HARBOUR PORPOISE PRESENCE AT KATTEGATT SYD OFFSHORE WINDFARM SITE FROM DECEMBER 2020 TO DECEMBER 2023

Final Report

Technical Report from DCE – Danish Centre for Environment and Energy No. 309 2024

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Abstract: A three-year monitoring study was conducted in a future offshore windfarm area, Kattegatt Syd, in Swedish Waters, Southern Kattegat. Harbour porpoises were monitored by means of passive acoustic monitoring with CPODs for three full years at five stations. The monitoring showed that in general detection rates in the area were lower than at the Natura 2000 site *Lilla Middelgrund* to the north and higher than at the Natura 2000 site *Stora Middelgrund & Röda Bank* to the south, when comparing to monitoring results from the Swedish national monitoring program. Across all three years the lowest detection rates of harbour porpoises were observed in November-February, and the highest levels were observed in March-May and August-September. This final report includes three years of data and supplements the report *Kattegatt Syd Offshore Windfarm - Effects of pile driving, gravity foundations and sediment spill on marine mammals.*

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Preface

Monitoring of harbour porpoises at the potential offshore windfarm site Kattegatt Syd was carried out from December 2020 - December 2023. The study was commissioned by Vattenfall Vind A/B, Sverige, and this report summarizes the results. The work was carried out by DCE – Danish Center for Environment and Energy, Aarhus University in the role as a consultant for Vattenfall Vind A/B. The report includes all three years of data and thus supplements the technical report *Kattegatt Syd Offshore Windfarm -Effects of pile driving, gravity foundations and sediment spill on marine mammals (Kyhn et al., 2021)*, wherein all background information and earlier data can be found along with assessments of impact on marine mammals. This report and recommendations herein do not replace the assessments and recommendations in the above-mentioned report. This report is an update of the report *Harbour porpoise presence at Kattegatt Syd Offshore Windfarm site from monitoring in December 2020 – December 2022* and contains an update of the data collected.

This report contains a description of the temporal presence of harbour porpoises at Kattegatt Syd offshore windfarm as recorded over three full years (December 2020 - December 2023) and the variation is reported as harbour porpoise detection rates measured as Detection Positive Minutes (DPM) over monthly and diurnal timescales. The data are compared to nearby Swedish National monitoring of harbour porpoises.

Sammenfatning

Marsvin er almindeligt forekommende i det sydlige Kattegat og tilhører Bælthavspopulationen, som er listet som *Livskraftig* (LC) på de nationale rødlister i Sverige og Danmark, selvom de seneste bestandsoptællinger har vist en drastisk nedgang. For at undersøge tilstedeværelsen af marsvin og i hvilken grad marsvin i området vil blive forstyrret af etablering af en vindmøllepark i det udpegede område under både konstruktion og driftsfase, blev der udført passiv akustisk monitering (PAM) af marsvin med fem PAM stationer i området i tre år fra december 2020 til december 2023. Dette er den afsluttende rapport, som sammenfatter resultaterne fra hele perioden og således bygger videre på de to præliminære rapporter fra hhv. 2021 og 2022.

Resultaterne viser, at marsvin er almindelige i Kattegatt Syd offshore wind farm-området og forekommer på et forholdsvist stabilt niveau, dog med variation stationerne imellem. Niveauet af marsvinedetektioner i området ligger midt mellem de to nærmeste svenske moniteringsområder ved hhv. *Lilla Middelgrund* (2 PAM stationer) og *Stora Middelgrund & Röda Bank* (2 PAM stationer).

Generelt lå niveauerne i Kattegatt Syd lidt højere i 2021 og 2023 end i 2022. I alle tre år var der et årligt mønster med et lavpunkt i januar-februar, og en stigning i marts-maj, ligesom der blev registreret en stigning igen i august-september i 2021 og 2022. Her adskilte 2023 sig ved at forblive på et relativt højt niveau på gennemsnitligt 60-430 DPM (DPM = Detektions-Positive Minutter = antal minutter med registrerede marsvin) per dag per måned fra oktober og året ud, dog med individuelle forskelle mellem stationerne over de tre år.

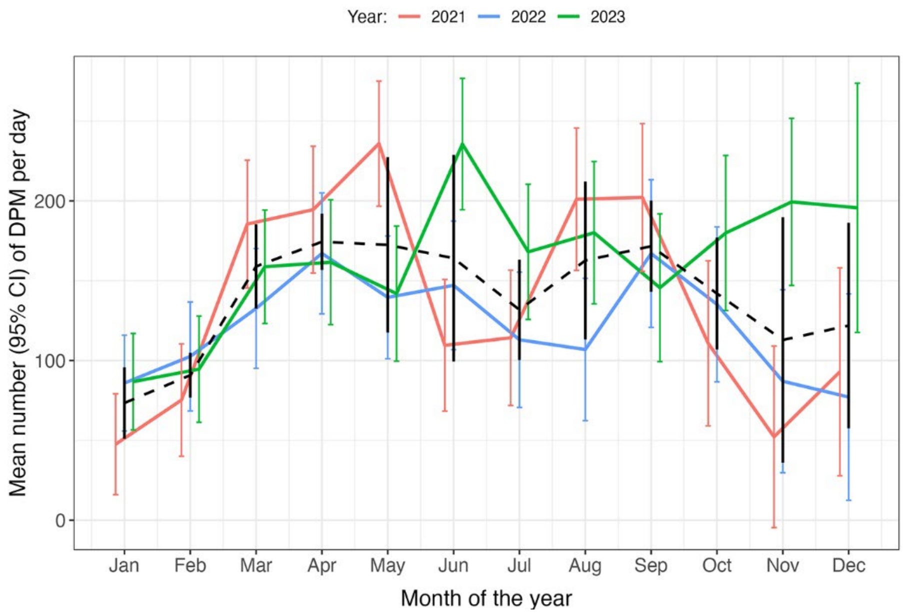
De fem stationer fulgte overordnet set hinanden i løbet af monitoreringsperioden og registrerede tilstedeværelse af marsvin i ca. samme størrelsesorden. Dog var der nogle udsving på enkelte stationer i kortere perioder.

Fra moniteringen begyndte og frem til september 2023 var den laveste tilstedeværelse i perioden november-februar med et gennemsnit pr måned for alle fem stationer tilsammen på ca. 40-100 DPM per dag. November og december 2023 skilte sig imidlertid ud derfra med gennemsnit omkring 200 DPM per dag (Figur 1), hvorfor der reelt kun i januar-februar blev registreret en tilstedeværelse under 100 DPM per dag per måned set over alle tre års monitorering (Figur 3.9).

Modellering af undervandsstøj fra nedhamring af vindmøllefundamenter viste, at støjen spreder sig dobbelt så langt væk om vinteren, som om sommeren. Altså til fire gange så stort et areal. Set som gennemsnit over de fem stationer og de tre år, var der ca. 1,4 gange så mange detektioner af marsvin i området om sommeren (april - september), som om vinteren (oktober - marts). Færrest marsvin vil derfor blive påvirket, hvis konstruktionsfasen ligger om sommeren, fremfor om vinteren.

Af de to nærliggende Natura 2000-områder, *Lilla Middelgrund* og *Stora Middelgrund & Röda Bank*, som blev overvåget af de svenske myndigheder, fulgte *Stora Middelgrund & Röda Bank* tendenserne for Kattegatt Syd offshore windfarm området alle årene blot på et lidt lavere niveau. *Lilla Middelgrund* lå i stort set hele perioden væsentligt over de andre områder (Figur 3.9).

Figur 1. Gennemsnitligt antal DPM/dag/måned for hhv. 2021, 2022 og 2023 med 95% konfidensintervaller udregnet over alle stationer. Den stiplede sorte linje viser gennemsnit for alle år tilsammen. At konfidensintervallet for december 2023 er noget større end i de øvrige år, skyldes kombinationen af stor spredning imellem de fem stationer samt færre data for denne måned, idet udstyret blev taget op 11. december 2023. Bemærk, at idet figuren er baseret på gennemsnit af modellerede output, afviger den på nogle punkter lidt fra gennemsnittet beregnet ud fra rådata (se Figure 3.9).



Summary

Harbour porpoises are common in the southern part of Kattegat and belong to the Belt Sea Population, which is listed as *Least Concern* on the national red lists of both Sweden and Denmark although recent abundance estimates from 2020 and 2022 has shown a severe decline. To understand the temporal presence of harbour porpoises in the area of the planned offshore windfarm passive acoustic monitoring (PAM) of harbour porpoises was conducted with five PAM stations in the area for three consecutive years from December 2020 to December 2023. This final report summarizes results from the entire period and thus build on the two preliminary reports from 2021 and 2022, respectively.

Data from the three years' monitoring show that harbour porpoises are common in the area, though with pronounced variation among the individual stations.

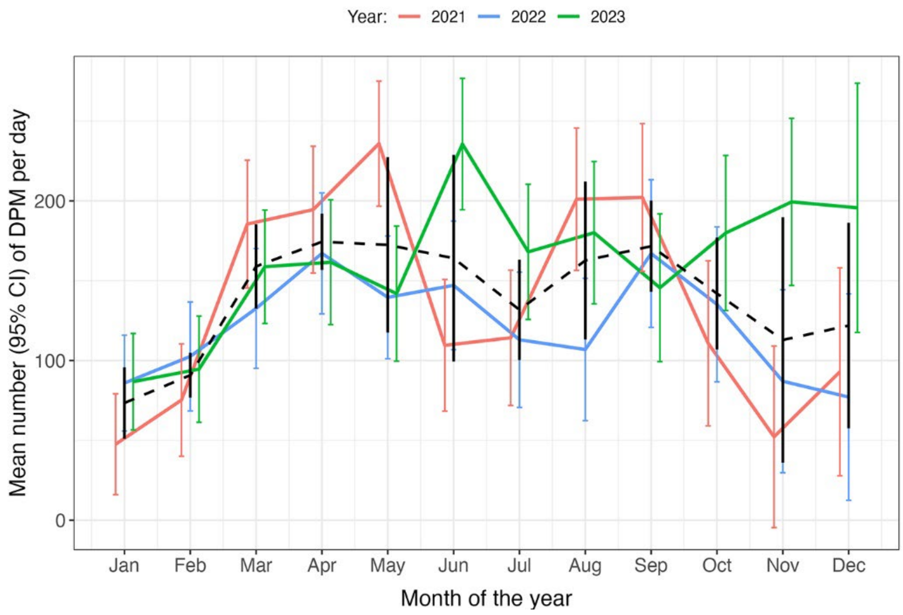
In general, detection rates in Kattegatt Syd offshore windfarm were slightly higher in 2021 and 2023 than in 2022. In all three years, detection rates increased from a low in January-February through March-May, and increased again in August-September (2021 and 2022).Year three, 2023, differed somewhat as detection rates remained at a relatively high level in October-December with between approximately 60 and 430 DPM (DPM = Detection Positive Minutes = number of minutes in which harbour porpoise clicks were registered) per day per month on average from October and throughout the year with individual differences between the stations (Figure 3.9).

From the time the monitoring began and until September 2023, the lowest detection rates were seen in the period November-February with an average of approx. 40-100 DPM per day per month for all five stations together. However, November and December 2023 stood out with an average of around 200 DPM per day (Figure 2). Thus, only January-February had an average detection rate below 100 DPM per day per month seen across all stations and all three years of monitoring.

Modelling shows that underwater piling noise spreads twice as far in winter than in summer due to the sound propagation differences, i.e. to four times the area. On average across stations and years there were approximately 1.4 times as many harbour porpoise detections in summer (April – September) than in winter (October – March). This means that more animals will be affected during construction in winter, than if construction takes place in summer.

Of the two nearby Natura 2000 sites, *Lilla Middelgrund* and *Stora Middelgrund & Röda Bank*, which were monitored by the Swedish authorities, *Stora Middelgrund & Röda Bank* followed the trends of Kattegatt Syd offshore windfarm in all three years, just at a slightly lower level. *Lilla Middelgrund* was well above the other areas for almost the entire period (Figure 3.9).

Figure 2. Average number of DPM/day/month for 2021, 2022 and 2023 with 95% confidence intervals calculated across all five stations. The dashed black line shows monthly averages for all years combined. The confidence interval for December 2023 is larger due to the combination of a large spread between the five stations and less data for this month, as the equipment was retrieved 11th December 2023. Note that, as the figure is based on averages of model output, it deviates slightly on some points from the average calculated from raw data (Figure 3.9).



1 Background

Vattenfall Vind A/B has gotten permission to establish an offshore wind farm between the Natura 2000 sites *Lilla Middelgrund* and *Stora Middelgrund & Röda Bank* in Swedish Kattegat (Figure 1.1). The offshore wind farm site is called Kattegatt Syd. This report provides information on the monthly and diurnal pattern of harbour porpoise *(Phocoena phocoena)* presence in the area as documented with three years of passive acoustic monitoring in the area. All background information pertaining to harbour porpoises and the windfarm, including assessment of disturbance effects, can be found in the report *Kattegatt Syd Offshore Windfarm -Effects of pile driving, gravity foundations and sediment spill on marine mammals* (Kyhn et al., 2021).

