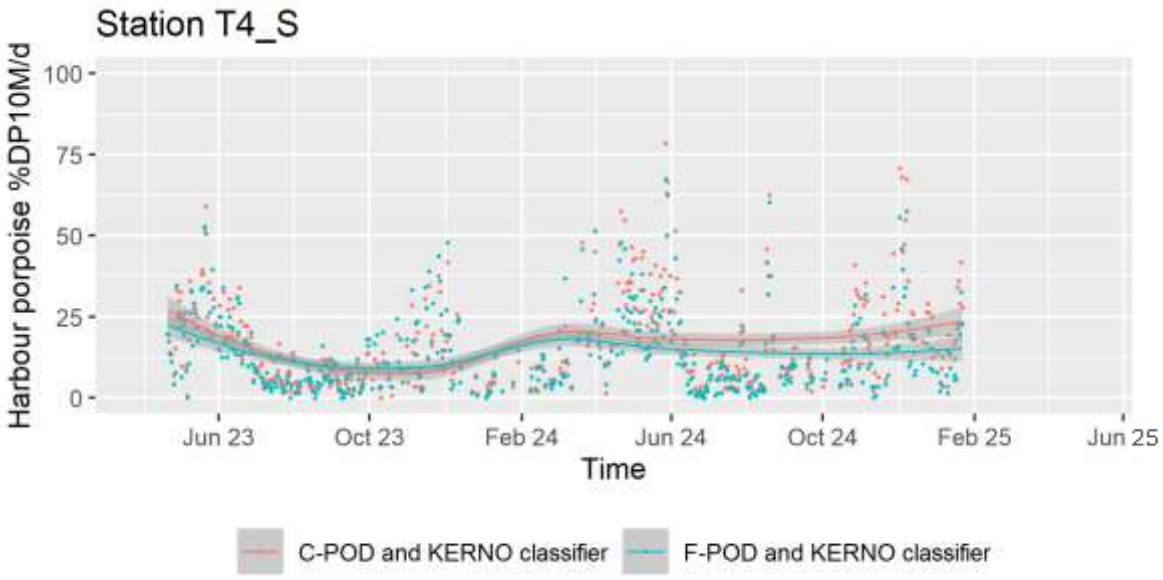

Figure 3.53 *Harbour porpoise detection rates at the station T4_S using the temporal scale %DP10M/d from CPOD devices with the KERNO classifier (red) and from FPOD devices with the KERNO classifier (blue) during the study period (April 2023 – April 2025); only complete recording days and only the two highest data quality classes used; FPOD quality class "high".*

