PORPOISE MONITORING IN PINGER-NET FISHERY

Status report

Technical Report from DCE – Danish Centre for Environment and Energy No. 57 2015

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

[Blank page]

PORPOISE MONITORING IN PINGER-NET FISHERY

Status report

Technical Report from DCE – Danish Centre for Environment and Energy No. 57 2015

Jonas Teilmann
Signe Sveegaard
Jeppe Dalgaard Balle
Line Kyhn
Jacob Carstensen

Aarhus University, Department of Bioscience

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

Data sheet

Series title and no.: Technical Report from DCE – Danish Centre for Environment and Energy No. 57

Title: Porpoise monitoring in pinger-net fishery. Status report
Dansk titel: Marsvinemonitering i pinger garnfiskeri (MIP)

Authors: Jonas Teilmann, Signe Sveegaard, Jeppe Dalgaard Balle, Line Kyhn & Jacob Carstensen

Institution: Aarhus University, Department of Bioscience

Publisher: Aarhus University, DCE – Danish Centre for Environment and Energy ©
URL: http://dce.au.dk/en

Year of publication: May 2015
Editing completed: 1 May 2015
Referees: Anja Gadgård Boye & Pernille Birkenborg Jensen
Quality assurance, DCE: Jesper Fredshavn

Financial support: NaturErhvervstyrelsen

Please cite as: Teilmann, J., Sveegaard, S., Balle, J.D., Kyhn, L. & Carstensen, J. 2015. Porpoise monitoring in pinger-net fishery. Status report. Aarhus University, DCE – Danish Centre for Environment and Energy, 38 pp. Technical Report from DCE – Danish Centre for Environment and Energy No. 57. http://dce2.au.dk/pub/TR57.pdf

Abstract: Harbour porpoises are part of the assignment of 16 Natura 2000 areas in Danish waters and Denmark are obliged to monitor and protect the species. The harbour porpoise faces the threat of entanglement in gill nets but by using acoustic alarms, so-called "pingers" placed on the nets, bycatch can be reduced. Pingers may, however, scare the porpoises out of important areas such as the Natura 2000 areas. This project aim to examine if porpoise density will change in the Great Belt, when mandatory use of pingers in all set net fisheries are enforced during a limited time period from mid-2015. By comparing the presence of porpoises before, during and after pingers are introduced in the Great Belt, with a control area in Kalundborg Fjord, we will be able to estimate the effect of pingers on porpoises in relation to density and acoustic behaviour. Porpoise presence is examined by deployment of acoustic data loggers (C-PODs) that can detect echolocation sounds emitted almost continuously by porpoises during foraging, communication and orientation. This report covers the baseline period from July 2011 to October 2014 for the 14 C-POD stations that have listened for porpoises more or less continuously during this period. The porpoise detections were analysed as PPM (Porpoise Positive Minutes) and CPPM (no. of clicks during each PPM. This may be interpreted as a measure of acoustic behaviour). Both are aggregated as average values per 24 hours. The results show that the seasonal patterns in the study area are significant and common to the control and impact areas. Over the four years with baseline data, echolocation activity (CPPM) has remained relatively constant over the entire study area, but there have been seasonal shifts in porpoise presence (PPM) between stations, most pronounced in the winter period, where porpoises apparently move from shallower stations to the deeper stations. Power analysis show that the current baseline data and a continuation of the monitoring program during the employment of pingers for one year, would allow for detecting relative changes of density (PPM) around 22% and echolocation behaviour (CPPM) around 42%. If monitoring continue for up to four years the relative changes that can be detected is reduced gradually to 14% and 25%, respectively.

Keywords: Marsvin, harbour porpoise, C-POD, PPM, CPPM, pinger, bycatch, bifangst, gillnet fishery, BACI, statistical power

Layout: Graphic Group, AU Silkeborg
Front page photo: Tre marsvin i Storebælt. Photo: Jonas Teilmann

ISBN: 978-87-7156-145-6
ISSN (electronic): 2245-019X

Number of pages: 38

Internet version: The report is available in electronic format (pdf) at http://dce2.au.dk/pub/TR57.pdf

Contents

[Blank page]

Preamble

This report is an updated version of the project status report from April 2014 and replaces the draft note from September 2014.

Additional data collected in 2014 have been included in the data analysis. Recently, we have also discovered that the detection of porpoise click trains recorded by the C-POD depends on the signal/noise level in the sea (other click sounds coming from waves, rain, ships etc.). Therefore, we have adjusted the data according to the function described in Section 2.4. This means that we can no longer use the indicators “encounter duration” and “waiting time” as we now know that some click trains will be shortened or completely masked by noise. However, “waiting time” and “PPM” are closely linked and both are proxies for density of porpoises. Similarly “Encounter duration” and “CPPM” are both related to porpoise behaviour. Very little additional information is therefore missing by leaving out “waiting time” and “encounter duration“. This report also includes further investigations of the correlations between stations and a statistical power analyses have been made to predict the approximate level of change in porpoise presence that can be significantly detected.

Summary

Harbour porpoises are part of the assignment of 16 Natura 2000 areas in Danish waters and Denmark are obliged to monitor and protect the species. The harbour porpoise faces the threat of entanglement in gill nets but by using acoustic alarms, so-called “pingers” placed on the nets, bycatch can be reduced. Pingers may, however, scare the porpoises out of important areas such as the Natura 2000 areas. This project aim to examine if porpoise density will change in the Great Belt, when mandatory use of pingers in all set net fisheries are enforced during a limited time period from mid-2015. By comparing the presence of porpoises before, during and after pingers are introduced in the Great Belt, with a control area in Kalundborg Fjord, we will be able to estimate the effect of pingers on porpoises in relation to density and acoustic behaviour. Porpoise presence is examined by deployment of acoustic data loggers (C-PODs) that can detect echolocation sounds emitted almost continuously by porpoises during foraging, communication and orientation. This report covers the baseline period from July 2011 to October 2014 for the 14 C-POD stations that have listened for porpoises more or less continuously during this period. The porpoise detections were analysed as PPM (Porpoise Positive Minutes) and CPPM (no. of clicks during each PPM. This may be interpreted as a measure of acoustic behaviour). Both are aggregated as average values per 24 hours. The results show that the seasonal patterns in the study area are significant and common to the control and impact areas. Over the four years with baseline data, echolocation activity (CPPM) has remained relatively constant over the entire study area, but there have been seasonal shifts in porpoise presence (PPM) between stations, most pronounced in the winter period, where porpoises apparently move from shallower stations to the deeper stations. Power analysis show that the current baseline data and a continuation of the monitoring program during the employment of pingers for one year, would allow for detecting relative changes of density (PPM) around 22% and echolocation behaviour (CPPM) around 42%. If monitoring continue for up to four years the relative changes that can be detected is reduced gradually to 14% and 25%, respectively.

Sammenfatning

Marsvin er på udpegningsgrundlaget i 16 Natura 2000 områder i danske farvande, og Danmark er forpligtiget til at overvåge og beskytte arten. Marsvin trues bl.a. af utilsigtet bifangst i fiskegarn, men ved at placere akustiske alarmer, såkaldte pingere, på nettene kan bifangst reduceres. Pingere kan imidlertid risikere at skræmme marsvinene ud af vigtige områder så som Natura 2000 områderne. Dette projekt vil undersøge om marsvinetætheden i Storebælt vil ændres, når obligatorisk brug af pingere implementeres i en begrænset periode begyndende formentlig fra sommer 2015. Ved at sammenligne tilstedeværelse før, under og efter pingerbrug i Storebælt med et referenceområde i Kalundborg Fjord, vil vi estimere den effekt som pingere har på tætheden af marsvin samt deres akustiske adfærd. Marsvins tilstedeværelse bliver undersøgt ved at udlægge akustiske dataloggere (kaldet C-PODs), der kan detektere de ekkolokaliseringsklik, marsvin laver for at kommunikere og orientere sig i vandet samt under byttefangst. Denne rapport indeholder data fra baselineperioden (juli 2011 - oktober 2014) for 14 C-POD stationer udsat i Kalundborg Fjord og Storebælt. Marsvinedetektionerne blev analyseret som PPM (Marsvine (Porpoise) Positive Minutter) som udtryk for tætheden af marsvin samt CPPM (antal klik per PPM) hvilket kan fortolkes som et mål for marsvins akustisk adfærd. Begge måleenheder er aggregeret som gennemsnit per 24 timer. Resultaterne viser, at der er signifikant sæsonvariation i undersøgelsesområdet og at denne er sammenlignelig i både reference- og "pinger"-områderne. I løbet af de 4 års baseline-periode har ekkolokaliseringsadfærden (CPPM) været relativt konstant i hele undersøgelsesområdet, mens der har været sæsonvariation i marsvinetætheden (PPM) mellem stationer, især om vinteren, hvor marsvin bevæger sig fra stationer på lavt vand til stationer med dybere vand. Power analyser viser, at de nuværende baseline data og en 1-årig fortsættelse af overvågningsprogrammet under pingerimplementering vil give mulighed for at detektere en relativ ændring i tæthed af marsvin (PPM) på ca. 22% og en ændring i ekkolokaliseringsadfærd (CPPM) på ca. 42%. Hvis pingerimplementeringen fortsættes i 4 år, styrkes den statistiske power til hhv. 14% for PPM og 25% for CPPM.

1 Introduction

Harbour porpoises have since 2010 been part of the assignment of 16 Natura 2000 areas in Danish waters. From 2011 porpoises became part of the national monitoring program of species and nature, NOVANA. In the inner Danish waters the Natura 2000 areas are monitored by static acoustic monitoring using C-PODs. C-PODs detect and record porpoise echolocation sounds in a radius of up to 500 meter and thereby provides a relative estimate of abundance (Kyhn et al. 2012).