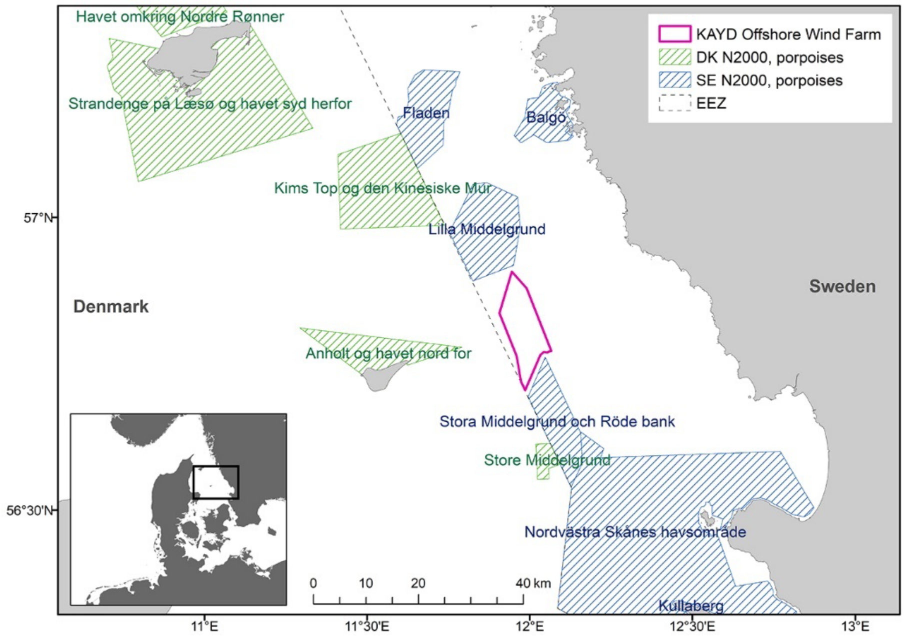


Figure 1.1. Map of Swedish and Danish Natura 2000 sites appointed for harbour porpoises in southern Kattegat. The proposed offshore wind farm site is shown with pink. KAYD offshore windfarm = Kattegatt Syd.

1.1 Harbour porpoises in Kattegat

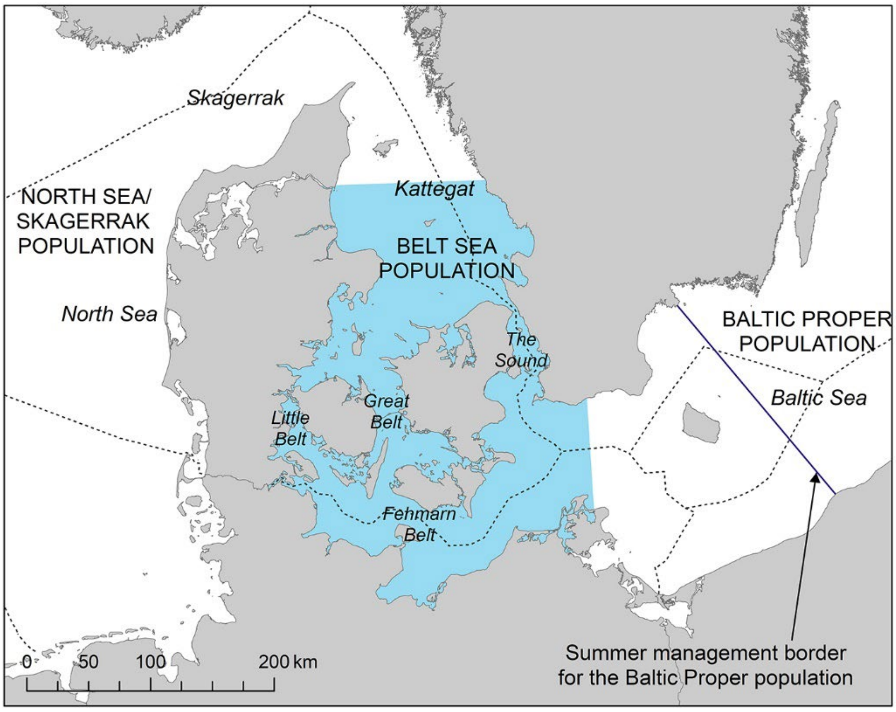
The harbour porpoise is the most common cetacean in Swedish Waters and is present throughout Kattegat. It is listed in Annex II and IV of the EU Habitats Directive (92/43/EEC), Annex II of the Bern convention, Annex II of the Bonn convention and Annex II of the Convention on the International Trade in Endangered Species (CITES). Furthermore, it is included in descriptor 1 "Biodiversity" of the Marine Framework Strategy Directive (European Commission, 2008/56/EY) aiming for a good environmental status. Harbour porpoises are also covered by the terms of the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS, a regional agreement under the Bonn Convention) and by HELCOM (The Helsinki Commission; protection of the marine environment of the Baltic Sea from all sources of pollution). The EU Habitats Directive requires habitat protection for a range of habitat types and for species listed in Annexes I and II, as well as strict protection is enforced for a range of species listed in Annex IV. The harbour porpoise is listed in both Annex II and IV, which means that it is protected throughout its range, as well as with additional protection within special areas of conservation that has been designated for harbour porpoises (Natura 2000 sites).

There are three different populations of harbour porpoises inhabiting Swedish Waters: The North Sea (including Skagerrak), the Belt Sea (southern Kattegat, the Belt Sea and the western Baltic) and Baltic Proper population (Celemín et al., 2023; Galatius et al., 2012; Wiemann et al., 2010). Management areas have been established for the Belt Sea population (Sveegaard et al., 2015) and the Baltic Proper population (Carlén et al., 2018) (Figure 1.2). The harbour porpoises inhabiting the southern Kattegat, relevant to the proposed Kattegatt Syd offshore wind farm, belongs mainly to the Belt Sea population although individuals from the North Sea population may also be present. The management area of the Belt Sea population includes the Belt Sea, the Sound, southern Kattegat, and the western Baltic Sea. The abundance of harbour porpoise in the Belt Sea area has been estimated in 1994 ((Hammond et al., 2021), revised from Hammond et al. (2002)), 2005 ((Hammond et al., 2021), revised from Hammond et al. (2013)), 2012 (Viquerat et al., 2014), 2016 (Hammond et al., 2021), 2020 (Unger et al., 2021) and 2022 (Gilles et al., 2023) with SCANS and mini-SCANS surveys. However, due to differences in survey strata only the latter four surveys (from 2012 and on) can be directly compared.

The survey in 2012 estimated the Belt Sea population to 40,475 harbour porpoises (95% CI = 25,614-65,041; CV = 0.24, density = 0.79) and in 2016 the estimate was even higher with 42,324 individuals (95% CI = 23,368-76,658; CV = 0.30, density = 0.79). Recent estimates, however, have been lower. In 2020 the Belt Sea population was estimated to 17,301 individuals (95% CI = 11,695-11,695; CV = 0.20, density = 0.41) and the latest survey in 2022 (SCANS-IV) estimated 14,403 harbour porpoises (95% CI = 9,555-21,769; CV = 0.21, density = 0.34). The estimated densities of the Belt Sea population have varied over the years, but the latest trend analysis covering the years 2005-2020 showed a negative trend of -1.2% p.a. (95% CI: -3.8% – 4.4%) calculated across the SCANS and mini-SCANS surveys of that period (Gilles et al., 2023). Although not statistically significant it does indicate a declining population, which is supported by SCANS IV survey results.

The national red lists of the harbour porpoise in Sweden and Denmark do not yet reflect the negative trend in population size of the Belt Sea population, as they were published prior to the two most recent estimates. Both thus determine the Belt Sea population as Least Concern.

Figure 1.2. Map of management areas for the three Swedish populations of harbour porpoises. The North Sea population (white) overlaps with the Belt Sea population (blue) in southern Kattegat.



The density of harbour porpoises varies within the Belt Sea population area (Sveegaard et al., 2011) and protected Special Areas of Conservation (or Natura 2000 sites) have been designated in high density areas. Within Swedish waters there are three Natura 2000 sites appointed for harbour porpoises close to the Kattegatt Syd offshore wind farm: to the north at 1 km distance, *Lilla Middelgrund* (SE0510126) of 17840.2 ha and to the south at 1 km distance, *Stora Middelgrund & Röda Bank* (SE0510186) with a combined area of 11,410 ha. Further to the southeast, there is another large area *Nordvästra Skånes havsområde* (SE0420360) of 134,240.8 ha also appointed for harbour porpoises (Figure 1.1). There are also Natura 2000 sites appointed for harbour porpoises in Danish waters. The Natura 2000 site *Store Middelgrund* (No. DK00VA250) comprises a 2,094-ha area south of the offshore wind farm area. To the west hereof there are *Kims Top & the Chinese Wall* and *Anholt og havet nord for*.

1.2 Monitoring of harbour porpoises in the potential offshore windfarm Kattegatt Syd

To quantify the use of the offshore wind farm site for harbour porpoises and to obtain data on temporal monthly pattern of presence of harbour porpoises in the potential offshore wind farm Kattegatt Syd, Vattenfall Vind A/B decided to conduct a monitoring study to inform the EIA. The collected data were to be compared with data from the Swedish monitoring to get an impression of the importance of the area for harbour porpoises with respect to the nearby Natura 2000 sites. Because the monitoring data also provides data on the monthly pattern of presence in the area, the data are also relevant for finding the period where the fewest harbour porpoises will be affected in the area during construction of the windfarm. This information is necessary for assessing the principle of *Best Environmental Practice,* defined as "the application of the most appropriate combination of environmental control measures and strategies" (OSPAR Commission).

2 Methods

Harbour porpoises are the only species in the Belt Sea emitting characteristic and distinct high frequency narrow band clicks during echolocation and communication (Kyhn et al., 2013; Møhl and Andersen, 1973). Moreover, harbour porpoises emit clicks almost constantly (Wisniewska et al., 2016) and they are therefore ideal to study via passive acoustic monitoring (PAM) (Kyhn, 2010). In PAM, acoustic dataloggers are deployed to detect and record clicks and noise from the surroundings. For this study, the CPOD (Chelonia Ltd.) was chosen as it is used in both the Swedish and Danish national monitoring of harbour porpoises, making comparisons straight forward.

The Kattegatt Syd offshore wind farm site is comparable in size to the Danish Natura 2000 sites and the density of harbour porpoises is also similar (Unger et al., 2021). In the Danish monitoring program NOVANA, five stations have proven sufficient to statistically clarify differences between monitoring years (Hansen and Høgslund, 2023). For this study, the aim was to find differences between months and years. As the expected level of harbour porpoise detection rates were likely to be similar to the other areas of the Belt Sea population, five stations were deemed sufficient to analyse for variation between months of a full year or several years. The positions of the PAM stations were chosen randomly in a specific grid with respect to environmental parameters influencing harbour porpoise presence. This approach was chosen in order not to bias the data collection, but to get the actual level of presence in the area across different environmental drivers. The distribution of dataloggers in the Kattegatt Syd offshore wind farm site and in the closest Swedish Natura 2000 areas is shown in Figure 2.1.

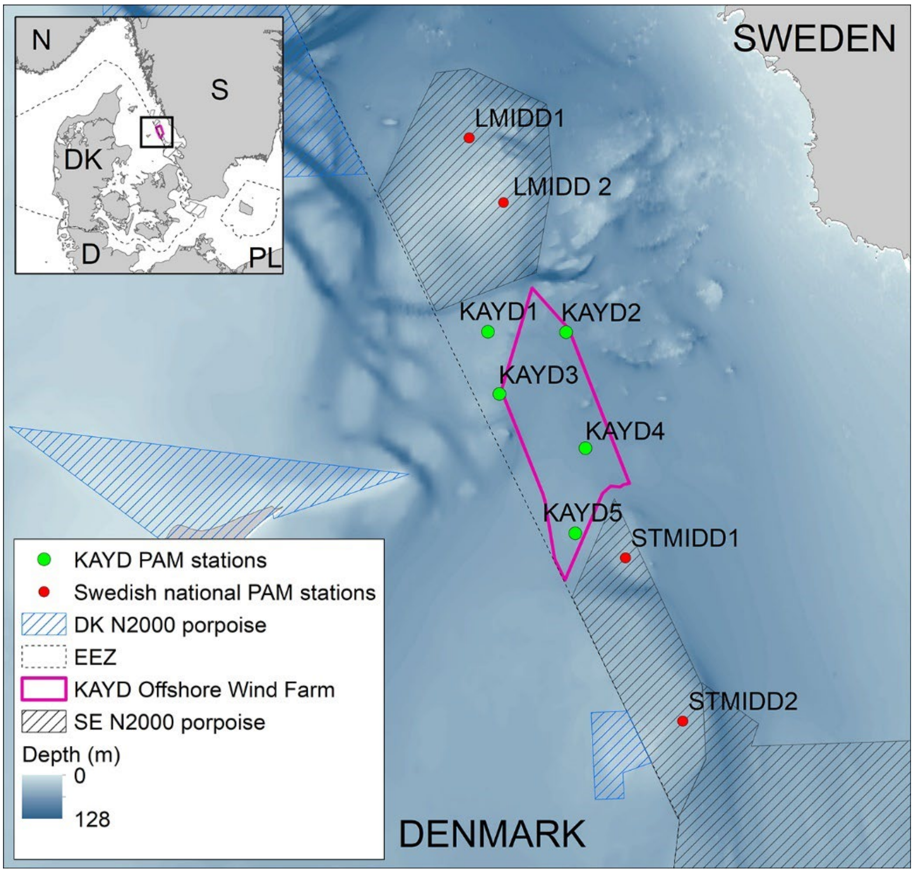


Figure 2.1. Position of the five passive acoustic monitoring (PAM) stations in the Kattegatt Syd offshore wind farm (green dots). Red dots denote the Swedish national monitoring stations. LMIDD= Lilla Middelgrund, STMIDD= Store Middelgrund & Röda Bank.