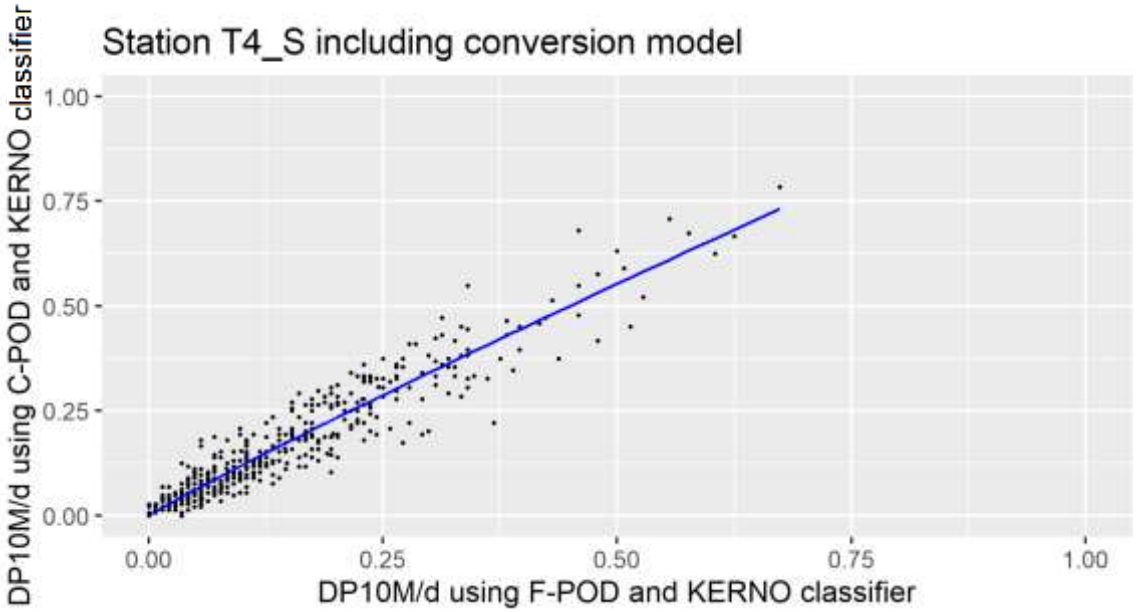

Figure 3.54 *Comparing harbour porpoise detection rates at the station T4_S using the temporal scale DP10M/d from CPOD devices with the KERNO classifier and from FPOD devices with the KERNO classifier during the study period (April 2023 – April 2025); the blue line is a curve fitting using a generalised log-logistic model; FPOD quality class "high".*

*Table 3.12 Comparing the detection rates for each station using %DP10M/D: Results of the t-test; signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; FPOD quality class "high".*

	Average CPOD detection rate	Average FPOD detection rate	t	df	p-value
HR3_1	32.32	27.09	3.6	506	3e-04 ***
HR3_2	22.32	18.25	5.4	885	7e-08 ***
HR3_3/NS23	20.78	18.77	2.8	1212	0.005 ***
HR3_4	10.03	11.26	-1.6	494	0.1
HR3_5	14.80	14.47	0.34	540	0.7
HR3_6	17.23	17.34	-0.12	742	0.9
T2	17.15	16.49	0.94	1239	0.3
T3/ NS26	18.11	18.49	-0.39	852	0.7
T4	16.06	13.68	2.8	938	0.005 ***

3.2.3 Comparison of detection rates between the two monitoring years

In general, higher detection rates were observed during the second year of monitoring (April 2024 – April 2025; Table 3.14) compared to the first year of monitoring (April 2023 – March 2024; Table 3.13) – irrespectively of the temporal scale.

In both years of monitoring, detection rates of CPODs and FPODs always correlated significantly – irrespectively of the temporal scale (Table 3.15, Table 3.16). As a reminder, this was also the case when data of both monitoring years were combined (see chapter 3.2.1, Table 3.11). Besides, the same statistical significances were observed when using the two highest quality classes for FPODs ("high" and "moderate"; see chapter 3.1.1 and 3.1.3).

Furthermore, in both years of monitoring, the CPOD generally recorded more detections than the FPOD, regardless of the temporal scale – except for the first year of monitoring with the temporal scales %DPD/m and %DPM/d (Table 3.13, Table 3.14). However, this difference was only significant in the first year of monitoring using the temporal scale %DPH/d (Table 3.13), and in the second year of monitoring using the temporal scales %DPD/m, %DPH/d, %DP10M/d, and %DPM/d (Table 3.14). As a reminder, when data of both monitoring year were combined, the CPOD also recorded more detections and this difference was significant using the temporal scales %DPH/d and %DP10M/d (see chapter 3.2.1, Table 3.10).

Also when using the two highest quality classes for FPODs ("high" and "moderate"), detection rates of CPODs and FPODs always correlated significantly – irrespectively of the temporal scale: however, in contrast, in both years of monitoring, the FPOD generally recorded more detections than the CPOD, regardless of the temporal scale – except for the second year of monitoring with the temporal scale %DPD/m (see chapter 3.1.3).

*Table 3.13 Comparing the detection rates using different temporal scales averaged over all stations in the Danish North Sea (1st year of monitoring): Results of the t-test; signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; FPOD quality class "high".*

	Average CPOD detection rate	Average FPOD detection rate	t	df	p-value
%DPD/m	98.39	98.64	-0.38	166	0.7
%DPH/d	41.95	40.28	2.3	3646	0.02 *
%DP10M/d	15.28	14.79	1.3	3644	0.2
%DPM/d	4.197	4.463	-1.7	3501	0.09 .