Throughout its range, the harbour porpoise (*Phocoena phocoena*, L 1758) faces the threat of entanglement in gill nets (e.g. (IWC 1994; Read 1994; Vinther 1999; Northridge et al. 2003). The exact reason for bycatch is not well known, but using acoustic alarms, so-called “pingers” placed on the set nets are reducing bycatch of porpoises (e.g. Kraus et al. 1997). The temporal and spatial effect of pingers on porpoises is not fully understood, but experiments have shown, that e.g. the PICE pinger may scare porpoise away from the net in a radius of ca. 500 m (Culik et al. 2001, Carlstrøm et al. 2009). Although, habituation seems to occur (e.g. Kyhn et al. in press) and reduce the deterrence radius and potentially the effectiveness of pingers, there is a risk, that the porpoises are scared out of, or change behaviour, in important habitats like Natura 2000 areas, when pingers are used. It is therefore important to investigate the effect of pingers, not only around individual stationary pingers, but also in larger areas with real life fishery where gear and number of pingers may change spatially from day to day. Before pingers are fully implemented as the solution to mitigate bycatch in areas designated to protect porpoises, the large scale and long term effects must be known.

Using a BACI design, this project aim to examine if porpoise density will changed in a larger area of the Great Belt, when mandatory use of pingers in all set net fisheries are enforced a limited time period from mid-2015. By comparing the presence of porpoises before, during and after pingers have been introduced in the Great Belt, in combination with a control area in Kalundborg Fjord, we will be able to estimate the effect of pingers on porpoises in relation to density and acoustic behaviour. To increase the statistical certainty the presence of pingers in the vicinity of the recording stations will be monitored using noise loggers that are able to record pinger sounds out to about 700 meters. Furthermore, noise loggers will be used to make sure that pingers are not used in the control area in Kalundborg Fjord.

Simultaneously with the project described in this report, a project managed by DTU Aqua, will use video surveillance on-board 9 commercial set net fishing vessels to document the bycatch before and during the use of pingers in the Great Belt.

DTU Aqua is also gathering information on the gillnet fishing effort in the Great Belt across the year by counting all set nets from boat along the coast several times a year 2013-2014.

This report is the second status report covering the baseline period from July 2011 to October 2014 for the 14 C-POD stations that have listened for porpoises more or less continuously during this period. The present report fully replaces the previous report as it includes several fundamental changes to the data analysis.

1.1 Description of the area

The Great Belt is one of three narrow straits between the Baltic Sea and the Kattegat / North Sea. This results in strong currents especially during and after storms where water is pushed in and out of the Baltic Sea. Kalundborg Fjord is more protected by two peninsulas stretching out in the northern Great Belt. The water depth is variable down to about 60 m. The Great Belt Bridge crosses east-west in the middle of the belt and the belt hosts one of the busiest ship routes (t-route) connecting the Baltic and the North Sea crossing the Belt from north to south. As seen in figure 2.1.1 a large part of the Great Belt and Kalundborg Fjord is designated as Natura 2000 areas for harbour porpoises.

1.2 Harbour porpoise biology

Harbour porpoises reach a maximum length of about 1.8 m and maximum weight about 90 kg. They are relatively short-lived compared to other odontocetes, with an expected lifetime of about 15-20 years (Fig. 1.2.1, Lockyer and Kinze 2003).

Figure 1.2.1. Harbour porpoises. Photo: Jonas Teilmann.

The breeding period of harbour porpoises begins in late June and ends in late August. Ovulation and conception typically take place in late July and early August (Sørensen and Kinze 1994). The pregnancy period is about 11 months and the females thus give birth to the single calf in early summer. The calves begin suckling immediately after birth and feed by their mother until the following year possibly until the next calf is born (Teilmann et al. 2007). The females can conceive when they are 3 or 4 years old (Kinze et al. 2003). Changes in food resources may influence the reproduction of porpoises. Calves seem to be sighted throughout their range and there may not be any particular breeding / nursing areas (Hammond et al. 1995; Kinze et al. 2003). However, satellite tracking of adult females show that they may have individual preference for particular areas (Teilmann et al. 2004; Teilmann et al. 2008).

Between 1985 and 2006, the stomach contents of 392 harbour porpoises from the Kattegat, Danish Straits and the western part of the Baltic Sea were studied. The preferred food sources of harbour porpoises in Danish waters comprise 24 fish species. The percent of occurrence in the 392 stomachs was 45% with gobies (*Gobiidae*), 40% with herring (*Clupea harengus*), 33% with cod (*Gadus morhua*), 18% with saithe (*Pollacius virens*), 12% with sprat (*Sprattus sprattus*) and 11% with sandeel (*Ammodytes spp.*) as the six most important groups (Sveegaard 2011).

Like other toothed whales (odontocetes) harbour porpoises have good underwater hearing and use sound actively for navigation and prey capture (echolocation). They produce short ultrasonic clicks (130 kHz peak frequency, 50-100 µs duration; Møhl and Andersen 1973; Teilmann et al. 2002) and are able to orient and find prey even in complete darkness. Porpoises tagged with acoustic data loggers indicate that they use their echolocation almost continuously (Akamatsu et al. 2007; Linnenschmidt et al. 2012).

1.3 Density and distribution

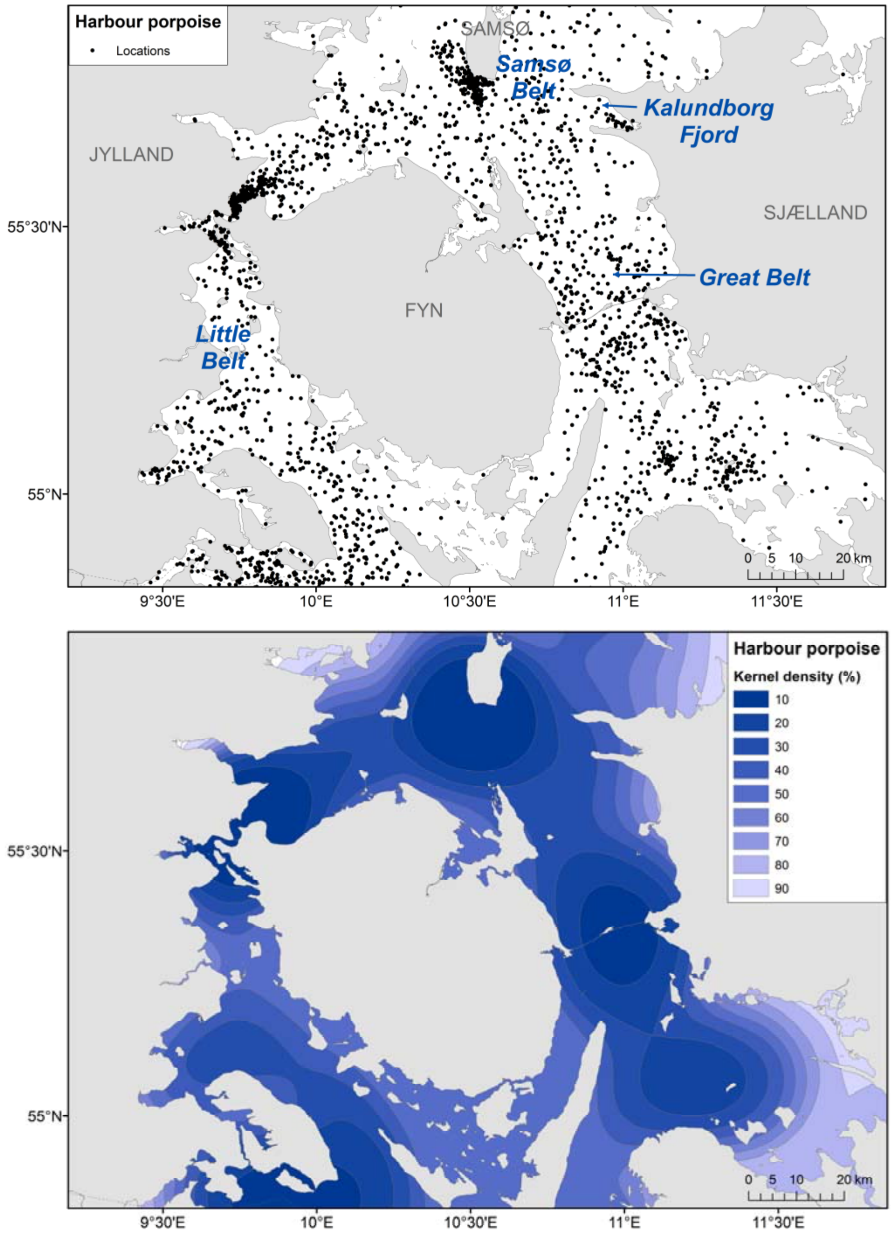
The two SCANS surveys, conducted in 1994 and 2005 represents the largest coordinated effort to map the distribution and abundance of cetaceans, including harbour porpoises in European waters. They were conducted in July both years and thus represent summer distribution of animals. In July 2012, the SCANS method was used in a smaller scale survey covering the inner Danish waters (Kattegat, Belt Seas and Western Baltic). In all three surveys, porpoises were observed within the Inner Danish waters, but such large scale surveys cannot subsequently be utilised for calculating abundance for much smaller area such as the Great Belt or Kalundborg Fjord. Furthermore, visual surveys have a short temporal scale, and would have to be repeated continuously throughout the year to detect any effect of pinger-implementation. Thus, when examining the effect of pingers, it is preferable to use a sampling method with long temporal scale such as static acoustic monitoring.