The CPODs were factory calibrated prior to the fieldwork. This makes it possible to compare data from the different stations directly and to move individual CPODs among the five stations during servicing. If a CPOD was trawled, it was not redeployed before it had been re-calibrated, as its sensitivity may be affected by the rather brutal treatment during trawling and later stranding. Only units meeting the factory standards were used in the study.

The CPODs were deployed using an acoustic releaser (Sub Sea Sonics AR-60, type, San Diego) attached to two hessian bags filled with stones as an anchor. Upon an acoustic signal send through a hydrophone submerged from the service vessel, two iron links melt via electrolytic erosion, and the releaser and CPOD float to the surface, where they are caught from the vessel. Two trawl floats are attached above the CPOD to ensure positive buoyancy and hence flotation in case the station is trawled. From 2023, all units were equipped with a satellite transmitter using ARGOS location system to be able to track and collect trawled stations.

As protection against trawling, a large surface buoy was placed next to each PAM station within some 50 meters. Permission for deployment of the buoys were obtained from the Swedish authorities. As station KAYD4 kept loosing its surface buoy, while the CPOD remained in place at the bottom, it was decided to not redeploy a new surface buoy in 2023. The most likely cause for the loss of the surface buoy was that it was hit by a vessel, and not trawled as that would have led to loss of the scientific equipment as well.

The service vessels used were *R/V Aurora* owned by Aarhus University and *Skoven*, privately owned. From the last service in 2021 and onwards *Skoven* was used. Permission to sail within 12 nm of the Swedish coast was applied for at the Swedish maritime authorities, but they deemed it irrelevant as only one station was at the boarder of the 12 nm zone. Also, permission to deploy the buoys was obtained.

A service interval of two months was chosen to ensure as high a data return as possible in an area with a high trawling intensity. The schedule was deployment in December 2020. Hereafter, service in February, April, June, August, October, December every year, until final retrieval in December 2023.

2.1 Data analysis

The CPOD stores so called CP1 files, which are analysed via the custom-made software CPOD.exe v 2.048 (Chelonia Ltd., 29th March 2022). With this software CP3 files are extracted with the Kerno classifier (unpublished algorithm) to find click trains. Click trains are grouped into narrow band high frequency origin, e.g. harbour porpoises, dolphins or boat sonars. For each category, click trains are categorised into either '*high*', '*medium*' or '*low*' probability of originating from the stated source. Harbour porpoise is the only narrow-band high-frequency species in Kattegat. Thus, only narrow band high frequency click trains were selected and only when categorized with a *high* or *moderate* probability of originating from a narrow band high frequency species. This methodology is used in both the Swedish and Danish monitoring of harbour porpoises. Since the harbour porpoise is the only species emitting this click type in the Baltic region, it is fair to assume that the narrow band high frequency click trains in the CP3 files originated from harbour porpoises. The Danish monitoring data is further analysed with an extra algorithm (Hel1) that was developed for extreme low-density areas such as the Baltic Proper, with which this monitoring data is compared. Hel1 reduces the likelihood of false positives. This is important in areas of very low density, such as the Baltic Proper. In high density areas, such as Kattegat and the Danish Straits there is hardly any difference in data analysed with the Hel1 classifier or only with the Kerno classifier. In a test dataset from the present study at Kattegatt Syd offshore wind farm, the Hel1 classifier removed app. 0.16% of the minutes with harbour porpoise clicks, which means that it has no effect when analysed on a daily basis. Thus, the data from Kattegatt Syd are comparable to both Swedish and Danish monitoring data.

Following extraction of click trains from harbour porpoises in the high and moderate categories, number of minutes with these click trains were exported from CPOD.exe on an hourly basis. The unit *Detection Positive Minutes* (DPM) *per hour* was then analysed in R to obtain daily and monthly patterns of harbour porpoise detection rates at the five stations.

2.2 Statistical analysis

To quantify variation in diurnal harbour porpoise detection rates, data collected by the five PAM stations were analysed using Generalized Additive Mixed Models (GAMMs). DPM per hour was fitted as the response variable using a log function (Poisson family). Hour and month were fitted as fixed effects as well as interactive smoothing terms to assess diurnal variation in harbour porpoise presence for each month of the year. Here we used a cyclic cubic regression spline to ensure that DPMs at hour 01:00 matched with hour 00:00. Month and Year were fitted as nested random variables to account for unbalanced data over time. A separate model was constructed for each PAM station to limit any spatial autocorrelation in the data and to avoid use of overly complex models with 3-way interactions. Temporal autocorrelation in the data was modelled by fitting a continuous time covariate autocorrelation structure of order 1 (corCAR1) using hour as the time covariate and Julian day as grouping variable.

To quantify differences in harbour porpoise presence between months, data collected by the five PAM stations were analysed using linear mixed-effects models (LME). In the LME, DPM per day was fitted as the response variable and month and year as well as their interaction were fitted as fixed effects. Station ID and Year were fitted as nested random variables to account for unbalanced data. Temporal autocorrelation in the data was modelled by fitting a continuous time covariate autocorrelation structure of order 1 (corCAR1) using Julian day as the time covariate and station ID nested within Year as grouping variables. Based on the results of the LME, a *post hoc* Tukey Honest Significance Difference test was used to determine differences in the mean DPM/day between all months across 3 years of monitoring.

To estimate if the overall presence of harbour porpoises differed between years, monthly averages of DPM/day from all stations were used in an ANOVA with year as the fixed effect. Based on the results of the ANOVA, a *post hoc* Tukey Honest Significance Difference test was used to determine differences across 3 years of monitoring.

3 Results

3.1 Servicing and data loss

The five stations were monitored from 27th November 2020 – 10th December 2023. At first servicing on 11th February 2021, two PAM units were lost and a third CPOD had malfunctioned (i.e. not recorded). Upon evaluation it was decided to move station 3 and 5 to locations with less trawling activity, as deemed by evaluation of VMS data obtained from the Danish authorities (Figure 3.1). Later on, the borders of the offshore wind farm were moved to have a 1 km distance to the nearest Natura 2000 sites, why the new stations therefore were placed on the boarder of the offshore wind farm. On the second servicing on 11th April 2021, three PAM units were gone along with two surface buoys. Hereafter, all stations were generally in place, however, see Figure 3.3 for a full overview. At three servicings, the CPOD had malfunctioned; KAYD1A, KAYD5F and KAYD4L.

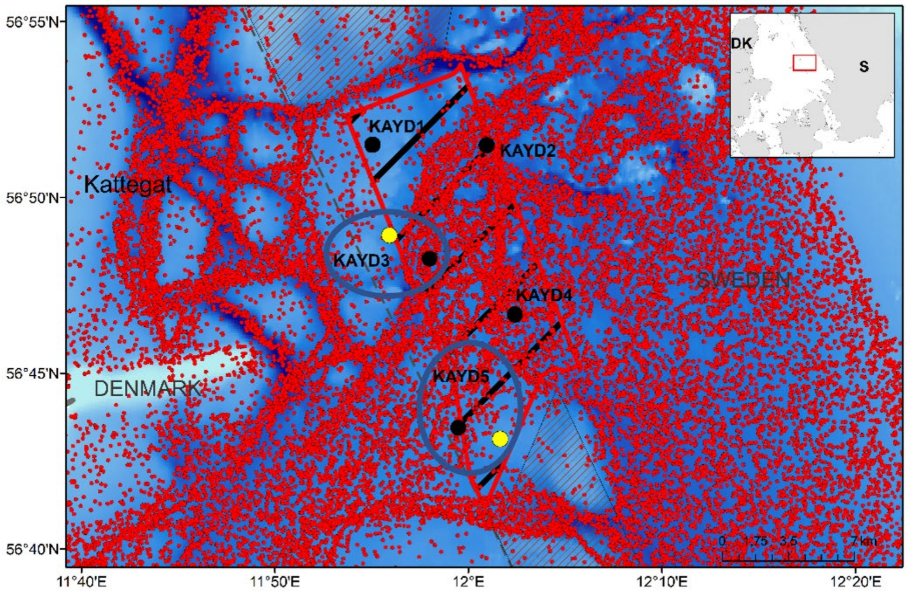


Figure 3.1. Station KAYD3 and KAYD5 were moved as they were trawled during the first two deployments. Original stations are in black and moved stations are in yellow. See inside the blue circles. The red dots are VMS data from 2020 signifying trawling. Please note: The potential wind farm area (red line) was reduced after production of this figure. See Figure 2.1 for the updated area.

All, but one lost PAM unit, were eventually recovered and data could be retrieved. Trawling events are clear from the data analysis as the angle of the CPOD changes markedly along with an immense increase in and saturation of background noise (Figure 3.2). Prior to analysis data were cut, so that only full days were included. For example, on the day of deployment on 1st December, only data from 2nd December at 00:01 onwards was used. The same for the date of retrieval on 30th December, only data from 29th December until 00:00 was included. The same goes for trawling events. Thus, a full day per servicing is lost as well as the days following trawling.

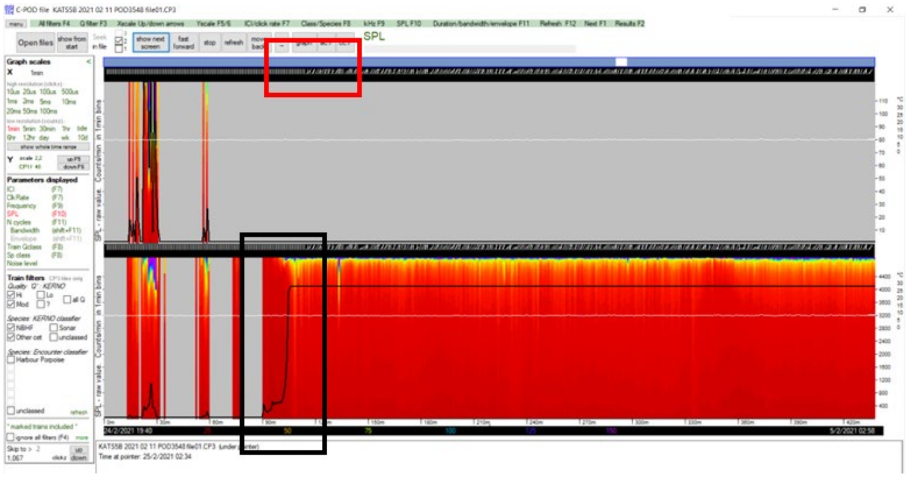


Figure 3.2. Example of a CPOD that has been trawled. Deployment KAYD 2B. Notice how the background noise increases and saturates (red colour in lower graph inside the black rectangle) along with a change in angle (red rectangle in upper graph).

3.2 Data

A summary of the covered periods is shown in Figure 3.3. Also, four deployments, KAYD01A, KAYD05F, KAYD04L and KAYD01O, contained no data as the CPODs malfunctioned. In KAYD4L one battery had corroded and there was no data. It is very clear that the fishermen adapted to the presence of the surface buoys over the course of the study as trawling was mostly a problem during the first year.