*Table 3.14 Comparing the detection rates using different temporal scales averaged over all stations in the Danish North Sea (2nd year of monitoring): Results of the t-test; signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; FPOD quality class "high".*

	Average CPOD detection rate	Average FPOD detection rate	t	df	p-value
%DPD/m	99.96	99.51	2.9	100	0.005 **
%DPH/d	52.52	48.48	5.6	3838	2e-08 ***
%DP10M/d	22.01	19.59	5.3	3805	1e-07 ***
%DPM/d	6.829	6.253	2.9	3685	0.004 **

*Table 3.15 Comparing the detection rates using different temporal scales averaged over all stations in the Danish North Sea (1st year of monitoring): Results of the correlation test; signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; FPOD quality class "high".*

	Sample estimate: cor	t	df	p-value
%DPD/m	0.57	6.6	91	2e-09 ***
%DPH/d	0.9117	95	1823	<2e-16 ***
%DP10M/d	0.9273	106	1823	<2e-16 ***
%DPM/d	0.9302	106	1754	<2e-16 ***

*Table 3.16 Comparing the detection rates using different temporal scales averaged over all stations in the Danish North Sea (2nd year of monitoring): Results of the correlation test; signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; FPOD quality class "high".*

	Sample estimate: cor	t	df	p-value
%DPD/m	0.4255	4.5	90	2e-05 ***
%DPH/d	0.9223	105	1918	<2e-16 ***
%DP10M/d	0.9443	126	1918	<2e-16 ***
%DPM/d	0.9401	119	1855	<2e-16 ***

3.2.4 Potential reasons for differences in detection rates

According to the best explanatory Generalised Additive Model, the detection rates of both CPODs (Table 3.17, Figure 3.55) and FPODs (Table 3.18, Figure 3.56) were significantly affected by temporal patterns: The model showed daily patterns (variable “hourofday”) and seasonal patterns (variable “dayofyear”). Besides, the detection rates were significantly affected by spatial patterns (tensor product of the variables “Lon” and “Lat”), and by whether or not a harbour porpoise was detected within the previous 10 minutes (variable “harbour_porpoise_detection_t”). Furthermore, significantly fewer harbor porpoises were detected when PODs recorded many signals and thus presumably high background noise levels occurred (variable “Nall.m”). In contrast, in the CPOD model, the variable “depth” did not significantly affect the detection rates, whereas in the FPOD model, the variable “depth” significantly affected the detection rates.

When using the two highest quality classes for FPODs (“high” and “moderate”; see chapter 3.1.4), the same statistical significances were observed – except for the the variable “depth”.

In the CPOD model, the deviance explained by the GAM was 38.2%, whereas in the FPOD model, the deviance explained by the GAM was 30.1%. Therefore, other factors that were not considered in this modeling may also have a significant impact on the detection rates.

*Table 3.17 Generalised Additive Model for CPOD data to analyse which variables affect the detection rates most. For the best explanatory model, the values for all variables and additionally the indices of the model were given. Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.*

Variable	Edf/ Estimate	Ref.df/ Std. Error	Chi.sq/ z value	p-value/ Pr(>|z|)
harbour_porpoise_detection_t	2.182070	0.009764	223.5	<2e-16 ***
Tensor product: Lon – Lat	7.988	8.00	13378.34	<2e-16 ***
depth	excluded from the best explanatory model			
hourofday	5.610	8.00	71.72	<2e-16 ***
dayofyear	7.911	8.00	48036.06	<2e-16 ***
Nall.m	16.579	18.72	62271.27	<2e-16 ***
podident	22.729	23.00	4213.56	<2e-16 ***
N (number of 10-minute blocks analysed)	**535155**			
R-squared (adjusted)	**0.412**			
Deviance explained	**38.2%**			