During the years 1997-2013, 99 harbour porpoises were tagged with satellite transmitters. The animals were incidentally caught alive by Danish pound net fishermen, who provided access to the animals through a close cooperation. Individual animals were tracked for up to 500 days. From the data it is evident that animals cover extensive areas and tagged animals moved between areas in Kattegat, the Belt Seas and the western Baltic (Fig. 1.3.1. Sveegaard et al. 2011). Furthermore, the porpoises do not distribute evenly but spend more time in certain high density areas such as the central Great Belt, the southern Samsø Belt and the northern Little Belt.

1.4 Protection

The harbour porpoise is listed in Annex II and IV of the Habitats Directive (92/43/EEC), Annex II of the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention), Appendix II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS, Bonn Convention) and Annex II of the Convention on International Trade in Endangered Species (CITES), and it is covered by the Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS), and by the Convention on the Protection of the Marine environment of the Baltic Sea (HELCOM).

Figure 1.3.1. Locations from 99 harbour porpoises equipped with satellite transmitters in part of their range in the Danish Belt Seas from 1997 to 2013. Black dots in the upper map show one daily position from each tracked porpoise. Coloured areas in bottom map indicate kernel density home ranges with darker blue indicating higher density and lighter blue lower density of animals (Methodology from Sveegaard et al. 2011).



The annex IV of the Habitats Directive, among other implies that "*Member States shall take the requisite measures to establish a system of strict protection for the animal species listed in Annex IV (a) in their natural range, prohibiting: ... (b) Deliberate disturbance of these species, particularly during the period of breeding, rearing, hibernation and migration ...*" (article 12).

2 Material and methods

2.1 Stations and deployment period

In total 14 C-POD stations have been deployed in the study area, 5 of which act as control stations (no impact) in the Kalundborg Fjord and 9 as impact stations in the Great Belt (Fig. 2.1.1, Table 2.1.1).

Battery capacity and memory in the C-PODs is under normal conditions sufficient for continuous operation for 6 months and therefore all stations have been visited within this timeframe for service. The time series obtained from the C-POD signals contained some gaps where they were not deployed or lost from the position. The 14 C-POD stations did, however, successfully record on 53-97% of the deployment days (Fig. 2.1.2).

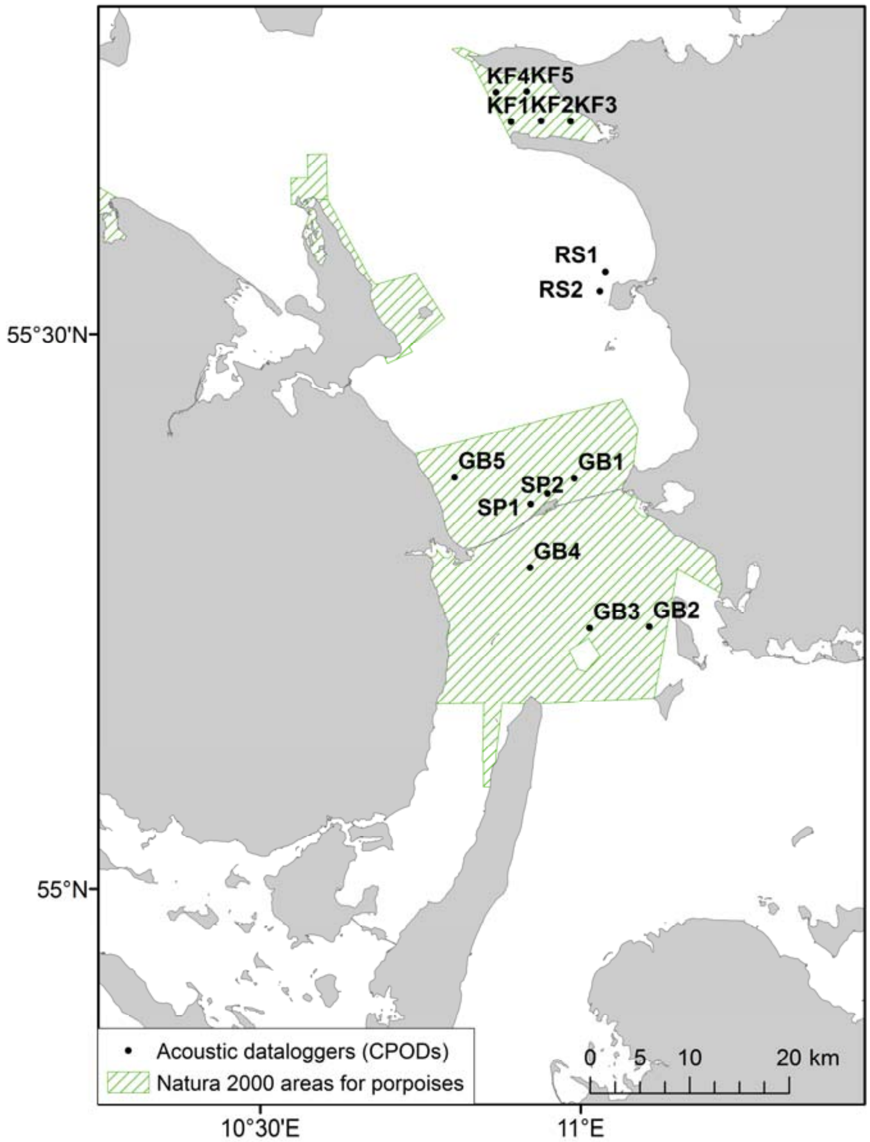


Figure 2.1.1. Map of the study area with black dots indicating the five C-POD stations called Great Belt (GB) including two stations near Sprogø (SP) and two stations near Reersø (RS) comprising the impact stations and five control stations in Kalundborg Fjord (KF).

Table 2.1.1. List of the 14 C-POD stations, their coordinates and water depth as well as location. KF= Kalundborg Fjord, GB=Great Belt, RS= Reersø, SP=Sprogø.

Area	Station	Position (WGS84)		Depth (m)
Control 1	KF1	10° 56,034'E	55° 40,956'N	6.2
Control 2	KF2	10° 58,922'E	55° 40,956'N	13.4
Control 3	KF3	11° 01,718'E	55° 40,900'N	13.1
Control 4	KF4	10° 54,659'E	55° 42,575'N	16
Control 5	KF5	10° 57,608'E	55° 42,574'N	15.2
Impact 1	GB1	11° 01,096'E	55° 21,600'N	18
Impact 2	GB2	11° 07,763'E	55° 13,477'N	10
Impact 3	GB3	11° 02,125'E	55° 13,492'N	27
Impact 4	GB4	10° 56,658'E	55° 16,842'N	26.5
Impact 5	GB5	10° 49,738'E	55° 21,837'N	21
Impact 6	RS1	11° 04,620'E	55° 32,700'N	8
Impact 7	RS2	11° 04,050'E	55° 31,680'N	8
Impact 8	SP1	10° 56,880'E	55° 20,280'N	7.6
Impact 9	SP2	10° 58,500'E	55° 20,820'N	8

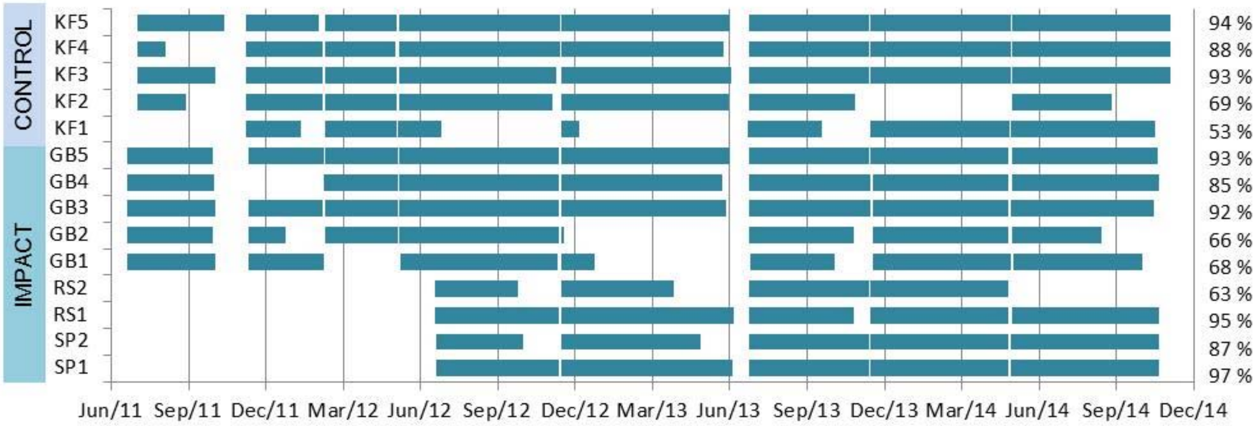


Figure 2.1.2. Overview of CPOD recording periods by station during the baseline deployment period (June 2011-November 2014). The column to the right shows percent days with CPOD recordings out of the total number of deployment days. KF= Kalundborg Fjord, GB=Great Belt, RS= Reersøe, SP=Sprogø.

2.2 C-POD deployment system

Two deployment systems were used in the study area: Acoustic release and surface buoy. The acoustic release system consisted of two 25 kg sand bags as anchor, an acoustic release (Sonardyne, type 7986 Lightweight Release Transponder), the C-POD and 3 orange floats at the top. The releaser and the C-POD were placed in a black tube for protection against trawlers (Fig. 2.2.1).

Figure 2.2.1. Acoustic equipment with and without protective tube with the CPOD hydrophone at the top and acoustic release mechanism closest to the sand bags. The orange buoys keep the equipment vertical in the water column and bring the equipment to the surface after release while the sand bags remain at the bottom and are lost.

The deployment system using acoustic releasers were used on larger depths (10-27m) while the surface buoy system were used on the positions with shallow water (6-8 m). The surface buoy system consisted of a surface buoy with a yellow cross and radar reflector on the top. This was connected to an anchor at the bottom by a metal chain. This anchor was connected to a sec-onds anchor with typhoon wire, which again connects to an orange float at the surface. The C-POD was attached to the wire at the bottom (Fig. 2.2.2, Fig. 2.2.3).