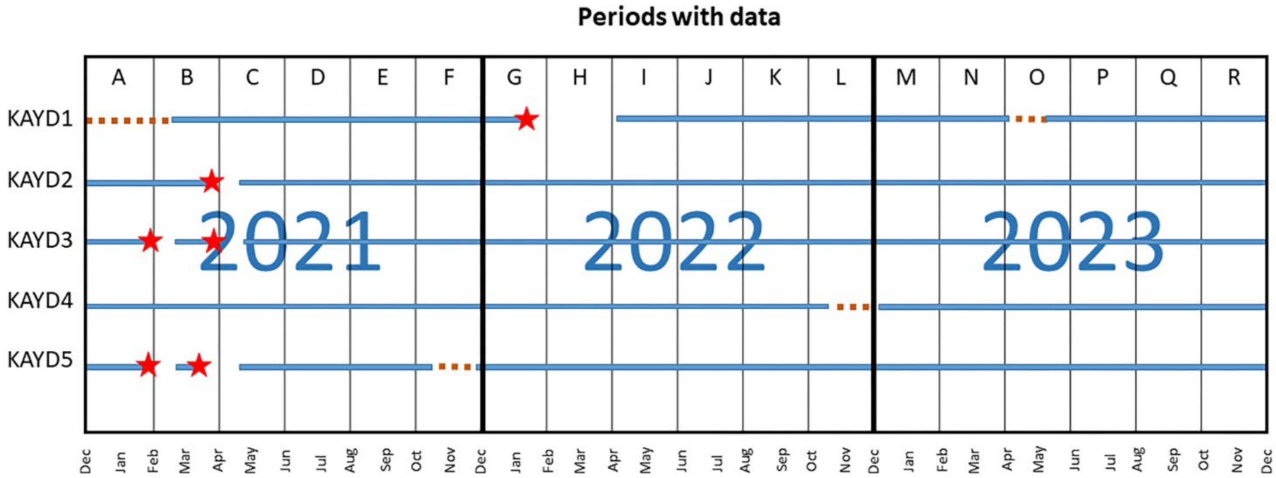
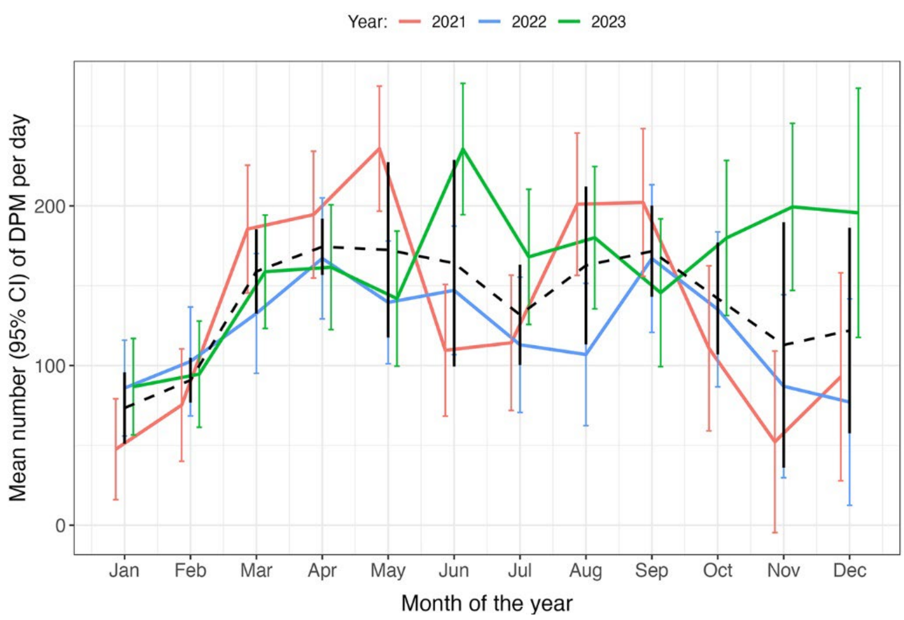


Figure 3.3. Periods with data during consecutive two-months deployment periods between December 2020 and December 2023. The PAM stations were trawled multiple times during the first year causing loss of data as shown with the empty periods following red stars. On four occasions the CPODs had not recorded (KAYD1A, KAYD5F, KAYD4L and KAYD1O). This is shown with broken orange lines. The day of deployment/retrieval is omitted from the analysis. The deployment periods are signified by the letters A-R.

3.3 Diurnal and monthly patterns in detection rate

Monthly patterns in detection rates across all five stations are shown in Figure 3.4. In general, harbour porpoise detection rates at the five stations varied both between the stations and throughout the year, however the area was used by harbour porpoises all year round.

Figure 3.4. Average number of DPM/day/month for 2021, 2022 and 2023 with 95% confidence intervals calculated across all five stations. The dashed black line shows monthly averages for all years combined. The confidence interval for December 2023 is larger due to the combination of a large spread between the five stations and less data for this month, as the equipment was retrieved 11th December 2023. Note that, as the figure is based on averages of model output, it deviates slightly on some points from the average calculated from raw data (Figure 3.9).



The variation in harbour porpoise detection rates across the three years of monitoring appeared substantial (Figure 3.5 and Figure 3.7). There were, however, only statistically significant differences between 2021 and 2023 in June and November, where 2023 had double or more detection positive minutes per day on average in June and November (Table 7.1, Table 7.2, Table 7.3, Figure 7.1).

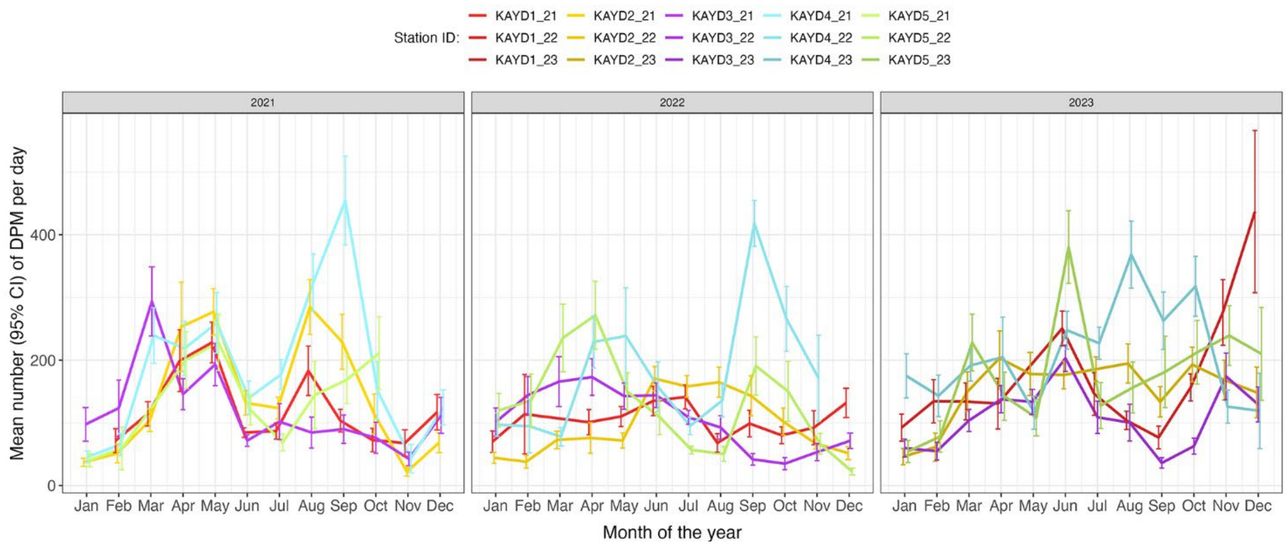


Figure 3.5. Monthly pattern in detection rates at the five monitoring stations at Kattegatt Syd offshore wind farm in 2021-2023. The y-axis shows mean number of detection positive minutes (DPM) per day per station as a function of month (x-axis) across the three years of monitoring. Identical stations have a nuance of the same colour across the years.

Across all three years, there were no statistical difference when analyzed as averages across all months and stations (Figure 3.6, Table 7.4). However, overall, 2023 have a higher level of detections than in the other years.

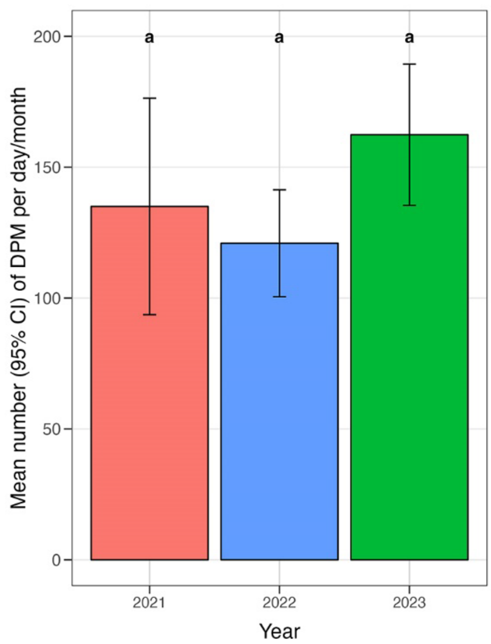


Figure 3.6. Mean number of DPM per day per month for each monitoring year. The identical letters above the blocks signify that the months are not significantly different (Table 7.4)

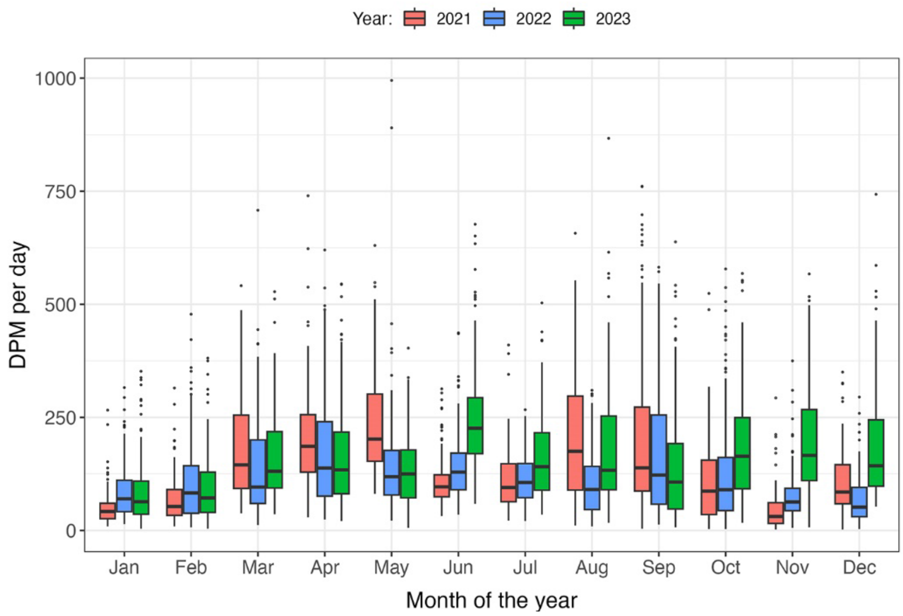


Figure 3.7. Monthly pattern in detection rates at the five monitoring stations at Kattegatt Syd offshore wind farm. The plot shows median number of detection positive minutes (DPM) a day per month across all stations. The box contains 50 % of DPM. The box and whiskers are 95% of the DPM. The individual dots are the remaining 5% of DPM.

In Figure 3.7 more details in the variation between stations can be seen. Although not significantly different from a statistical point of view, there seem to be trends across the three years (Figure 3.5). In 2021 and 2022 the highest harbour porpoise detection rates were observed in March - May and in August - September. Rates in these months were also high in 2023, but in contrast to the previous years, no clear decrease was observed during summer or autumn.

The lowest level of detection rates in 2021 and 2022 was during November to February, whereas 2023 had high detection rates throughout November and December (Figure 3.4). Thus, the months with fewest detections (> 100 DPM per day on average) across all three years were January and February.

Detection positive minutes (DPM) per hour were analysed using generalized additive mixed models (GAMMS) to estimate diurnal patterns in detection rates across months of the year at the five PAM stations in Kattegatt Syd offshore wind farm. The results are shown in Figure 3.8. As light is likely an im-portant driver of behaviour of both harbour porpoises and their prey, the period of sunrise and sunset for each month is shown in Figure 3.8.. The statistical results of the GAMMs are presented in Appendix 1, Table 7.1 (2021), Table 7.2 (2022), Table 7.3 (2023). The output of the GAMMs show that DPM varies non-linearly over the hours of the day in all months and stations. Moreover, detection rates appeared highest during the dark hours and lowest during daylight hours, indicating a diurnal behaviour of porpoises in the area. KAYD5 differed, however, as the highest detection rates were found during daytime in almost all months of the year.

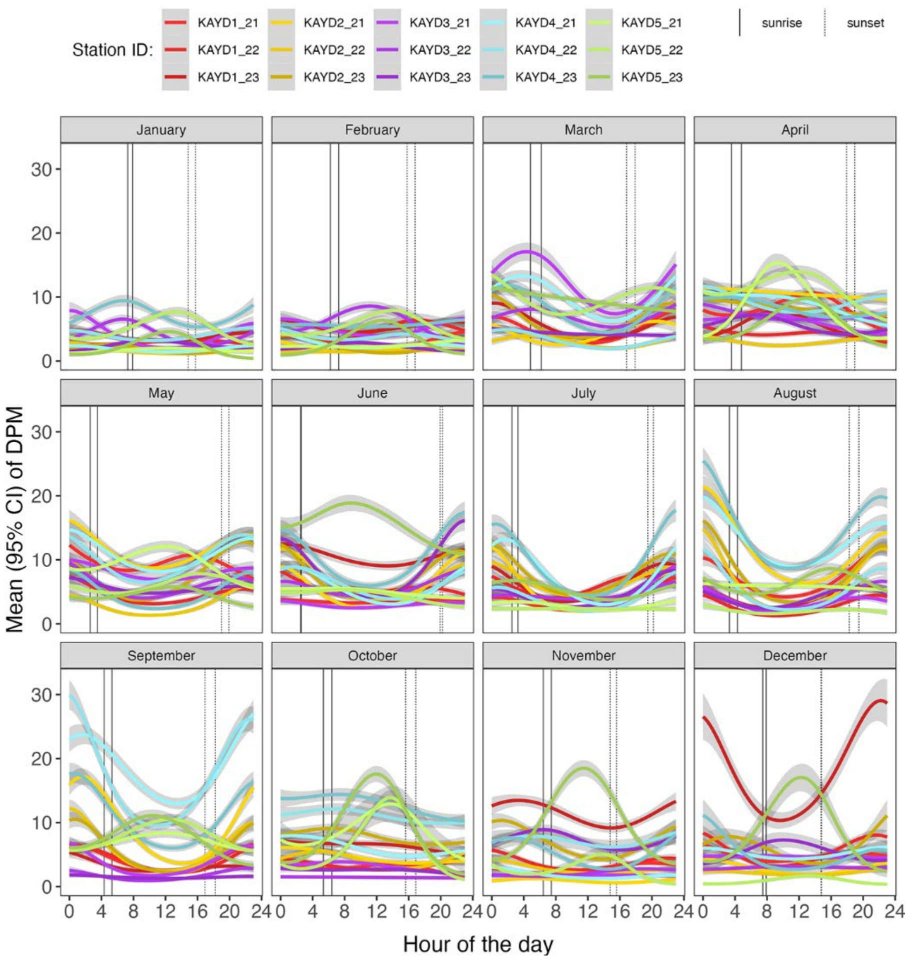


Figure 3.8. Diurnal and monthly pattern in harbour porpoise detection rates (DPM per hour) at the five monitoring stations at Kattegatt Syd offshore wind farm (2021-2023). The y-axis shows mean number of detection positive minutes per hour as a function of time of the day (x-axis) across the twelve months of monitoring. The solid vertical lines indicate earliest and latest times of sunrise that month. Vertical broken lines indicate earliest and latest times of sundown. Note that station KAYD3 and KAYD5 was moved to more trawl-safe locations on 11th April 2021. The same station has a nuance of the same colour in the three years, e.g. red nuances for station KAYD1.