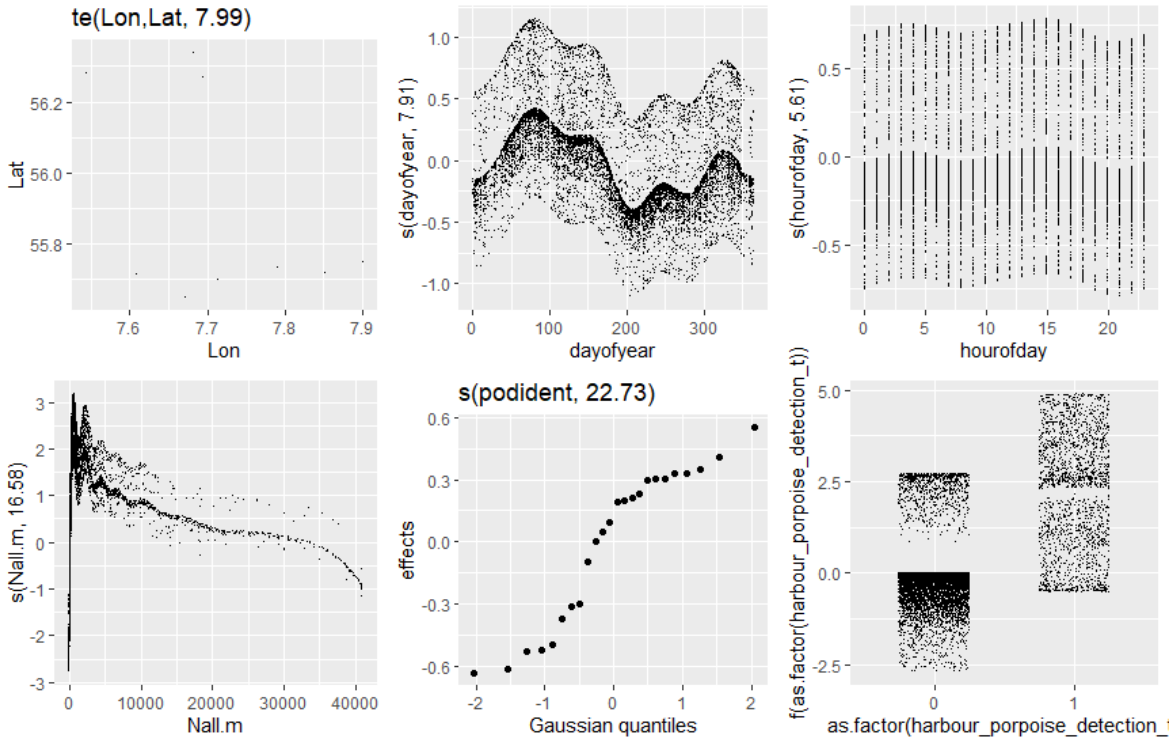

Figure 3.55 Generalised Additive Model for CPOD data to analyse which variables affect the detection rates most. For the best explanatory model, the relationship between the variables and the detection rate was shown. The plots indicate the effect of the individual variable on the detection rate. Positive values on the y-axis indicate an increase in detection rates; negative values indicate a decrease in detection rates.

*Table 3.18 Generalised Additive Model for FPOD data to analyse which variables affect the detection rates most. For the best explanatory model, the values for all variables and additionally the indices of the model were given. Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; FPOD quality class "high".*

Variable	Edf/ Estimate	Ref.df/ Std. Error	Chi.sq/ z value	p-value/ Pr(>|z|)
harbour_porpoise_detection_t	2.384436	0.009319	255.87	<2e-16 ***
Tensor product: Lon – Lat	6.826	6.934	299.00	<2e-16 ***
depth	1.041	1.042	12.24	0.000373 ***
hourofday	6.036	8.000	103.47	<2e-16 ***
dayofyear	7.938	8.000	83740.55	<2e-16 ***
Nall.m	13.547	15.099	36608.09	<2e-16 ***
podident	41.905	44.000	6345.34	<2e-16 ***
N (number of 10-minute blocks analysed)	**535152**			
R-squared (adjusted)	**0.329**			
Deviance explained	**30.1%**			