Figure 2.2.2. The deployment system used for mooring C-PODs. The set-up has been designed so that the instruments can be lifted to the surface by hand by pulling in the orange float (yellow square).

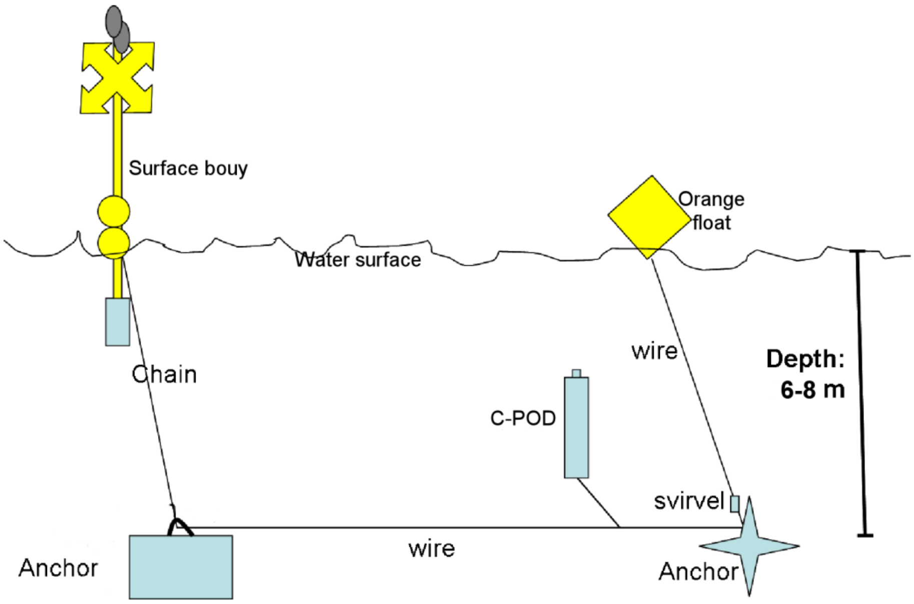


Figure 2.2.3. The buoy system viewed from the surface. The red float is used to retrieve the instruments without pulling the heavy anchor up.

2.3 C-PODs – principle of operation and characteristics

The C-POD or POrpoise Detector is a self-contained data-logger that logs echolocation clicks from harbour porpoises and other cetaceans. It is developed by Nick Tregenza (Chelonia, UK). It is programmable and can be set to specifically detect and record the echolocation signals from harbour porpoises.

The C-POD consists of a hydrophone, an amplifier, a number of band-pass filters and a data-logger that logs echolocation clicks.

The C-POD relies on the highly stereotypical nature of porpoise sonar signals. These are unique in being very short (50-150 µs) and containing virtually no energy below 100 kHz (Fig. 2.3.1). The main part of the energy is in a narrow band (120-150 kHz), which makes the signals ideal for automatic detection. Most other sounds in the sea, with the important exception of boat echosounders, are characterised by being either more broadband (energy distributed over a wider frequency range), longer in duration, with peak energy at lower frequencies or combinations of the three. In addition echo-sounders has a more regular pattern than porpoise echolocation. No other cetacean regularly found in the Great Belt area has sonar signals that can be confused with porpoise signals.

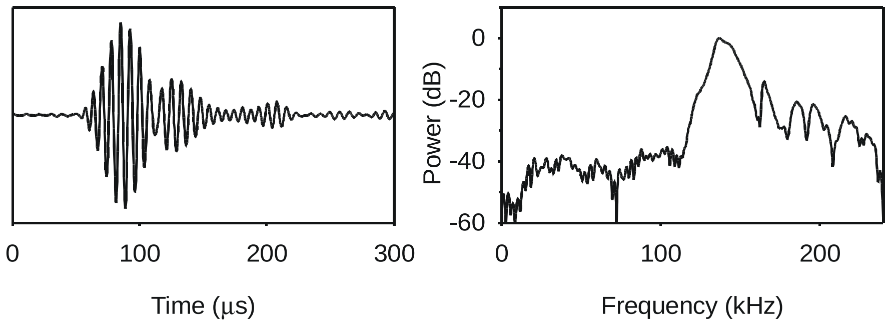


Figure 2.3.1. Porpoise click time signal (left) and power spectrum (right). There is virtually no energy present below 100 kHz (the curve below 100 kHz represents background noise of the recording).

Prior to the first deployment, the C-PODs were calibrated in a circular cedar wood tank, 2.8 m deep, 3 m diameter located at University of Southern Denmark's research facility in Kerteminde. C-PODs were fixed in a holder with the hydrophone pointing downwards and placed 0.5 m below the water surface. A projecting hydrophone (Reson TC4033) was placed in the same depth, 1 m from the C-POD. Calibration signals were 100 µs pulses of 130 kHz pure tones, shaped with a raised cosine envelope. Signals were generated by an Agilent 33250A arbitrary waveform generator. Projector sensitivity was measured prior to calibration by placing a reference hydrophone (Reson TC4034) at the position of the C-POD hydrophone.

The data recorded by the C-PODs were processed using the software C-POD.exe v2.042 (Fig. 2.3.2) using the "Hel1" classifier, which is an algorithm especially designed for the Baltic conditions, and the train filter (the encounter classifier) "Harbour Porpoise". Data from each station were exported as number of identified porpoise clicks ($N_{filtered}$) with a frequency of one minute. In addition to the identified porpoise clicks the total number of clicks (N_{all}, i.e. without the "Harbour Porpoise" train filter) was recorded as an indicator of the general noise level (porpoise clicks and ambient noise).

2.4 Adjusting for variable detection range

When examining the data from the C-PODs, it was realised that the likelihood of recording click trains (defined as Porpoise Positive Minutes, i.e. PPM) decreased with decreasing signal/noise level and that the number of porpoise clicks/porpoise positive minute (CPPM) increased with decreasing signal/noise level for all stations both individually (data not shown) and combined (Fig. 2.4.1). Although it is possible that porpoises adjust their echolocation to the noise level by producing clicks less frequently and produce more clicks when they start clicking (less frequent and more intense); however, it is more likely that increasing noise level will mask porpoise clicks in the click train detection process, particularly weaker clicks emitted from longer distances. Consequently, the porpoises recorded in more noise will have to be closer to the C-POD and therefore more likely to have more clicks recorded. Hence, it is proposed that increasing noise level reduces the detection range for the C-POD. It is therefore important to adjust the detected signals on the C-POD to account for varying noise levels before comparison, i.e. to calculate PPM and CPPM levels that are independent of the noise level.

Figure 2.3.2. Screen snapshot from the C-POD.exe software showing a harbour porpoise encounter with time (seconds) on the X-axis and frequency (kHz) of the received clicks on the Y-axis. Red is high probability of click train arriving from a harbour porpoise and yellow is moderate probability of click train arriving from a harbour porpoise. The probabilities are based on an undocumented detection algorithm provided by the CPOD manufacturer.

If the noise level is high, porpoise click trains will be identified from the recorded signals only if they are loud and long, whereas weaker and shorter click trains will gradually disappear in the noise and not be detected as the ambient noise level increases (Fig. 2.4.1, left panel). Porpoise click trains also contribute to the total signal ($N_{all}=N_{filtered}+N_{noise}$) and therefore low signal levels indicate both low ambient noise level and low echolocation activity. As a consequence, the probability of presence of porpoise click in a given minute (PPM=Porpoise Positive Minutes) increases with the noise level up to a noise level of around 400 clicks/min and then decreases with the increasing noise level (Fig. 2.4.1, right panel). Thus, at low ambient noise levels the detection range is longer and the C-POD will record more click trains, and many of these will consist of just a few clicks.

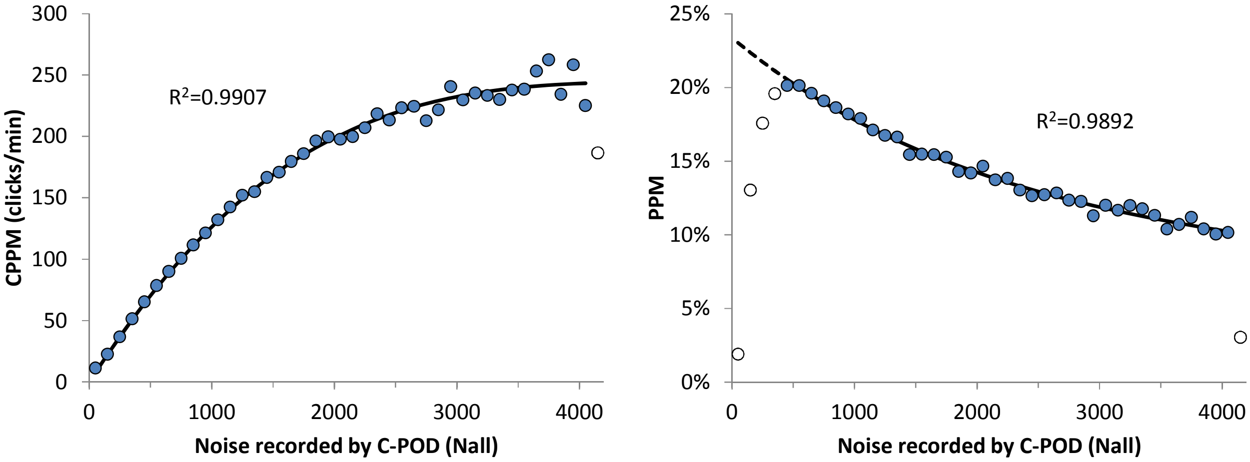


Figure 2.4.1. Average number of porpoise clicks (CPPM) and number of minutes with porpoise clicks (PPM) as a function of noise level (bins of 100 noise clicks as a mean of all 14 stations). Lines show the estimated models employed to account for varying noise level, interpreted as changing detection range. The maximum recorded noise level and PPM for noise level less than 400 (open circles) were not included for estimating the models as they seem to be unaffected by noise.