The combined analyses of the passive acoustic monitoring data from 2021-2023 at hourly and monthly scales (Figure 3.4 to Figure 3.8 and statistics in Appendix 1) suggest that harbour porpoise detection rates in the area were highest between March - September during 2021 and 2022 with a temporary significant decline during the summer months: June - July. However, the pattern changed in 2023 where detection rates were high from March - December without a decline during the summer months – in fact an increase was seen here.

Harbour porpoise detection rates appeared to be lowest in January - February and despite generally quite different patterns between the three years, the period January-April was very similar with a continuous increase in DPM from January onwards.

In 2021, a simultaneous temporal and spatial monitoring study was conducted for a different potential windfarm, namely Galatea (OX2 AB) by AquaBiota. The data was collected at four stations inside an area covering Kattegatt Syd offshore wind farm and directly bordering the two nearby Natura 2000 sites, and hence a little larger than Kattegatt Syd offshore wind farm. The data was collected from August 2020 to September 2021 and showed monthly means in DPM across the four stations (Stensland et al., 2021). The monthly detection rates were lower than in the present study but with a similar peak in March and lower detection rates in August-September, Detection levels during winter was not as low as in the present study. There is a potential explanation to the difference in levels observed in the same year/area between the two studies. Stensland et al. 2021 intentionally chose to place all the stations on hardbottom substrate as they retrieve their stations by hauling. In the present study, we placed the stations with a stratified random design to include different bottom substrates. It is likely that harbour porpoises for some reason do not prefer the hardbottom substrate, and that the study hence unintentionally negatively biased their data sampling.

The overlap began in December, so the period August-November 2020 was not overlapping.

3.4 Kattegatt Syd offshore wind farm data in a wider Kattegat context

In order to examine the relative importance of the Kattegatt Syd compared to surrounding areas, data from this study were compared with Swedish monitoring data from the nearest stations, i.e. the PAM stations at *Stora Middelgrund & Röda Bank* (STMIDD) and *Lilla Middelgrund* (LMIDD).

The locations of these stations are shown in Figure 2.1. National Swedish monitoring data are made available by Havs- och vattenmyndigheten och SMHI, and can used and downloaded free of charge from a webpage (https://sharkweb.smhi.se/hamta-data/) even for commercial use as in this study.

There are three years of national Swedish monitoring data available; from May 2019 to April 2023. The data from this study are compared to the national monitoring in Figure 3.9. In general, during most months, the detection rates through all three years were higher at *Lilla Middelgrund* compared to Kattegatt Syd and *Stora Middelgrund & Röda Bank*. It should be noted that although the stations KAYD5 and STMIDD1 are situated within few km of distance of each other, there is substantial differences in harbour porpoise detection rates, which might be due to differences in e.g. depth, substrate or prey availability.

It is worth noticing that overall detection rates are lower in 2022, at both the Swedish monitoring stations (Figure 3.9) and at Kattegatt Syd (Figure 3.6) which matches the general low level of harbour porpoise abundance observed during SCANS IV in the Belt Sea area.

There are some variations between the years for the two stations at *Lilla Middelgrund*, with a high number of DPM in all of 2021 and lower but still relatively stable detection rates in 2022. In December 2022 the detection rates at LMIDD1 (LMIDD2 data not available) were rather high, compared to Kattegatt Syd stations (Figure 3.9).

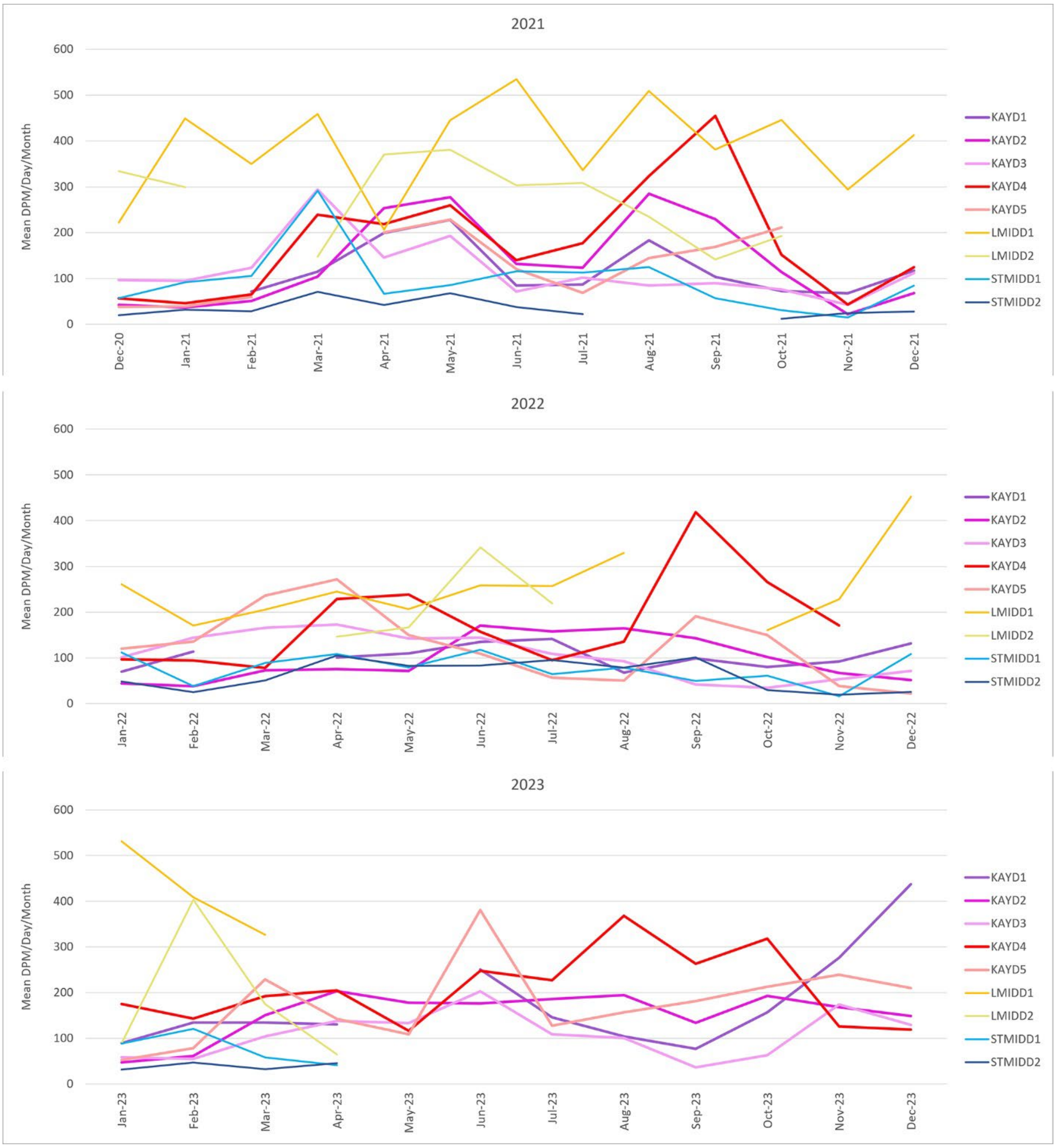


Figure 3.9. Monthly pattern in detection rates at the five monitoring stations at Kattegatt Syd offshore wind farm in 2021-2023 compared with the two closest Swedish monitoring stations from January 2020 to December 2023 Yellow colours signify *Lilla Middelgrund*, blue colours signify *Stora Middelgrund & Röda Bank*, and red-purple colours signify Kattegatt Syd monitoring. Please see Figure 2.1 for position of the Swedish national monitoring stations. The Swedish national monitoring in the two areas ended April 2023.

In contrast to the KAYD stations, harbour porpoise detection rates increased at *Lilla Middelgrund* during winter 2022-2023.

Although at a lower level, *Stora Middelgrund & Röda Bank* south of the Kattegatt Syd area followed the pattern of the KAYD stations most months in 2021 and 2022. Thus, detection rates decreased in October-November and increased in March. But in contrast to the KAYD stations, detection rates increased in December these years. In 2023 detection rates increased through late winter months but decreased in March and April which contrasts with the KAYD stations but follow the *Lilla Middelgrund* stations, although at a much lower level.

4 Discussion

4.1 Harbour porpoise detection rates at Kattegatt Syd offshore wind farm

The harbour porpoise detection rates in the Kattegatt Syd offshore wind farm, measured as average DPM per day per month per station, fell in between those of the northern Natura 2000 site, *Lilla Middelgrund* and the southern site, *Stora Middelgrund & Röda Bank*. Of these, *Lilla Middelgrund* had the highest detection rates in almost all months of the monitoring period (Figure 3.9). There was a decrease in detection rates at all stations (Swedish national monitoring stations, as well as at the Kattegatt Syd stations), in 2022. The decrease was not tested statistically for the Swedish monitoring data, and for Kattegatt Syd, the results were not significant. Nevertheless, a decrease was also documented during the SCANS IV surveys (Gilles et al., 2023) that saw the lowest abundance of harbour porpoises in the Belt Sea area to date, however since the area was not covered by aerial surveys in 2021 and 2023, we cannot know if the results would have been mirrored in those results in those years. This could be due to random fluctuations in harbour porpoise distribution, as in general, long data series are needed to document seasonal patterns in presence in a specific area. However, the population growth for the Belt Sea population has been documented to be negative since 2016, which could suggest that there have been some detrimental changes in their environment. The driver behind the decrease is not known. However, with a population decrease as large as is documented for this population, it may be that the distribution of harbour porpoises has also shifted, so that animals to a larger degree concentrate in the best available habitats in a given season per year. The relative abundance of harbour porpoises in the Kattegatt Syd area was higher in 2023 than in the previous years and for a larger part of the year.

After delivery of the first draft of this report we learned that geophysical surveys have been conducted simultaneously in the Kattegatt Syd OWF as well as in the cable corridor. It has not been possible to evaluate how the geophysical surveys affected the collected data. It is however known that harbour porpoises avoid geophysical surveys up to several kilometers. The collected data may hence present a minimum presence in the periods where geophysical surveys were carried out.

Most harbour porpoise detections were registered during the dark hours except at station KAYD5, where highest detection rates were during daytime in almost all months of the monitoring period. This must be related to some specific conditions at this station, either in terms of prey availability or animal behavior other than foraging.

At the southern Natura 2000 site *Stora Middelgrund & Röda Bank* detection rates were lower than at Kattegatt Syd offshore wind farm. As discussed in the result section above, OX2 AB conducted a similar monitoring study in the same area, which they call Galatea (Stensland et al., 2021). The study overlapped in time from December 2020 to September 2021. The data were collected with the same methodology, however the Galatea CPOD positions were deliberately chosen to be on hard-bottom substrate, whereas the present study chose PAM positions following a random but fixed grid. The reason for doing so is to ensure that the data are representative of the area, and not just of a specific bottom substrate. The detection rates at Galatea were lower than in this study, suggesting that the hard-bottom substrate is not preferred by harbour porpoises or their prey and that Stensland et al. unintentionally might have biased their data negatively.

4.2 Seasonal pattern in detection rates

In general, harbour porpoises move around throughout the year (Teilmann et al., 2008) and their temporal presence and abundance is important to consider in relation to establishment of offshore wind farms to disturb as few individuals as possible. Following the principle of *Best Environmental Practice*, application of the most appropriate combination of environmental control measures and strategies must be considered when disturbing the environment (OSPAR Convention). One aspect of this, is minimizing the disturbance of harbour porpoises, but many other factors must be considered as well.