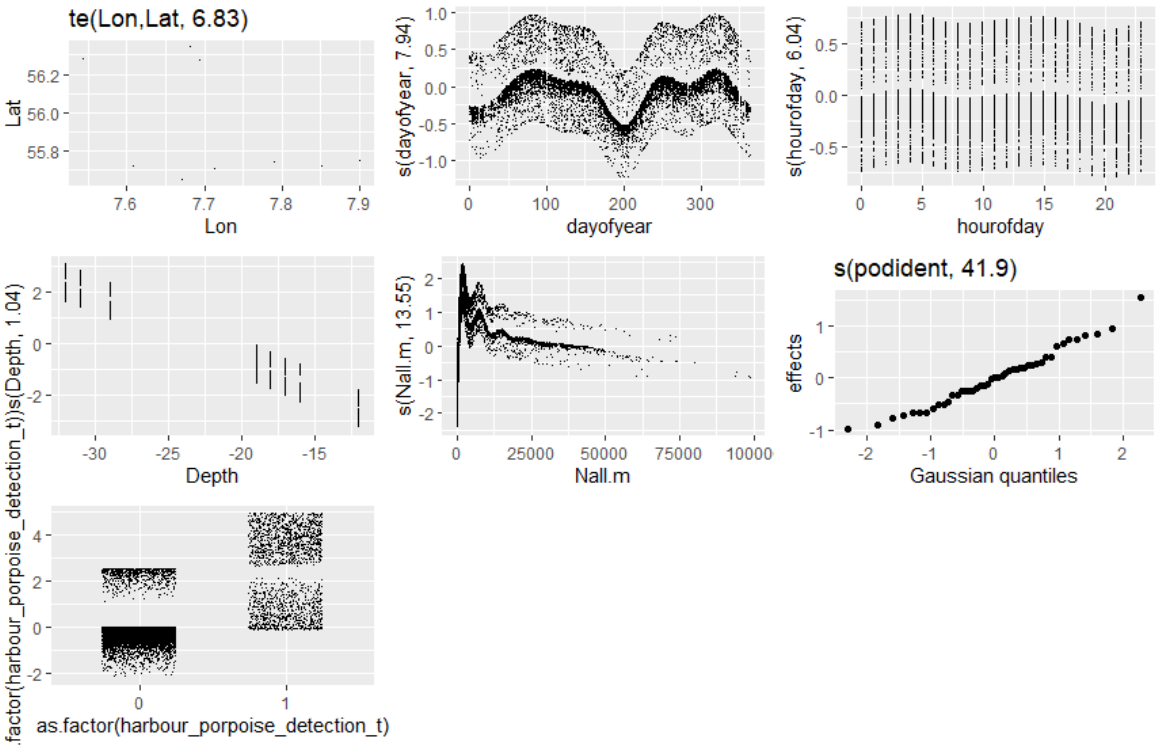

Figure 3.56 Generalised Additive Model for FPOD data to analyse which variables affect the detection rates most. For the best explanatory model, the relationship between the variables and the detection rate was shown. The plots indicate the effect of the individual variable on the detection rate. Positive values on the y-axis indicate an increase in detection rates; negative values indicate a decrease in detection rates; FPOD quality class "high".

4 DISCUSSION

4.1 Methodology

Studies comparing CPOD PAM results to simultaneously recorded visual observations (KYHN ET AL. 2012; WILLIAMSON ET AL. 2016; JACOBSON ET AL. 2017; SCHUBERT ET AL. 2019) showed that the results of acoustic monitoring roughly correspond to absolute densities. Based on a comparison of telemetric data of harbour porpoises and CPOD recordings in the Baltic Sea around the island of Rügen, Germany, a study by MIKKELSEN ET AL. (2016) showed that both datasets were correlated. The more tagged animals were present in an area the higher were the detection rates recorded in this area. In the past, PAM data recorded by using CPODs were proven to provide information on the habitat use of harbour porpoises (TOUGAARD ET AL. 2009; DIEDERICHS ET AL. 2010, 2014; BRANDT ET AL. 2011, 2018; DÄHNE ET AL. 2013; WOLLHEIM ET AL. 2013). One of the advantages of PAM is the very high temporal resolution. Data are recorded down to millisecond resolution. Therefore, even short-term patterns can be investigated. Furthermore, PODs are capable of continuously recording data, a major advantage in comparison to other survey methods like aerial or ship-based surveys. This produces large quantities of data, allowing for robust statistical analyses. In areas with a low presence of harbour porpoises, recordings of echolocation signals are the only method to possibly obtain a sufficiently large amount of data to allow for statements about the distribution and presence of harbour porpoises. Furthermore, PODs also record harbour porpoises at night, whereas aerial and ship-based surveys are limited to daylight hours. A disadvantage of the PAM method is the small spatial coverage. The detection range of a POD reaches only up to about 400 metres according to the manufacturer, and it depends on the direction into which the harbour porpoise click was sent out by the animal. Only deployment of several PODs at different locations, like in the present study, allows for information about the spatial distribution of harbour porpoises.