Assuming that the detection range of the C-POD (r) can be described as a minimum range ($r_{\min}$) at maximum noise level increasing exponentially to a maximum range ($r_{\max}$) for low ambient noise

$$r = r_{\min} + (r_{\max} - r_{\min}) \cdot \exp(-\beta \cdot \mathrm{N}_{\mathrm{all}})$$

On average, the probability of detecting porpoises (PPM) is proportional (coefficient k) to the area covered by the detection range

$$\mathrm{PPM} = k \cdot \pi \cdot r^2$$

Further, it is assumed that the proportion of porpoise clicks recorded to those emitted decreases with increasing range, i.e. more clicks are lost the longer they have to travel and become weaker. This implies that there will be more minutes with low number of clicks when the range is far, whereas relatively more clicks will be recorded when emitted at shorter distances. Therefore, CPPM will increase with the noise level and decrease with detection range, because less clicks will be lost (below detection level) on the passage from porpoise to the C-POD or in other words, a low noise level allows for weaker click signals to be detected. This is modelled using a reversed spherical function which has constant CPPM (no loss) for detection ranges below a certain distance r_{sill} and decreases as a third order polynomial function reaching zero at the maximum detection range ($r_{\max}$).

$$\mathrm{CPPM} = \begin{cases} C_{\max} & 0 < r \le r_{sill} \\ C_{\max} \cdot \left(\frac{3}{2} \cdot \frac{r_{\max} - r}{r_{\max} - r_{sill}} - \frac{1}{2} \cdot \left(\frac{r_{\max} - r}{r_{\max} - r_{sill}}\right)^3\right) & r_{sill} < r < r_{\max} \end{cases}$$

The parameters of these three equations can be estimated using the CPPM and PPM for different bins of the noise ($\mathrm{N}_{\mathrm{all}}$) (Fig. 2.4.1). However, the distance parameters ($r_{\min}$, $r_{\max}$ and r_{sill}) cannot all be estimated independently, since essentially any scaling of the distance will solve the equations. Thus, it is necessary to fix one of the distance parameters.

Calibration of C-PODs with hydrophones has suggested that the maximum detection range under low noise conditions is on the order of 300-400 m (J. Tougaard, personal communication); hence, setting $r_{\max} = 350$ m allowed for estimating the other parameters. Conditional on $r_{\max} = 350$ m, the other parameters suggest that the maximum detection range under very noisy conditions was $r_{\min} = 186$ m (±9.7 m), CPPM was constant for detection ranges less than $r_{sill} = 227$ m (±2.9 m), the maximum CPPM was $C_{\max} = 244$ clicks / minute (±3.1 clicks / minute), whereas $\beta = 0.000316$ (±0.000039) and $k = 0.608$ (±0.010).

The models for CPPM and PPM describe average conditions across all 14 stations, whereas differences between stations were mostly related to scaling issues for PPM (k parameter) and to a lesser extent for CPPM ($C_{\max}$). However, the objective of these models was to establish calibration models accounting for differences in noise levels at the 14 stations as well as over time. The average noise level for recording porpoises across all 14 stations was N_{all}=400.7, which according to the models corresponded to an average detection range of $r = 330$ m, an average CPPM of 57.5 clicks / minute and an average PPM of 20.8%. Thus, the detection range was close to the maximum most of the time, but there were periods when the detection range was less than 250 m, reducing the detection area by ~50%. The calibration models were used to calculate CPPM and PPM to a common detection range.

2.5 Porpoise activity indicators from C-POD signals

In compliance with previous studies, the CPOD data were grouped in number of porpoise clicks for each one minute interval. Two indicators of daily echolocation activity were calculated from the C-POD signals, namely PPM and CPPM. These are defined as:

PPM (porpoise positive minutes): This is defined as minutes where porpoises are recorded. This indicator shows presence / absence of porpoises in a particular minute. Data were subsequently given as the percentage of 1-minute periods where porpoises were recorded for each 24 hour period. This indicator provides a relative measure of density.

CPPM (click porpoise positive minutes): This is defined as the number of porpoise clicks in a minute where porpoise activity is recorded, i.e. number of porpoise clicks in each PPM. This indicator has also been aggregated as average values per 24 hours.

The two parameters were extracted from the C-POD software with a one-minute resolution, using the intercalibration models described above. This signal extracted from the C-POD (Nfiltered), denoted x_t, in the following, describes the recorded number of porpoise clicks per minute and consisted of many zero observations (no clicks) and relatively few observations with click recordings. For each minute with data the detection range (r_t) and detection area ($A(r_t) = \pi \cdot r_t^2$) as well as the expected $\mathrm{CPPM}(r_t)$ were calculated based on the noise level (N_{all}) using the equations above. The detection range could not be determined if the noise signal reached the maximum (4095 clicks, cf. Fig. 2.4.1) as the recording automatically stops when maximum is reached and only part of the minute contains data. Click recordings from such minutes were not used in the calculation of daily porpoise activity indicators (~0.9 % of the minutes with porpoise clicks).

For each minute recording PPM was adjusted to account for the varying noise level by scaling with a ratio of the expected detection area (see above) at a standard detection range ($A(r = 330\text{ m})$) to the expected detection area at the estimated detection range ($A(r_t)$) for that particular minute recording (see formula below). The adjusted daily PPM (PPM_{ADJ}) was found by averaging the adjusted PPM for each minute over the entire day.

$$\text{PPM}_{\text{ADJ}} = \frac{1}{N_d} \sum I(x_t > 0) \cdot \frac{A(r = 330\text{ m})}{A(r_t)}$$

where N_d is the number of minute observations per day and $I(x_t > 0)$ is an indicator function taking the value 1 if $x_t > 0$ and 0 otherwise.

Similarly, the CPPM was adjusted to the varying noise level by scaling with a ratio of the expected click intensity at a standard detection range ($\text{CPPM}(r = r_{standard})$) to the expected click intensity at the estimated detection range ($\text{CPPM}(r_t)$) for that particular minute recording. The adjusted daily CPPM ($CPPM_{ADJ}$) was found by averaging the adjusted minute click intensities over the entire day.

$$\text{CPPM}_{\text{ADJ}} = \frac{1}{N_d\{x_t > 0\}} \sum_{x_t > 0} x_t \cdot \frac{\text{CPPM}(r = 330\text{ m})}{\text{CPPM}(r_t)}$$

where $N_d\{x_t > 0\}$ is the number of minute observation with recorded porpoise clicks within the given day.

The two indicators of porpoise echolocation activity aggregated into daily signals describe different aspects of the porpoise echolocation activity. The number of minutes where porpoise activity is recorded (PPM), expresses how often porpoise clicks are captured by the C-POD and assuming that porpoises use their echolocation regularly every day, as indicated by Linnenschmidt et al. (2012), the PPM represents a proxy measure of the porpoise density in the area around the C-POD. Clicks / PPM (CPPM) may express porpoise behavioral activity as it is known that porpoises use their echolocation more actively during foraging, when approaching an object and for social activities (e.g. Verfuss et al. 2009; Linnenschmidt et al. 2012).

2.6 Statistical analyses

The main objective of the statistical analysis of the baseline data was to evaluate the suitability of the current monitoring design for assessing a potential effect on harbour porpoise echolocation activity of employing pingers on all deployed set net fishing gear in the Great Belt. This objective will be investigated with a BACI design, where the implicit assumption is that the porpoise detection activity in the control and the impact area are essentially governed by the same mechanisms over time, such that a potential effect of using pingers can be traced as a deviation in the impact area compared to the control area after the pingers have been employed.

$CPPM_{ADJ}$ and PPM_{ADJ} were transformed using the log and angular transformations, respectively, as $CPPM_{ADJ}$ was right-skewed with positive values only and PPM_{ADJ} described the proportion of minutes with porpoise recordings, including zero observations. The transformation employed will be referred to as $g(y)$.

2.6.1 Are the different areas behaving similarly?

The similarity in echolocation activity among stations was investigated by calculating correlation matrices for CPPM and PPM. With 14 stations each matrix contained 91 correlation pairs (excluding the diagonal). If there were no correlation between any of the stations, approximately five correlations would come out significantly with a confidence level of 95% (i.e. α=0.05) and approximately one correlation would come out significantly with a confidence level of 99% (i.e. α=0.01). Therefore, to avoid several spurious correlations and to focus on the stronger relationships a confidence level of 99% was chosen.

Correlation patterns were examined to identify if there were distinct geographical regions, where stations displayed different patterns over time. In the North Sea – Baltic Sea region porpoise densities normally display pronounced seasonal patterns, which affect number of detected PPMs on CPODs (SW Baltic: Carstensen et al. 2006; E North Sea: Tougaard et al. 2006; S North Sea: Scheidat et al. 2011). Such seasonal patterns are believed to be caused by seasonal migration of porpoise populations, and if the monitored echolocation activity correlates among different C-POD stations, this can be interpreted as the same porpoise population occupying the entire region. However, correlation on a day-to-day basis in a larger region such as the present study area should not be expected. Thus, if the C-POD stations correlate this indicates that the entire study area is most likely occupied by the same porpoise population, and that a potential effect of employing pingers can be identified as a relative shift between control and impact areas, i.e. a change from baseline to impact period. However, this does not necessary imply that a decrease in Great Belt following introduction of pingers will result in an increase in Kalundborg Fjord, just that the two areas will behave differently. Even belonging to the same population the porpoises in Great Belt may prefer to migrate south following introduction of pingers.