Considering harbour porpoises alone, this means that construction of the offshore windfarm should be carried out at the time of the year when the fewest animals will be disturbed and/or when the impact will be smallest. This can be achieved in two ways: 1) by conducting the construction work at the time of the year where sound propagation properties are least favorable for long-range transmission in order to disturb as small an area as possible and thereby as few animals as possible, and/or 2) by conducting the construction work when the fewest harbour porpoises are present in the disturbed area. Furthermore, the impact on the animals will be smallest in the period where the affected animals are least sensitive. The sensitivity of porpoises and the impact on the harbour porpoise population in the Kattegatt Syd offshore wind farm following Best Available Technology was assessed as minor based on the first year of data (Kyhn et al., 2021) and adding a layer of mitigation in terms of Best Environmental Practice is therefore unlikely to further reduce the assessment for harbour porpoises. It may be deemed that other environmental aspects will be more important than lowering the effect on harbour porpoises in order to live up to the Best Environmental Practice principle. Nevertheless, the aspect of when there are fewest harbour porpoises in the area is considered in the following.

At Kattegatt Syd offshore wind farm, data from the first two years of monitoring showed that the period with the fewest porpoises present is likely from November until February (Figure 3.5), where detection rates were lowest. When the 2023 data are included, the period with the fewest animals is reduced to January-February. To make a simple approach to when the fewest animals would be disturbed, we here use the mean values per month across the three years (Figure 3.4), which is the period November to February.

Winter is also the time of year where sound propagation properties are most favorable for long-range transmission, as was evident in the sound modelling performed for the Environmental Impact Assessment (EIA) conducted for the Kattegatt Syd offshore windfarm (Kyhn et al., 2021). In the EIA, the summer period was therefore recommended as construction period, as fewest harbour porpoises were expected to be affected due to shorter noise transmission distances, and since harbour porpoises were evaluated as being equally sensitive all year. In the EIA, noise propagation for construction of the windfarm by piling was modelled with use of Best Available Technology noise abatement with Double Big Bubble Curtains and Hydrosound Dampeners. The difference between worst case (December) and best case (July) was a factor 4 in area.

The dilemma is therefore: If winter is the period with the fewest harbour porpoises present, will construction in the winter period then result in more harbour porpoises being affected than during the summer period, because noise spreads to four times the area?

Since the data obtained with PAM only provides a relative estimate of abundance, it is not possible to calculate the total difference in number of affected animals. However, the relative difference can be approximated by differences in number of DPM per day/month for the summer and winter periods. Since the construction period is deemed to last up to six months it is relevant to evaluate across seasons, summer and winter.

When seen across all stations and all three years the mean DPM/day for summer months (April-September) was 164.3 DPM/day (sd=119.7, se = 2.3) and for winter months (October-March) it was 116.1 DPM/day (sd=102.7, se = 2.1). Thus, for a ballpark estimation, there is about 1.4 times as many DPM per day on average over summer (April-September) as during winter (October-March). If we assume, unjustified, that this corresponds to 1.4 times as many individuals, this means that more individuals will be affected in the winter season where the noise spreads a factor four further than in summer.

This calculation is based on the maximum sound velocity in winter. In reality the difference is smaller between the seasons, as the sound velocity changes gradually across the seasons with temperature and changes in the salinity. Furthermore, the calculation is based on the average for 'winter' and 'summer' across the three years and the five stations. In reality, however, there are large differences in detection rates between months and stations.

4.3 Data loss

During the period November 2020-May 2021 five PAM stations were lost and in January 2022 one was lost. The winter and spring period coincides with the season for bottom trawling for lobsters in the area. It appeared that we did loose CPODs due to incidental trawling despite that all stations were clearly marked with a large surface buoy, as well as the position of each buoy had the required permits and had been communicated to the fishery community by the Swedish authorities.

To enhance chances of retrieving trawled equipment all dataloggers were equipped with satellite transmitters from December 2022. Satellite transmitters are active only when at the surface. It is interesting to notice that the fishery seems to have realized the presence of the surface buoys and scientific equipment after a year's presence. That is something to note for future studies.

5 Conclusion

The detection rates of harbour porpoises in the Kattegatt Syd offshore wind farm area were monitored during three full years (Dec. 2020 – Dec. 2023) with five PAM stations.

The diurnal pattern in the Kattegatt Syd offshore wind farm area showed that harbour porpoises were more active in the dark hours, except at one station.

The monthly pattern in harbour porpoise detection rates showed that harbour porpoises had the highest level of activity in the Kattegatt Syd offshore wind farm area in the periods March through May and August through September. However, 2023 was somewhat different, as detection rates remained high from March to December.

Overall, lowest rates were detected during November-February when seen as an average across all three years.

The harbour porpoise detection rates were lower at all stations (Kattegatt Syd stations and national monitoring) in 2022 than in the two other years.

The detection rates in the Kattegatt Syd offshore wind farm are in between the two closest Natura 2000 areas monitored by the Swedish national monitoring program, where *Lilla Middelgrund* has higher detection rates and *Stora Middelgrund & Röda Bank* has lower detection rates.

The present results showed a similar annual pattern in 2021 and 2022. However, for 2023 the pattern changed, emphasising the importance of prolonged monitoring to document general patterns of presence in relation to large scale construction projects at sea.

Combining monthly pattern in detection rates measured as average DPM/month across all five stations in winter and summer with the results of the bi-seasonal modelling of piling noise propagation performed by NIRAS for the EIA (Kyhn et al., 2021), suggest that fewer individuals will be disturbed by construction of the Windfarm in summer than in winter.

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7 Appendix 1

Table 7.1. Output of the Generalized Additive Mixed Models (GAMMs) used to estimate diurnal patterns in the 2021 data. For each station and month patterns were estimated using hourly aggregated Detection Positive Minutes (DPM). A p-value less than 0.05 indicates that DPM varied during the 24-hour cycle in that month for that station.

Station	Parameter	Estimate	Std. Error	t value	p-value
KS1_21	(Intercept)	0,977	0,078	12,49	<0.001
	HOUR	0,006	0,006	1,017	0,309
	MONTH3	0,454	0,090	5,022	0,000
	MONTH4	1,264	0,089	14,232	<0.001
	MONTH5	1,546	0,086	18,068	<0.001
	MONTH6	0,286	0,096	2,983	0,003
	MONTH7	-0,047	0,095	-0,492	0,623
	MONTH8	0,747	0,087	8,627	<0.001
	MONTH9	0,416	0,092	4,526	<0.001
	MONTH10	0,456	0,101	4,531	<0.001
	MONTH11	-0,052	0,102	-0,51	<0.001
	MONTH12	0,750	0,092	8,164	<0.001
	Smoothing term	**edf**	**Ref.df**	**F**	**p-value**
	s(HOUR):MONTH2	1,908	2	30,741	<0.001
	s(HOUR):MONTH3	1,978	2	135,44	<0.001
	s(HOUR):MONTH4	1,952	2	50,668	<0.001
	s(HOUR):MONTH5	1,957	2	34,266	<0.001
	s(HOUR):MONTH6	1,35	2	2,737	0,018
	s(HOUR):MONTH7	1,971	2	99,115	<0.001
	s(HOUR):MONTH8	1,988	2	244,068	<0.001
	s(HOUR):MONTH9	1,975	2	112,728	<0.001
	s(HOUR):MONTH10	1,869	2	12,236	<0.001
	s(HOUR):MONTH11	1,881	2	13,895	<0.001
	s(HOUR):MONTH12	1,902	2	21,269	<0.001

Station	Parameter	Estimate	Std. Error	t value	p-value
KS2_21	(Intercept)	0,559	0,079	7,034	<0.001
	HOUR	-0,014	0,006	-2,219	0,03
	MONTH2	0,198	0,108	1,834	0,07
	MONTH3	0,860	0,106	8,127	<0.001
	MONTH4	1,885	0,086	21,823	<0.001
	MONTH5	1,954	0,085	23,046	<0.001
	MONTH6	0,923	0,090	10,256	<0.001
	MONTH7	1,098	0,089	12,273	<0.001
	MONTH8	1,883	0,084	22,292	<0.001
	MONTH9	1,555	0,086	18,071	<0.001
	MONTH10	1,051	0,093	11,28	<0.001
	MONTH11	-0,780	0,139	-5,629	<0.001
	MONTH12	0,522	0,100	5,223	<0.001

	Smoothing term	edf	Ref.df	F	p-value
	s(HOUR):MONTH1	1,82	2	14,61	<0.001
	s(HOUR):MONTH2	1,91	2	25,17	<0.001
	s(HOUR):MONTH3	1,94	2	35,62	<0.001
	s(HOUR):MONTH4	0,00	2	0	0,696
	s(HOUR):MONTH5	1,97	2	108	<0.001
	s(HOUR):MONTH6	1,99	2	271,83	<0.001
	s(HOUR):MONTH7	1,99	2	344,55	<0.001
	s(HOUR):MONTH8	1,99	2	418,28	<0.001
	s(HOUR):MONTH9	2,00	2	447,02	<0.001
	s(HOUR):MONTH10	1,91	2	21,4	<0.001
	s(HOUR):MONTH11	1,86	2	10,75	<0.001
	s(HOUR):MONTH12	1,94	2	42,46	<0.001

Station	Parameter	Estimate	Std. Error	t value	p-value
KS3_21	(Intercept)	1,436	0,056	25,635	<0.001
	HOUR	-0,011	0,004	-2,748	0,006
	MONTH2	0,177	0,083	2,146	0,032
	MONTH3	0,979	0,071	13,885	<0.001
	MONTH4	0,565	0,079	7,143	<0.001
	MONTH5	0,712	0,067	10,635	<0.001
	MONTH6	-0,293	0,082	-3,559	<0.001
	MONTH7	-0,340	0,074	-4,566	<0.001
	MONTH8	-0,083	0,077	-1,082	0,279
	MONTH9	-0,184	0,075	-2,451	0,014
	MONTH10	-0,174	0,084	-2,066	0,039
	MONTH11	-0,851	0,091	-9,393	<0.001
	MONTH12	0,130	0,071	1,822	0,068
	Smoothing term	**edf**	**Ref.df**	**F**	**p-value**
	s(HOUR):MONTH1	1,98	2	113,25	<0.001
	s(HOUR):MONTH2	1,89	2	24,97	<0.001
	s(HOUR):MONTH3	1,98	2	82,17	<0.001
	s(HOUR):MONTH4	1,76	2	10,36	<0.001
	s(HOUR):MONTH5	1,88	2	23,39	<0.001
	s(HOUR):MONTH6	1,78	2	10,48	<0.001
	s(HOUR):MONTH7	1,98	2	156,78	<0.001
	s(HOUR):MONTH8	1,96	2	64,33	<0.001
	s(HOUR):MONTH9	1,98	2	172,64	<0.001
	s(HOUR):MONTH10	1,78	2	8,82	<0.001
	s(HOUR):MONTH11	0,43	2	0,35	0,195
	s(HOUR):MONTH12	0,43	2	0,32	0,223

Station	Parameter	Estimate	Std. Error	t value	p-value
KS4_21	(Intercept)	0,598	0,076	7,858	<0.001
	HOUR	0,000	0,006	0,071	0,943
	MONTH2	0,588	0,101	5,844	<0.001
	MONTH3	1,584	0,084	18,940	<0.001
	MONTH4	1,829	0,084	21,691	<0.001
	MONTH5	1,817	0,082	22,043	<0.001
	MONTH6	1,065	0,088	12,100	<0.001
	MONTH7	1,288	0,085	15,171	<0.001
	MONTH8	1,937	0,081	23,832	<0.001
	MONTH9	2,225	0,080	27,795	<0.001
	MONTH10	1,262	0,088	14,371	<0.001
	MONTH11	0,222	0,108	2,062	0,039
	MONTH12	1,024	0,090	11,340	<0.001
	Smoothing term	**edf**	**Ref.df**	**F**	**p-value**
	s(HOUR):MONTH1	1,84	2	16,595	<0.001
	s(HOUR):MONTH2	1,88	2	22,789	<0.001
	s(HOUR):MONTH3	1,99	2	118,699	<0.001
	s(HOUR):MONTH4	1,52	2	4,342	0,004
	s(HOUR):MONTH5	1,97	2	91,025	<0.001
	s(HOUR):MONTH6	1,98	2	142,033	<0.001
	s(HOUR):MONTH7	1,99	2	307,605	<0.001
	s(HOUR):MONTH8	1,99	2	233,953	<0.001
	s(HOUR):MONTH9	1,99	2	219,289	<0.001
	s(HOUR):MONTH10	1,94	2	31,93	<0.001
	s(HOUR):MONTH11	1,84	2	16,529	<0.001
	s(HOUR):MONTH12	1,85	2	17,921	<0.001

Station	Parameter	Estimate	Std. Error	t value	p-value
KS5_21	(Intercept)	0,386	0,106	3,631	<0.001
	HOUR	0,010	0,008	1,220	0,222
	MONTH2	0,317	0,152	2,088	0,037
	MONTH4	1,624	0,126	12,932	<0.001
	MONTH5	2,053	0,114	18,040	<0.001
	MONTH6	1,376	0,117	11,752	<0.001
	MONTH7	0,595	0,124	4,788	<0.001
	MONTH8	1,406	0,113	12,418	<0.001
	MONTH9	1,586	0,116	13,650	<0.001
	MONTH10	1,993	0,162	12,326	<0.001

Smoothing term	edf	Ref.df	F	p-value
s(HOUR):MONTH1	1,65	2	6,787	<0.001
s(HOUR):MONTH2	1,12	2	1,791	0,043
s(HOUR):MONTH4	1,99	2	248,224	<0.001
s(HOUR):MONTH5	1,97	2	80,609	<0.001
s(HOUR):MONTH6	1,31	2	2,551	0,021
s(HOUR):MONTH7	1,89	2	17,903	<0.001
s(HOUR):MONTH8	0,00	2	0	0,618
s(HOUR):MONTH9	1,90	2	27,17	<0.001
s(HOUR):MONTH10	1,90	2	22,387	<0.001

Table 7.2. Output of the Generalized Additive Mixed Models (GAMMs) used to estimate diurnal patterns in the 2022 data. For each station and month patterns were estimated using hourly aggregated Detection Positive Minutes (DPM). A p-value less than 0.05 indicates that DPM varied during the 24-hour cycle in that month for that station.