4.2 Comparison of CPOD and FPOD

As the production of CPODs has been stopped, only FPODs are available for new purchases in the future. A comparison of the data collected for the respective POD types is therefore essential to obtain comparable data in the future. The manufacturer of CPODs and FPODs, Chelonia Ltd, advertises the FPOD with increased sensitivity, enabling faster and better detection of auditory signals, improved detection of click trains, more detailed information on the recorded clicks, improved differentiation between detected signals (e.g. harbour porpoises and other dolphins) and other ambient sounds, resulting in fewer false positive detections compared to the CPOD (CHELONIA LTD. 2020a; b).

When analysing data from CPODs and FPODs for comparison between the two devices, only the KERNO classifier was used. Therefore, all comparisons are based on data generated using the KERNO classifier. Both PAM devices reported detections at the same time and only the number of detections varied. CPOD and FPOD data correlated significantly when analysing data in different resolutions (%DPD/d, %DPH/d, %DP10M/d, %DPM/d; see chapters 3.1.1 and 3.2.1), which means that the data sets are well comparable. However, data also significantly differed – irrespectively of using the two highest quality classes for FPODs (“high” and “moderate”; see chapter 3.1.1) or using only the highest quality class for FPODs (“high”; see chapter 3.2.1).

These results, that FPOD detection rates significantly correlate, but also significantly differ, are consistent with previously published results on CPOD/FPOD comparisons (TODD ET AL. 2023; RANSIJN ET AL. 2024; GAUGER & TAUPP 2025): GAUGER & TAUPP (2025), however, manually validated the individual harbour porpoise click trains identified by the algorithm and observed a higher degree of precision and accuracy in CPODs when comparing harbour porpoise clicks trains in the quality classes "high" and "moderate" of the two POD types, while FPODs contained more false positives: Their quality classes "high" and "moderate" together had a false positive rate of just over 60%, while the quality class "high" alone had only about 2.5%. However, the comparative study was conducted in an estuary of the Ems with low water depths and more bottom movement, so that background noise levels may have been higher, and the results of this study thus cannot be transferred to other areas such as the North Sea without further research.

In this study, thus, comparisons were conducted between CPOD (quality classes "high" and "moderate") and FPOD with both the quality classes "high" and "moderate" as well as only with the quality class "high". In summary, when using the two highest quality classes for FPODs ("high" and "moderate"), at 7 out of 9 stations, the detection rates of FPODs were higher than the detection rates of CPODs (4 of them with significant difference; see chapter 3.1.2). Previously published studies using the same settings also observed higher detection rates for FPODs than for CPODs (TODD ET AL. 2023; RANSIJN ET AL. 2024; GAUGER & TAUPP 2025).

In contrast, when using only the highest quality class for FPODs ("high"), at 6 out of 9 stations, the detection rates of CPODs were higher than the detection rates of FPODs (4 of them with significant difference; see chapter 3.2.2). A previously published study using the same settings still observed higher detection rates for FPODs than for CPODs (TODD ET AL. 2023).

Overall, the differences in detection rates between CPODs and FPODs seem to depend on several factors:

(1) Temporal scale of data analysis: The difference in detection rates between FPODs and CPODs depends on the temporal scale at which detections are analysed. While differences were not significant when analysing %DPD/d (see chapters 3.1.1 and 3.2.1), differences increase and become significant as the temporal scale of analyses increases. If correction factors for a CPOD/FPOD comparison are calculated, curve fitting (e. g. a generalised log-logistic model) seems to be better suited than linear regression to keep deviation as low as possible. However, the results of a conversion model may differ in areas with lower or higher detection rates as the curve will always fit best in the range of the majority of data points and will have the largest confidence intervals outside this range. For calculating a conversion model, which is applicable in various areas, a similar data collection in areas with lower and higher detection rates than in this study is necessary.

(2) Study area: Even at stations such as those in this study, which are all located in a similar study area, there are differences in the extent to which CPODs and FPODs have similar detection rates (see chapters 3.1.2 and 3.2.2). On some days, more harbour porpoise clicks were recorded by the FPODs, on other days more clicks by the CPODs. This difference in detection rates was also observed between other projects within the North and Baltic Sea and even between individual stations during those projects (J. Voß, personal communication, April 30, 2025). Since the time span between clicks (inter-click interval) differs

depending on the behaviour of harbour porpoises (BERGES ET AL. 2019), it would be interesting to investigate the extent to which the detection rates of CPODs and FPODs differ with regard to different click train types (e.g. foraging buzzes). TODD ET AL. (2023), for example, showed that the FPOD consistently detected more echolocation clicks and foraging buzzes than the CPOD across the temporal scales of minutes, hours, and days, as well as all train quality classification groupings. In contrast, GAUGER & TAUPP (2025) might have observed the high detection rate of FPODs using the quality classes "high" and "moderate" including the high false positive rate because of the location (estuary of the Ems) where background noise levels may have been higher. Furthermore, the water depth at which the POD is deployed might affect the comparison, but this factor has not been considered within this study.