2.6.2 What are the sources of variation?

The baseline data were analysed to quantify the different sources of variation. Spatial variations included the difference between the two areas of consideration (control and impact) and variation between stations within these areas (five stations in the control area and 9 stations in the impact area). Temporal variations were described using monthly means for the seasonal pattern and yearly means for the interannual variation (four years) as well as changes in the seasonal pattern between years. Furthermore, variation between C-PODs was also included. Thus, the variation in $CPPM_{ADJ}$ and PPM_{ADJ} was modelled as a combination of fixed and random effects, i.e.

$$g(y) = \mu + e$$

where the fixed effects describe variation between the control vs impact area, the seasonal variation and the difference in seasonal variation between the two areas

$$\mu = area + month + area \times month$$

and the random factors included

$$e = year + year \times area + year \times month + area \times year \times month + station(area)$$
$$+ station(area) \times month + station(area) \times year \times month + podid + \varepsilon$$

The random factors described variations between years ($year$), changes in the interannual variation between the two areas ($year \times area$), changes in the seasonal pattern between years ($year \times month$), changes in the seasonal pattern between years and the two areas ($area \times year \times month$), variation between stations within the two areas ($station(area)$), variations in the seasonal pattern between stations within the two areas ($station(area) \times month$), variations in the seasonal pattern between station within the two areas across years ($station(area) \times year \times month$), and variations in sensitivity between C-PODs ($podid$). Finally, the error term (ε) described random variations in the daily observations within blocks of data from a single month at a single station. Daily observations of $CPPM_{ADJ}$ and PPM_{ADJ} were correlated over time, since there could be short term periods within a given month with echolocation activity above or below the mean level. Therefore, the error term was modelled as an autoregressive process, including a parameter (ρ) for the correlation between two consecutive days.

2.6.3 How will changes be detected?

The four years of data collected so far constitutes a baseline for assessing the potential effect of employing pingers in the impact area. This will be investigated using a BACI design (e.g. Green 1979, Underwood 1994). The basic idea behind the BACI design is to compare two areas before and after an intervention has occurred in impact area (BACI: Before-After-Control-Impact). The change in the impact area from before to after relative to the changes in the control area is interpreted as the effect size of the intervention. This is also referred to as the BACI effect and calculated as

BACI-effect= (AI – BI) – (AC-BC)

where AI is the mean level in the impact area after the intervention, BI is the mean level in the impact area before the intervention, AC is the mean level in the control area after the intervention and BC is the mean level in the control area before the intervention.

In the present study the baseline period is 2011-2014 and stations in Kalundborg Fjord constitute the control area, whereas the remaining stations constitute the impact area (Table 2.1.1). The intervention is the employment of pingers on fishing nets that will be initiated in the future.

Since the BACI effect is estimated from the means of the four combinations of before vs. after and control vs. impact, the significance of the BACI effect is tested by comparing the estimate to the uncertainty of the BACI effect estimate. Employing the log and angular transformations for $CPPM_{ADJ}$ and PPM_{ADJ}, respectively, to normalise the daily indicators, the BACI effect estimate is approximately Normal distributed due to the large amount of data. Essentially, the significance of the BACI effect depends on how large the effect is relative to the uncertainty of estimating the effect. Thus, in order to calculate the change that can be expected to be detected from a given design the uncertainty of the four means in the BACI effect must be calculated.

First, in order to simplify the calculations the uncertainty of a one-month block of correlated daily observations is calculated as (Cressie 1993)

$$s_{month} = \frac{s}{\sqrt{n}} \cdot \sqrt{\left\{1 + 2\left\{\frac{\rho}{1-\rho}\right\}\left\{1 - \frac{1}{n}\right\} - 2\left\{\frac{\rho}{1-\rho}\right\}^2 \left\{1 - \rho^{n-1}\right\} / n\right\}}$$

where s is the estimated standard deviation of the daily echolocation indicators, ρ is the autocorrelation and n is the number of observations within a month (n=30 for practical reasons). Correlation between monthly observations of $CPPM_{ADJ}$ and PPM_{ADJ} is approximately zero, as will be demonstrated in the results and therefore, the effect of autocorrelation is not accounted for in the next step where daily indicators aggregated at monthly resolution are considered.

The uncertainty of the four BACI means depends on the estimated uncertainty components (Section 2.6.2) and the combination of stations, years and months with monitoring data used for calculating each of the means. Since the BACI effect considers relative effects over time between control and impact areas, uncertainties associated with the combination of year and area / station should be included only, in addition to the residual variation given by s_{month}. Thus, the variance contribution of each of the four means to the BACI effect consists of the following components (cf. random factors in model in Section 2.6.2).

$$V[BACI_{mean}] = \frac{V[area \times year]}{N_y} + \frac{V[area \times year \times month]}{N_{y,m}} + \frac{V[station(area) \times year \times month]}{N_{s,y,m}} + \frac{s_{month}^2}{N_m}$$

where N_y is the number of years with data, $N_{y,m}$ is the number of years and month with data, $N_{s,y,m}$ is the number of stations, years and months with data, and N_m is the total number of months with data. The difference between the two latter comes into effect, if additional stations are included in the after period, since they only influence the residual variance contribution given by the last term (e.g. $N_{s,y,m}$=60 for the five stations in the control area with one year of monitoring, and including another station, for instance KF6, with 12 months of data in the after period gives N_m=72). The different variance components are estimated using the model in Section 2.6.2.

The variance of the BACI effect can be estimated by calculating the variance contribution for each of the four means used to calculate the BACI effect.

$$V[BACI_{mean}] = V[AI] + V[BI] + V[AC] + V[BC]$$

The number of stations and months has already been determined from the baseline monitoring design. Adding additional stations will have a marginal effect on the BACI analysis, since they influence the residual variance contribution only. Similarly, all 12 months have been monitored during the baseline and reducing the number of months with monitoring during the after period will increase the variance components associated with $area \times year \times month$ and $station(area) \times year \times month$. It is important to maintain the same stations and carry out monitoring in all months of the year. Thus, the potential changes in the echolocation indicators will be investigated by calculating the power of testing the BACI effect with one to four years of data in the ”pinger” period.

Using a standard confidence level of 95% and a standard power of 80% the change d (for the transformed echolocation indicators) likely (i.e. at least 80% probability) to be observed is calculated as

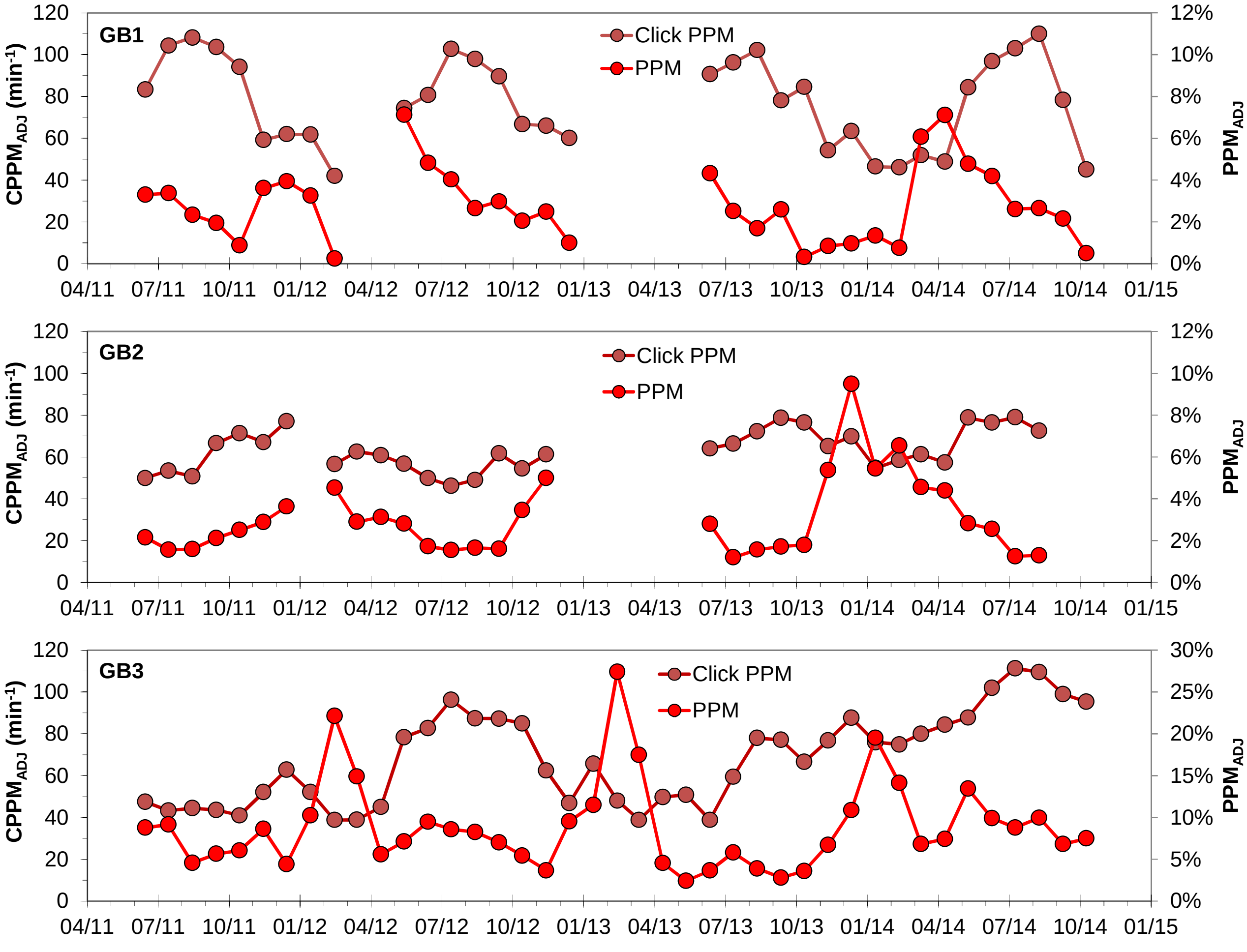
$$d \geq (z_{97.5\%} + z_{80\%}) \cdot \sqrt{V[BACI_{mean}]}$$