Station	Parameter	Estimate	Std. Error	t value	p-value
KS1_22	(Intercept)	1,078	0,064	16,948	<0.001
	HOUR	-0,001	0,005	-0,218	0,828
	MONTH2	0,439	0,106	4,141	<0.001
	MONTH4	0,658	0,084	7,856	<0.001
	MONTH5	0,576	0,078	7,379	<0.001
	MONTH6	0,797	0,077	10,332	<0.001
	MONTH7	0,769	0,076	10,057	<0.001
	MONTH8	-0,271	0,086	-3,142	0,002
	MONTH9	0,231	0,081	2,868	0,004
	MONTH10	0,144	0,084	1,714	0,087
	MONTH11	0,213	0,082	2,595	0,009
	MONTH12	0,608	0,076	8,012	<0.001
	Smoothing term	**edf**	**Ref.df**	**F**	**p-value**
	s(HOUR):MONTH1	1,674	2	5,294	0,002
	s(HOUR):MONTH2	1,882	2	12,156	0,000
	s(HOUR):MONTH4	1,808	2	7,529	0,000
	s(HOUR):MONTH5	1,961	2	72,45	<0.001
	s(HOUR):MONTH6	1,921	2	31,14	<0.001
	s(HOUR):MONTH7	1,968	2	53,346	<0.001
	s(HOUR):MONTH8	1,979	2	125,322	<0.001
	s(HOUR):MONTH9	1,978	2	112,73	<0.001
	s(HOUR):MONTH10	1,874	2	22,24	<0.001
	s(HOUR):MONTH11	1,958	2	69,004	<0.001
	s(HOUR):MONTH12	1,982	2	138,539	<0.001

Station	Parameter	Estimate	Std. Error	t value	p-value
KS2_22	(Intercept)	0,720	0,071	10,171	<0.001
	HOUR	-0,012	0,006	-2,226	0,026
	MONTH2	-0,491	0,109	-4,507	<0.001
	MONTH3	0,249	0,093	2,669	0,008
	MONTH4	0,317	0,092	3,444	0,001
	MONTH5	0,103	0,090	1,146	0,252
	MONTH6	1,116	0,080	13,953	<0.001
	MONTH7	1,174	0,080	14,625	<0.001
	MONTH8	0,933	0,079	11,760	<0.001
	MONTH9	1,019	0,081	12,650	<0.001
	MONTH10	0,600	0,087	6,853	<0.001
	MONTH11	0,388	0,093	4,169	<0.001
	MONTH12	-0,051	0,099	-0,517	0,605
	Smoothing term	**edf**	**Ref.df**	**F**	**p-value**
	s(HOUR):MONTH1	1,889	2	25,452	<0.001
	s(HOUR):MONTH2	0,762	2	0,811	0,121
	s(HOUR):MONTH3	1,954	2	34,708	<0.001
	s(HOUR):MONTH4	1,892	2	26,327	<0.001
	s(HOUR):MONTH5	1,982	2	151,439	<0.001
	s(HOUR):MONTH6	1,990	2	259,653	<0.001
	s(HOUR):MONTH7	1,975	2	113,473	<0.001
	s(HOUR):MONTH8	1,996	2	609,485	<0.001
	s(HOUR):MONTH9	1,992	2	359,117	<0.001
	s(HOUR):MONTH10	1,963	2	44,098	<0.001
	s(HOUR):MONTH11	1,914	2	31,376	<0.001
	s(HOUR):MONTH12	1,777	2	10,930	<0.001

Station	Parameter	Estimate	Std. Error	t value	p-value
KS3_22	(Intercept)	1,228	0,057	21,628	<0.001
	HOUR	0,014	0,004	3,172	0,002
	MONTH2	0,658	0,079	8,321	<0.001
	MONTH3	0,549	0,070	7,811	<0.001
	MONTH4	0,765	0,069	11,032	<0.001
	MONTH5	0,705	0,069	10,151	<0.001
	MONTH6	0,246	0,072	3,423	0,001
	MONTH7	0,083	0,076	1,094	0,274
	MONTH8	-0,275	0,077	-3,579	<0.001
	MONTH9	-0,812	0,094	-8,616	<0.001
	MONTH10	-0,796	0,091	-8,703	<0.001
	MONTH11	-0,791	0,095	-8,306	<0.001
	MONTH12	-0,186	0,082	-2,270	0,023

Smoothing term	edf	Ref.df	F	p-value
s(HOUR):MONTH1	1,981	2	77,777	<0.001
s(HOUR):MONTH2	1,968	2	93,044	<0.001
s(HOUR):MONTH3	1,957	2	39,500	<0.001
s(HOUR):MONTH4	1,854	2	18,795	<0.001
s(HOUR):MONTH5	1,973	2	91,759	<0.001
s(HOUR):MONTH6	1,967	2	87,536	<0.001
s(HOUR):MONTH7	1,843	2	17,454	<0.001
s(HOUR):MONTH8	1,982	2	157,455	<0.001
s(HOUR):MONTH9	1,949	2	51,831	<0.001
s(HOUR):MONTH10	0,000	2	0,000	0,461
s(HOUR):MONTH11	1,484	2	3,065	0,017
s(HOUR):MONTH12	1,131	2	1,776	0,045

Station	Parameter	Estimate	Std. Error	t value	p-value
KS4_22	(Intercept)	1,351	0,053	25,421	<0.001
	HOUR	0,003	0,004	0,700	0,484
	MONTH2	0,147	0,079	1,877	0,061
	MONTH3	-0,126	0,079	-1,595	0,111
	MONTH4	0,820	0,064	12,752	<0.001
	MONTH5	0,915	0,063	14,632	<0.001
	MONTH6	0,335	0,068	4,885	<0.001
	MONTH7	-0,241	0,074	-3,268	0,001
	MONTH8	0,222	0,068	3,282	0,001
	MONTH9	1,502	0,058	25,729	<0.001
	MONTH10	1,110	0,063	17,725	<0.001
	MONTH11	0,522	0,090	5,813	<0.001

Smoothing term	edf	Ref.df	F	p-value
s(HOUR):MONTH1	1,886	2	23,897	<0.001
s(HOUR):MONTH2	1,759	2	7,065	<0.001
s(HOUR):MONTH3	1,951	2	44,139	<0.001
s(HOUR):MONTH4	1,954	2	60,886	<0.001
s(HOUR):MONTH5	1,982	2	141,130	<0.001
s(HOUR):MONTH6	1,983	2	133,372	<0.001
s(HOUR):MONTH7	1,982	2	154,307	<0.001
s(HOUR):MONTH8	1,992	2	343,735	<0.001
s(HOUR):MONTH9	1,995	2	520,585	<0.001
s(HOUR):MONTH10	1,635	2	4,481	0,004
s(HOUR):MONTH11	1,694	2	5,163	0,002

Station	Parameter	Estimate	Std. Error	t value	p-value
KS5_22	(Intercept)	1,743	0,060	28,924	<0.001
	HOUR	-0,015	0,005	-3,085	0,002
	MONTH2	-0,057	0,084	-0,676	0,499
	MONTH3	0,638	0,069	9,223	<0.001
	MONTH4	0,808	0,071	11,366	<0.001
	MONTH5	0,070	0,077	0,916	0,360
	MONTH6	-0,067	0,082	-0,815	0,415
	MONTH7	-0,876	0,086	-10,215	<0.001
	MONTH8	-0,883	0,096	-9,228	<0.001
	MONTH9	0,302	0,077	3,949	<0.001
	MONTH10	0,443	0,089	4,970	<0.001
	MONTH11	0,070	0,146	0,481	0,630
	MONTH12	-1,782	0,248	-7,196	<0.001
	Smoothing term	**edf**	**Ref.df**	**F**	**p-value**
	s(HOUR):MONTH1	1,977	2	111,360	<0.001
	s(HOUR):MONTH2	1,946	2	49,037	<0.001
	s(HOUR):MONTH3	1,968	2	71,685	<0.001
	s(HOUR):MONTH4	1,946	2	53,444	<0.001
	s(HOUR):MONTH5	1,933	2	22,650	<0.001
	s(HOUR):MONTH6	1,706	2	7,809	<0.001
	s(HOUR):MONTH7	0,000	2	0,000	0,555
	s(HOUR):MONTH8	1,829	2	11,785	<0.001
	s(HOUR):MONTH9	1,964	2	79,839	<0.001
	s(HOUR):MONTH10	1,995	2	450,390	<0.001
	s(HOUR):MONTH11	1,959	2	40,507	<0.001
	s(HOUR):MONTH12	1,787	2	11,956	<0.001

Table 7.3. Output of the Generalized Additive Mixed Models (GAMMs) used to estimate diurnal patterns in the 2023 data. For each station and month patterns were estimated using hourly aggregated Detection Positive Minutes (DPM). A p-value less than 0.05 indicates that DPM varied during the 24-hour cycle in that month for that station.

Station	Parameter	Estimate	Std. Error	t value	p-value
KS1_23	(Intercept)	1,395	0,055	25,528	<0.001
	HOUR	-0,005	0,004	-1,194	0,232
	MONTH2	0,203	0,072	2,800	0,005
	MONTH3	0,402	0,069	5,832	0,000
	MONTH4	0,259	0,110	2,351	0,019
	MONTH6	0,988	0,064	15,504	<0.001
	MONTH7	0,358	0,068	5,298	<0.001
	MONTH8	-0,047	0,074	-0,643	0,520
	MONTH9	0,043	0,078	0,549	0,583
	MONTH10	0,566	0,065	8,750	<0.001
	MONTH11	1,009	0,063	15,927	<0.001
	MONTH12	1,410	0,068	20,694	<0.001
	HOUR:MONTH2	0,015	0,006	2,705	0,007
	HOUR:MONTH3	-0,007	0,005	-1,226	0,220

	Parameter	Estimate	Std. Error	t value	p-value
	HOUR:MONTH4	0,005	0,009	0,521	0,603
	HOUR:MONTH6	0,002	0,005	0,393	0,695
	HOUR:MONTH7	0,006	0,005	1,084	0,279
	HOUR:MONTH8	0,011	0,006	1,863	0,063
	HOUR:MONTH9	-0,022	0,006	-3,457	0,001
	HOUR:MONTH10	-0,003	0,005	-0,509	0,611
	HOUR:MONTH11	0,007	0,005	1,520	0,129
	HOUR:MONTH12	0,008	0,005	1,599	0,110
	Smoothing term	**edf**	**Ref.df**	**F**	**p-value**
	s(HOUR):MONTH1	1,85	2	19	<0.001
	s(HOUR):MONTH2	1,90	2	27,99	<0.001
	s(HOUR):MONTH3	1,97	2	102,02	<0.001
	s(HOUR):MONTH4	1,91	2	29,88	<0.001
	s(HOUR):MONTH6	1,89	2	24,57	<0.001
	s(HOUR):MONTH7	1,98	2	150,98	<0.001
	s(HOUR):MONTH8	1,97	2	79,69	<0.001
	s(HOUR):MONTH9	1,91	2	29,55	<0.001
	s(HOUR):MONTH10	0,00	2	0	0,676
	s(HOUR):MONTH11	1,95	2	40,36	<0.001
	s(HOUR):MONTH12	1,98	2	156,36	<0.001