(3) Sample size: When comparing the first (April 2023 – March 2024) and second year of monitoring (April 2024 – April 2025), similar results were observed for the individual years, but some of the differences between the two devices were less obvious (e. g. no significant difference; see chapters 3.1.3 and 3.2.3), highlighting the need for a large sample size and thus further data collection. Also, the previously published results on CPOD/FPOD comparisons are limited in their sample size: The study by TODD ET AL. (2023) is only based on a data set covering 15 months at one measuring position off Sherkin Island in Roaringwater Bay (south of Ireland), and the study by GAUGER & TAUPP (2025) is based on a total of 117 days of data recording between February and June 2023. Furthermore, the different sensitivity of the individual PODs might affect the comparison (increasing the need for a large sample size), but this factor has not been considered within this study.

(4) Detection range: For the FPOD, TODD ET AL. (2025) calculated a maximum detection distance of harbour porpoise playbacks between 400 – 500 m, and the effective detection radius (defined as distance at which the number of missed detections near the detector is equal to the number of recorded detections at greater distances, within a maximum truncation distance) was estimated at 241m (effective detection area 0.181 km²). For the CPOD, they measured a lower maximum detection distance, at 300 – 400 m, and an effective detection radius of 220 m (effective detection area 0.153 km²). Besides, for the CPOD, they found a significant difference between transects, possibly due to different ambient noise conditions (TODD ET AL. 2025). Also, TODD ET AL. (2023) showed that FPODs were less affected by environmental noise levels within the 20 to 160 kHz noise band than CPODs. We did not observe these results (see chapters 3.1.4 and 3.2.4) - presumably because our data were noise-adjusted (see chapter 2.5). The noise adjustment applied in this report stems from BioConsult SH's many years of experience and showed that with noise adjustment it is possible to compare CPOD and FPOD data quite well, as they are less affected by environmental noise.

(5) POD software used: For this report, the CPOD.exe 2.045 (applying the KERNO classifier) and FPOD.exe 1.0 software were used containing the final algorithms for click train detection. In case the algorithms of the software are modified, a new analysis of the data is necessary.

Due to the different factors affecting the differences in detection rates, and since a transition from CPODs to FPODs is imminent in the future, this study provides valuable data for comparing previous long-term CPOD datasets with future FPOD datasets. As CPODs and FPODs showed similar detection rates, both were considered suitable for detecting the presence and absence of harbour

porpoises in this area. However, the results of this study show the importance for further research into (1) the comparison of CPOD and FPOD data (including, for example, the dependence of background noise on the detection of porpoise clicks between the two types of devices), and (2) data validation to determine the extent to which the inclusion of the "moderate" quality class of FPODs leads to a high false positive rate, or whether this is only the case under certain environmental conditions. Therefore, further data collection is needed to determine which quality classes should be used in future data analyses and to calculate a conversion model which is applicable in various areas.

In summary, detection rates of CPODs and FPODs always correlated significantly, with the FPOD ("high" and "moderate") recording more detections than the CPOD ("high" and "moderate"), and with the FPOD ("high") recording less detections than the CPOD ("high" and "moderate"). High noise periods could be the only issue affecting this comparison, but our noise correction avoids this problem (see chapter 2.5). Since automatic noise reduction for FPODs is a black box, we recommend applying the two CPOD criteria also to FPODs defined based on CPOD experience in analysing various projects in the North and Baltic Seas (ROSE ET AL. 2019).