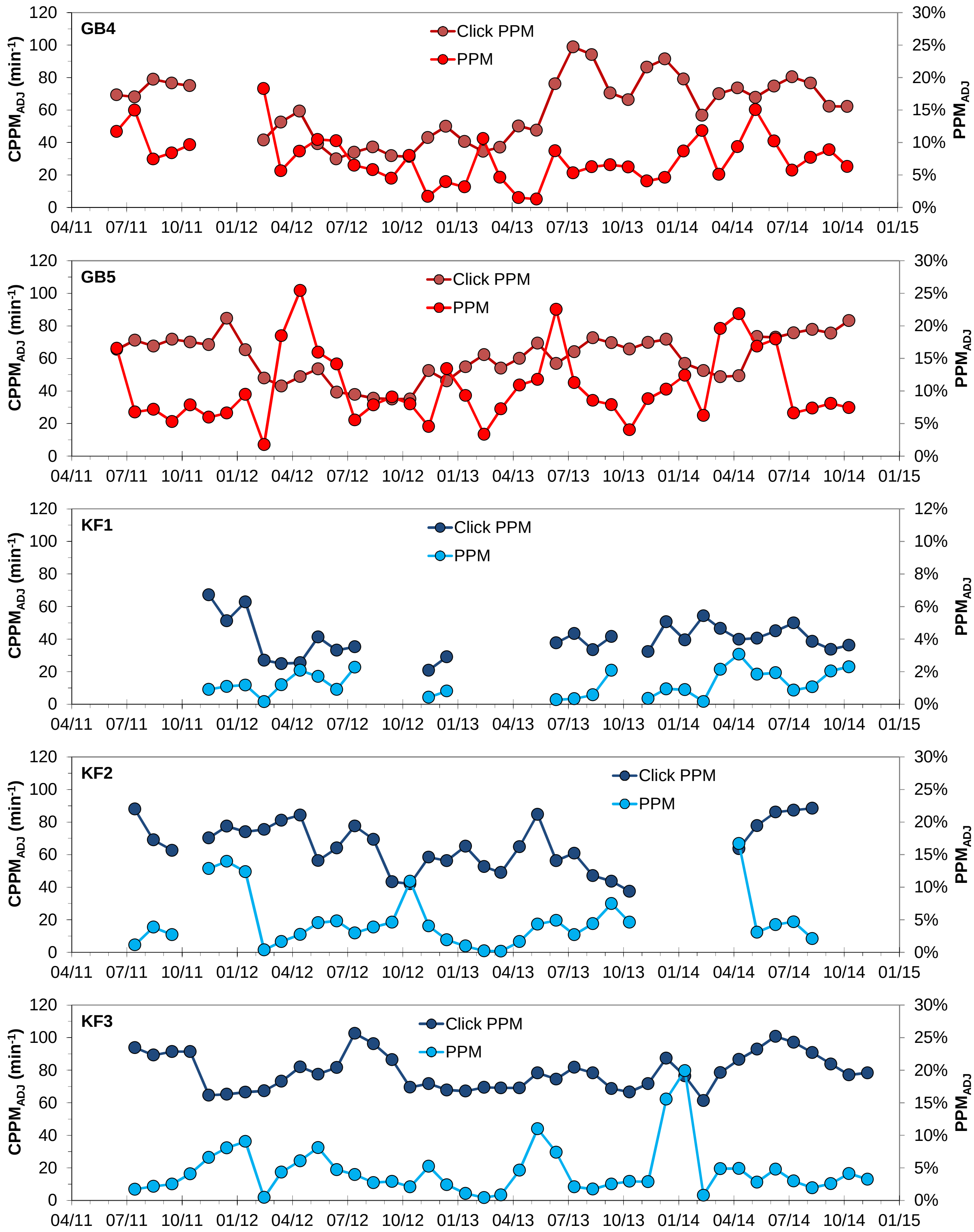
For $CPPM_{ADJ}$ (that was log-transformed) this corresponds to a relative change of $d^{'} = \exp(d) - 1$, whereas for PPM_{ADJ} (that was angular-transformed) the relative change was found by examining the effect of $\pm d$ relative to the mean level using the inverse of the angular transformation.

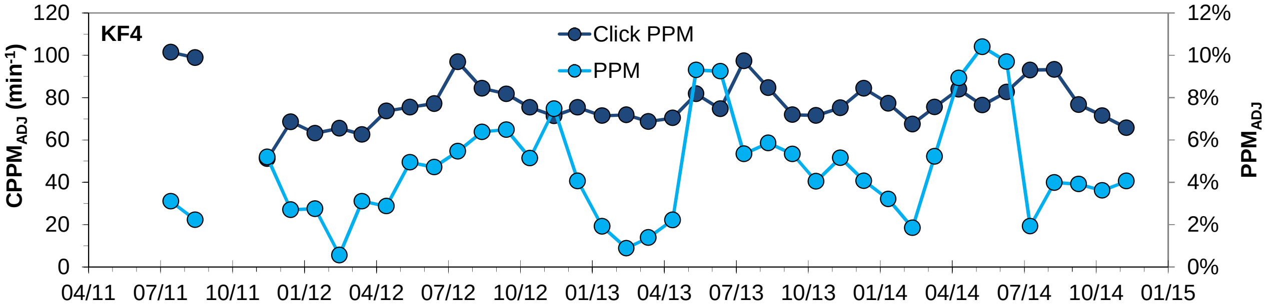
3 Results and discussion

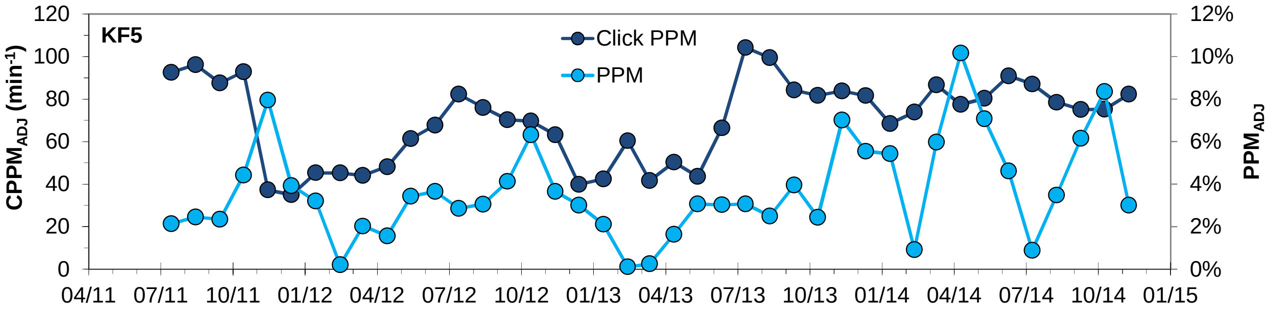
During the baseline period C-PODs were deployed in the study area between 23 June 2011 and 5 November 2014 at the 14 stations. The echolocation activity of harbour porpoises was assessed by means of the two indicators based on the recordings obtained from the C-PODs.

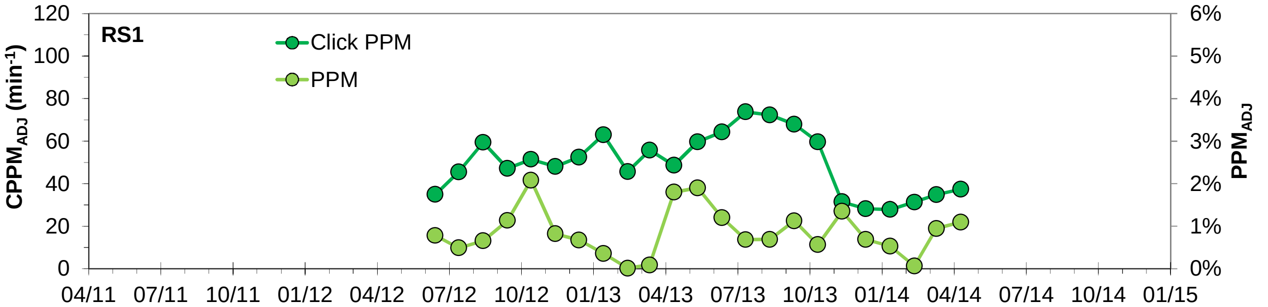
$CPPM_{ADJ}$ and PPM_{ADJ} were calculated from the C-POD recordings and displayed as monthly averages for the different stations (Fig. 3.1.1). There was a total of 12,338 days with C-POD monitoring data from the 14 positions with number of deployment days ranging from 381 at RS2 (due to deployment later in the study) to 1177 at KF5 during the baseline period (Table 3.1.1). Although, some stations were deployed later than others, all data can be included in the model. Clicks were recorded on most days (11,576 out of 12,338 days, ~94%). However, there were generally more silent days in January, February and March.