Station	Parameter	Estimate	Std. Error	t value	p-value
KS2_23	(Intercept)	0,439	0,082	5,358	<0.001
	HOUR	0,015	0,006	2,470	0,014
	MONTH2	0,278	0,106	2,634	0,008
	MONTH3	1,407	0,091	15,527	<0.001
	MONTH4	1,785	0,089	20,040	<0.001
	MONTH5	1,369	0,090	15,195	<0.001
	MONTH6	1,540	0,089	17,221	<0.001
	MONTH7	1,632	0,089	18,329	<0.001
	MONTH8	1,494	0,089	16,852	<0.001
	MONTH9	1,146	0,092	12,474	<0.001
	MONTH10	1,577	0,091	17,328	<0.001
	MONTH11	1,497	0,091	16,523	<0.001
	MONTH12	1,074	0,111	9,706	<0.001
	HOUR:MONTH2	-0,006	0,008	-0,743	0,457
	HOUR:MONTH3	-0,022	0,007	-3,186	0,001
	HOUR:MONTH4	-0,023	0,007	-3,367	0,001
	HOUR:MONTH5	-0,006	0,007	-0,820	0,412
	HOUR:MONTH6	-0,020	0,007	-2,931	0,003
	HOUR:MONTH7	-0,022	0,007	-3,351	0,001
	HOUR:MONTH8	-0,015	0,007	-2,234	0,026
	HOUR:MONTH9	-0,017	0,007	-2,507	0,012
	HOUR:MONTH10	-0,010	0,007	-1,448	0,148
	HOUR:MONTH11	-0,018	0,007	-2,712	0,007
	HOUR:MONTH12	0,008	0,008	0,922	0,356

	Smoothing term	edf	Ref.df	F	p-value
	s(HOUR):MONTH1	1,939	2	27,9	<0.001
	s(HOUR):MONTH2	1,974	2	97,3	<0.001
	s(HOUR):MONTH3	1,984	2	175,4	<0.001
	s(HOUR):MONTH4	1,242	2	2,3	0,0266
	s(HOUR):MONTH5	1,989	2	204,1	<0.001
	s(HOUR):MONTH6	1,989	2	240,7	<0.001
	s(HOUR):MONTH7	1,986	2	202,7	<0.001
	s(HOUR):MONTH8	1,994	2	492,9	<0.001
	s(HOUR):MONTH9	1,991	2	309,7	<0.001
	s(HOUR):MONTH10	1,929	2	20,7	<0.001
	s(HOUR):MONTH11	1,979	2	121,5	<0.001
	s(HOUR):MONTH12	1,955	2	48,2	<0.001

Station	Parameter	Estimate	Std. Error	t value	p-value
KS3_23	(Intercept)	0,721	0,084	8,603	<0.001
	HOUR	0,015	0,007	2,226	0,026
	MONTH2	0,041	0,118	0,347	0,728
	MONTH3	0,870	0,095	9,128	<0.001
	MONTH4	0,908	0,097	9,370	<0.001
	MONTH5	1,106	0,095	11,694	<0.001
	MONTH6	1,228	0,090	13,599	<0.001
	MONTH7	0,524	0,096	5,447	<0.001
	MONTH8	0,564	0,099	5,723	<0.001
	MONTH9	-0,260	0,117	-2,212	0,027
	MONTH10	0,301	0,100	3,008	0,003
	MONTH11	1,170	0,094	12,476	<0.001
	MONTH12	0,870	0,126	6,887	<0.001
	HOUR:MONTH2	-0,010	0,009	-1,093	0,274
	HOUR:MONTH3	-0,026	0,007	-3,456	0,001
	HOUR:MONTH4	-0,006	0,008	-0,798	0,425
	HOUR:MONTH5	-0,024	0,007	-3,293	0,001
	HOUR:MONTH6	-0,006	0,007	-0,852	0,395
	HOUR:MONTH7	0,003	0,007	0,462	0,644
	HOUR:MONTH8	-0,006	0,008	-0,723	0,470
	HOUR:MONTH9	-0,020	0,009	-2,219	0,026
	HOUR:MONTH10	-0,020	0,008	-2,571	0,010
	HOUR:MONTH11	-0,008	0,007	-1,049	0,294
	HOUR:MONTH12	-0,008	0,010	-0,820	0,412
	Smoothing term	**edf**	**Ref.df**	**F**	**p-value**
	s(HOUR):MONTH1	1,89E+00	2	23,199	<0.001
	s(HOUR):MONTH2	1,83E+00	2	13,18	<0.001
	s(HOUR):MONTH3	9,56E-01	2	1,239	0,077
	s(HOUR):MONTH4	1,96E+00	2	35,013	<0.001
	s(HOUR):MONTH5	1,84E+00	2	16,786	<0.001
	s(HOUR):MONTH6	1,99E+00	2	361,138	<0.001

	s(HOUR):MONTH7	1,98E+00	2	114,374	<0.001
	s(HOUR):MONTH8	1,96E+00	2	51,562	<0.001
	s(HOUR):MONTH9	1,49E+00	2	4,243	0,004
	s(HOUR):MONTH10	3,43E-06	2	0	0,571
	s(HOUR):MONTH11	1,95E+00	2	28,735	<0.001
	s(HOUR):MONTH12	1,88E+00	2	22,427	<0.001

Station	Parameter	Estimate	Std. Error	t value	p-value
KS4_23	(Intercept)	1,763	0,046	38,482	<0.001
	HOUR	0,017	0,003	5,002	<0.001
	MONTH2	-0,223	0,067	-3,316	0,001
	MONTH3	0,234	0,059	3,988	<0.001
	MONTH4	0,354	0,060	5,903	<0.001
	MONTH5	-0,256	0,064	-3,995	<0.001
	MONTH6	0,421	0,056	7,537	<0.001
	MONTH7	0,309	0,056	5,525	<0.001
	MONTH8	0,881	0,053	16,772	<0.001
	MONTH9	0,590	0,055	10,700	<0.001
	MONTH10	0,840	0,055	15,168	<0.001
	MONTH11	-0,264	0,065	-4,046	<0.001
	MONTH12	0,092	0,088	1,041	0,298
	HOUR:MONTH2	0,002	0,005	0,468	0,640
	HOUR:MONTH3	-0,015	0,004	-3,455	0,001
	HOUR:MONTH4	-0,017	0,005	-3,580	<0.001
	HOUR:MONTH5	-0,020	0,005	-4,146	<0.001
	HOUR:MONTH6	-0,010	0,004	-2,387	0,017
	HOUR:MONTH7	-0,012	0,004	-2,757	0,006
	HOUR:MONTH8	-0,017	0,004	-4,218	<0.001
	HOUR:MONTH9	-0,021	0,004	-4,938	<0.001
	HOUR:MONTH10	-0,020	0,004	-4,601	<0.001
	HOUR:MONTH11	-0,010	0,005	-2,005	0,045
	HOUR:MONTH12	-0,047	0,007	-6,925	<0.001
	Smoothing term	**edf**	**Ref.df**	**F**	**p-value**
	s(HOUR):MONTH1	1,972	2	52,694	<0.001
	s(HOUR):MONTH2	1,869	2	17,062	<0.001
	s(HOUR):MONTH3	1,987	2	172,215	<0.001
	s(HOUR):MONTH4	1,938	2	27,833	<0.001
	s(HOUR):MONTH5	1,985	2	191,92	<0.001
	s(HOUR):MONTH6	1,989	2	271,273	<0.001
	s(HOUR):MONTH7	1,994	2	431,965	<0.001
	s(HOUR):MONTH8	1,994	2	466,057	<0.001
	s(HOUR):MONTH9	1,991	2	302,777	<0.001
	s(HOUR):MONTH10	1,832	2	8,984	<0.001
	s(HOUR):MONTH11	1,983	2	127,654	<0.001
	s(HOUR):MONTH12	1,948	2	54,667	<0.001

Station	Parameter	Estimate	Std. Error	t value	p-value
KS5_23	(Intercept)	1,081	0,123	8,805	<0.001
	HOUR	-0,043	0,011	-3,945	<0.001
	MONTH2	-0,300	0,166	-1,808	0,071
	MONTH3	1,363	0,126	10,785	<0.001
	MONTH4	0,692	0,139	4,986	<0.001
	MONTH5	0,625	0,137	4,563	<0.001
	MONTH6	1,809	0,127	14,260	<0.001
	MONTH7	0,574	0,132	4,344	<0.001
	MONTH8	0,854	0,132	6,491	<0.001
	MONTH9	1,186	0,133	8,929	<0.001
	MONTH10	1,160	0,137	8,480	<0.001
	MONTH11	1,154	0,134	8,591	<0.001
	MONTH12	1,177	0,160	7,371	<0.001
	HOUR:MONTH2	0,062	0,014	4,394	<0.001
	HOUR:MONTH3	0,026	0,011	2,297	0,022
	HOUR:MONTH4	0,036	0,012	2,936	0,003
	HOUR:MONTH5	0,023	0,012	1,921	0,055
	HOUR:MONTH6	0,029	0,011	2,587	0,010
	HOUR:MONTH7	0,041	0,012	3,578	<0.001
	HOUR:MONTH8	0,037	0,012	3,179	0,001
	HOUR:MONTH9	0,017	0,012	1,409	0,159
	HOUR:MONTH10	0,021	0,012	1,702	0,089
	HOUR:MONTH11	0,037	0,012	3,087	0,002
	HOUR:MONTH12	0,020	0,014	1,456	0,146
	Smoothing term	**edf**	**Ref.df**	**F**	**p-value**
	s(HOUR):MONTH1	1,98	2	128,73	<0.001
	s(HOUR):MONTH2	1,98	2	155,38	<0.001
	s(HOUR):MONTH3	0,00	2	0	0,375
	s(HOUR):MONTH4	1,98	2	164,05	<0.001
	s(HOUR):MONTH5	1,93	2	34,83	<0.001
	s(HOUR):MONTH6	1,94	2	49,64	<0.001
	s(HOUR):MONTH7	1,94	2	31,26	<0.001
	s(HOUR):MONTH8	1,96	2	32,94	<0.001
	s(HOUR):MONTH9	1,98	2	135,92	<0.001
	s(HOUR):MONTH10	2,00	2	510,18	<0.001
	s(HOUR):MONTH11	1,99	2	478,2	<0.001
	s(HOUR):MONTH12	1,98	2	159,78	<0.001

Figure 7.1. Average number of DPM/day/month for 2021, 2022 and 2023 with 95% confidence intervals calculated across all five stations. The dashed black line shows averages for all years combined. The confidence interval for December 2023 is larger due to the combination of a large spread between the five stations and less data for this month, as the equipment was retrieved 11th December 2023.
Identical letters signify that the months are not significantly different. Months within and between years with dissimilar letters are significantly different.
Note that, as the figure is based on modelled output, it deviates slightly from the average calculated from raw data (Figure 3.9).

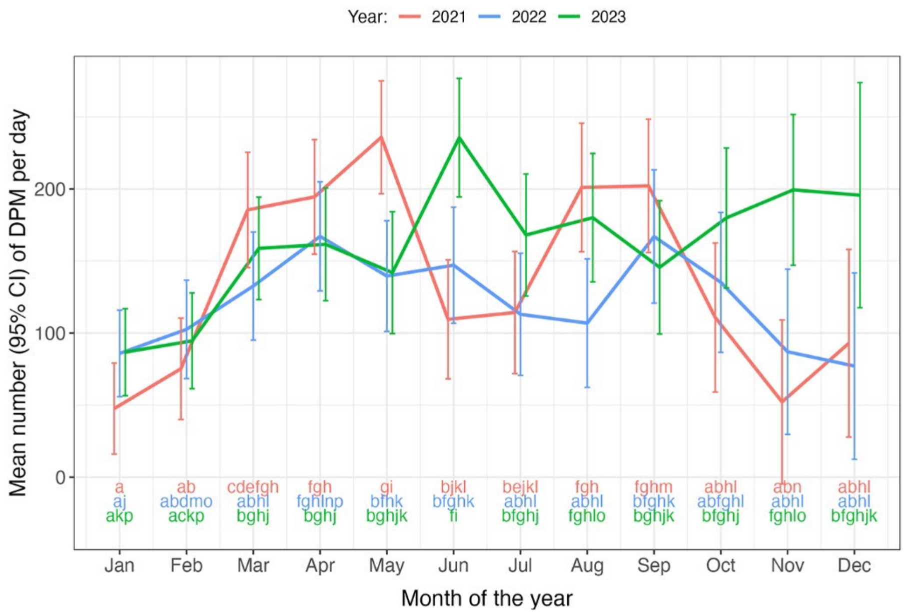

Table 7.4. Output of the ANOVA analysis of variance testing for differences in Detection Positive Minutes (DPM) day/month be-tween 2021, 2022 and 2023.

Parameter	Estimate	SE	t value	p-value
(Intercept)	135,14	13,91	9,712	<0.001
(Year)2022	-13,38	19,68	-0,68	0,501
(Year)2023	27,19	19,68	1,382	0,176

HARBOUR PORPOISE PRESENCE AT KATTEGATT SYD OFFSHORE WINDFARM SITE FROM DECEMBER 2020 TO DECEMBER 2023

Final Report

A three-year monitoring study was conducted in a future offshore windfarm area, Kattegatt Syd, in Swedish Waters, Southern Kattegat. Harbour porpoises were monitored by means of passive acoustic monitoring with CPODs for three full years at five stations. The monitoring showed that in general detection rates in the area were lower than at the Natura 2000 site Lilla Middelgrund to the north and higher than at the Natura 2000 site Stora Middelgrund & Röda Bank to the south, when comparing to monitoring results from the Swedish national monitoring program. Across all three years the lowest detection rates of harbour porpoises were observed in November-February, and the highest levels were observed in March-May and August-September. This final report includes three years of data and supplements the report *Kattegatt Syd Offshore Windfarm - Effects of pile driving, gravity foundations and sediment spill on marine mammals.*

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