5 SUMMARY

The harbour porpoise (*Phocoena phocoena* L., 1758) is the most common cetacean in the continental shelf waters of north-western Europe. To monitor harbour porpoise distribution and abundance, Passive Acoustic Monitoring (PAM) is often used. Passive Acoustic Monitoring based on CPODs is a cost-effective method of monitoring harbour porpoise populations compared to techniques such as aerial and ship-based surveys, and thus the CPOD has become an integral part of global monitoring programs for more than a decade. However, the phasing out of CPODs following the development of the FPOD with new electronics and software, represents an important methodological change in data collection, particularly when introduced into existing monitoring programs. Many studies currently using CPODs need to ensure the long-term comparability of their data for monitoring purposes, especially with regard to the question of possible changes due to anthropogenic impacts. Therefore, this study compares the detection rates of harbour porpoises using both CPODs and FPODs.

Being equipped with a pair of a CPOD and an FPOD, nine stations were deployed in the Danish North Sea. This report presents the results of two years of acoustic monitoring (i. e. data between April 2023 and April 2025). All comparisons are based on data generated using the KERNO classifier as well as the two highest quality classes ("high" and "moderate").

Out of 6,202 days with CPOD deployment, CPOD data could be analysed from 4,428 days (71 %). Out of 6,300 days with FPOD deployment, FPOD data could be analysed from 4,048 days (64 %). Data loss was caused by loss of devices, technical problems, a quality check (days with a lot of background noise were excluded) and the exclusion of incomplete recordings within one day (e. g. on days with exchanges of PODs).

Since both PAM devices reported detections at the same time and only the number of detections varied, CPOD and FPOD data correlated significantly when analysing data at different resolutions (%DPD/m, %DPH/d, %DP10M/d, %DPM/d), meaning that the data are generally comparable. When comparing the first (April 2023 – March 2024) and second year of monitoring (April 2024 – April 2025), similar results were observed for the individual years, but some of the differences between the two devices were less obvious (e. g. no significant difference).

When comparing the two highest quality classes for CPODs ("high" and "moderate") and the two highest quality classes for FPODs ("high" and "moderate"), the FPOD generally recorded more porpoise detections than the CPOD: With the CPOD, for example, an average detection rate of 18.7 %DP10M/d was calculated, whereas with the FPOD, an average detection rate of 20.1 %DP10M/d was calculated. At 7 out of 9 stations, the detection rates of FPODs were higher than the detection rates of CPODs (4 of them with significant difference). However, there were also some exceptions with more detections at a CPOD than FPOD at 2 out of 9 POD-stations and with short time intervals at POD-stations, when more detections were recorded by the CPOD.

When comparing the two highest quality classes for CPODs ("high" and "moderate") and the highest quality class for FPODs ("high"), the CPOD generally recorded more porpoise detections than the FPOD: With the CPOD, for example, an average detection rate of 18.7 %DP10M/d was calculated, whereas with the FPOD, an average detection rate of 17.3 %DP10M/d was calculated. At 6

out of 9 stations, the detection rates of CPODs were higher than the detection rates of FPODs (4 of them with significant difference). Accordingly, the average difference between the detection rates of CPODs and FPODs does not mean that one device generally records this percentage of detections more than the other device.

Overall, based on this study, the differences in detection rates seem to depend on the temporal scale of data analysis (e. g. %DPM/d or %DPD/m) and click train categories compared. Further studies should examine effects of detection range of devices/their sensitivity, study site, sample size and POD software used.

As a transition from CPODs to FPODs is imminent in the future, but research comparing the two devices is still very limited, this study provides valuable data for comparing previous long-term CPOD datasets with future FPOD datasets. As CPODs and FPODs showed similar detection rates, both were considered suitable for detecting the presence and absence of harbour porpoises in this area. However, the results of this studies show the importance for further research into (1) the comparison of CPOD and FPOD data (e.g. the dependence of background noise on the detection of porpoise clicks between the two types of devices), and (2) data validation (e.g. the extent to which the inclusion of the “moderate” quality class of FPODs leads to a high false positive rate, or whether this is only the case under certain environmental conditions).

In summary, detection rates of CPODs and FPODs always correlated significantly, with the FPOD (“high” and “moderate”) recording more detections than the CPOD (“high” and “moderate”), and with the FPOD (“high”) recording less detections than the CPOD (“high” and “moderate”). High noise periods could be the only issue affecting this comparison, but our noise correction avoids this problem. Since automatic noise reduction for FPODs is a black box, we recommend applying the two CPOD criteria also to FPODs defined based on CPOD experience in analysing various projects in the North and Baltic Seas.

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