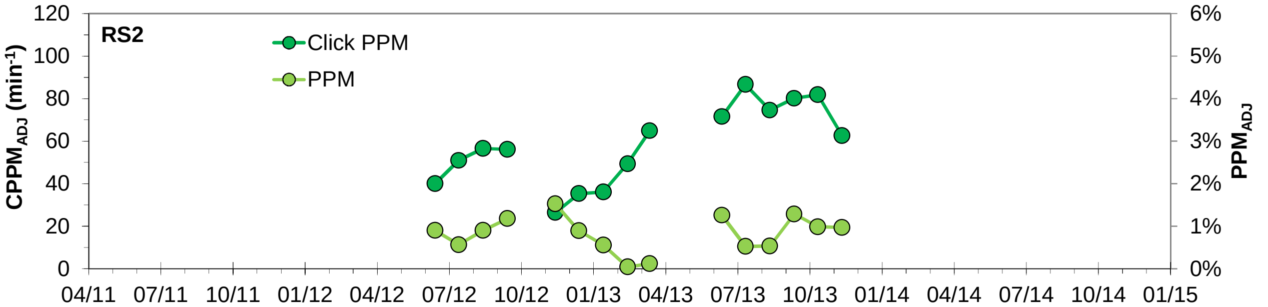


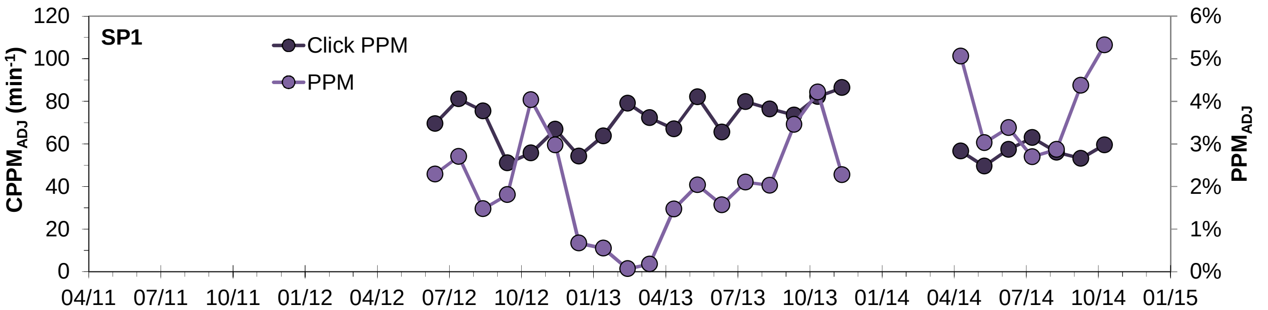

GB4
GB5
KF1
KF2
KF3
Click PPM
PPM
CPPM$_{ADJ}$ (min^{-1})
PPM$_{ADJ}$
04/11 07/11 10/11 01/12 04/12 07/12 10/12 01/13 04/13 07/13 10/13 01/14 04/14 07/14 10/14 01/15
0 20 40 60 80 100 120
0% 5% 10% 15% 20% 25% 30%
0% 2% 4% 6% 8% 10% 12%


KF4
Click PPM
PPM
CPPM$_{ADJ}$ (min^{-1})
PPM$_{ADJ}$
0
20
40
60
80
100
120
0%
2%
4%
6%
8%
10%
12%
04/11 07/11 10/11 01/12 04/12 07/12 10/12 01/13 04/13 07/13 10/13 01/14 04/14 07/14 10/14 01/15


KF5
Click PPM
PPM
CPPM$_{ADJ}$ (min^{-1})
PPM$_{ADJ}$
0
20
40
60
80
100
120
0%
2%
4%
6%
8%
10%
12%
04/11 07/11 10/11 01/12 04/12 07/12 10/12 01/13 04/13 07/13 10/13 01/14 04/14 07/14 10/14 01/15


RS1
Click PPM
PPM
CPPM$_{ADJ}$ (min^{-1})
PPM$_{ADJ}$
0
20
40
60
80
100
120
0%
1%
2%
3%
4%
5%
6%
04/11 07/11 10/11 01/12 04/12 07/12 10/12 01/13 04/13 07/13 10/13 01/14 04/14 07/14 10/14 01/15


RS2
Click PPM
PPM
CPPM$_{ADJ}$ (min^{-1})
PPM$_{ADJ}$
0
20
40
60
80
100
120
0%
1%
2%
3%
4%
5%
6%
04/11 07/11 10/11 01/12 04/12 07/12 10/12 01/13 04/13 07/13 10/13 01/14 04/14 07/14 10/14 01/15


SP1
Click PPM
PPM
CPPM$_{ADJ}$ (min^{-1})
PPM$_{ADJ}$
0
20
40
60
80
100
120
0%
1%
2%
3%
4%
5%
6%
04/11 07/11 10/11 01/12 04/12 07/12 10/12 01/13 04/13 07/13 10/13 01/14 04/14 07/14 10/14 01/15

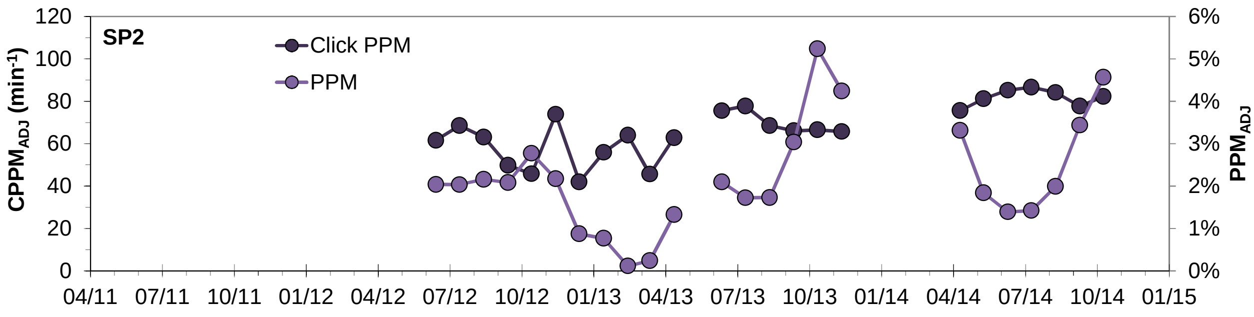


Figure 3.1.1. Monthly averages of CPPM$_{ADJ}$ (left axis) and PPM$_{ADJ}$ (right axis) calculated from C-POD data collected during the baseline (23 June 2011 to 5 November 2014). Stations from the same area have similar colours. Note that scaling for CPPM is the same for all plots, whereas it changes for PPM.

Temporal variations and variation between positions and C-PODs were relatively smaller for CPPM$_{ADJ}$ compared to PPM$_{ADJ}$ (Table 3.1.1). For the 14 stations the coefficients of variation varied between 23% and 54% for CPPM$_{ADJ}$ and between 81% and 140% for PPM$_{ADJ}$.

Table 3.1.1. Statistics of the two daily indicators monitored during the baseline periods in the Great Belt, Kalundborg Fjord, Reersø and Sprogø. Number of days with PPM is equal to the number of deployment days, whereas number of days with CPPM can be less due to days without any click recordings (missing value of CPPM).

Area	Position	CPPM$_{ADJ}$					PPM$_{ADJ}$				
		N	Min	Median	Mean	Max	N	Min	Median	Mean	Max
Great Belt	GB1	835	12.2	80.6	79.8	225	851	0.0%	2.3%	3.0%	24.4%
	GB2	824	13.4	62.4	63.1	180	833	0.0%	2.1%	3.0%	22.1%
	GB3	1151	16.4	70.0	69.6	156	1151	0.3%	6.5%	9.0%	101.4%
	GB4	1056	4.9	60.4	60.4	134	1062	0.0%	5.1%	7.3%	48.0%
	GB5	1144	9.4	60.6	60.0	123	1158	0.0%	8.2%	10.3%	61.1%
Kalundborg	KF1	569	3.6	36.1	40.7	168	661	0.0%	0.8%	1.3%	8.5%
Fjord	KF2	770	13.1	65.5	66.9	192	872	0.0%	2.3%	4.3%	58.6%
	KF3	1081	15.5	78.5	80.0	176	1167	0.0%	2.6%	4.5%	47.7%
	KF4	1066	12.9	76.4	77.5	264	1103	0.0%	3.3%	4.5%	31.1%
	KF5	1080	8.6	73.2	71.2	161	1177	0.0%	2.5%	3.7%	36.8%
Reersø	RS1	530	2.9	48.2	51.0	208	646	0.0%	0.6%	0.8%	6.6%
	RS2	304	3.1	59.6	60.2	257	381	0.0%	0.5%	0.8%	5.1%
Sprogø	SP1	626	11.6	67.4	66.9	169	679	0.0%	2.0%	2.4%	10.2%
	SP2	540	10.3	69.8	69.3	166	597	0.0%	1.5%	2.0%	14.1%

The seasonal patterns in echolocation showed a slightly higher click CPPM$_{ADJ}$ and PPM$_{ADJ}$ at most stations during summer months (Fig. 3.1.2). However, the seasonal variations were less pronounced compared to other POD studies (SW Baltic: Carstensen et al. 2006; E North Sea: Tougaard et al. 2006; S North Sea: Scheidat et al. 2011). This could suggest that the study area is occupied by a more resident porpoise population. There were large differences in PPM$_{ADJ}$ between winter months during the baseline period (Fig. 3.1.2), and these were most pronounced in Kalundborg Fjord, Reersø and Sprogø having very low PPM$_{ADJ}$ during February and to some degree also January and March. The almost opposite pattern was observed at stations GB3 and GB4 where PPM$_{ADJ}$ was highest in February, suggesting that porpoises may have shifted from the shallower coastal stations to the deeper and more open parts of the Great Belt. This shift in echolocation activity from shallower to deeper stations around February was also visible in the monthly means (Fig. 3.1.1); in particular, a complete drop in echolocation activity at KF2 and KF3. It is possible that this shift could have coincided with formation of thin surface ice in the more sheltered and near-shore stations or that the food source also moved to deeper warmer waters in these months. This pronounced shift between stations was not observed for $CPPM_{ADJ}$, likely because the remaining animals at each station continued the same feeding behaviour.

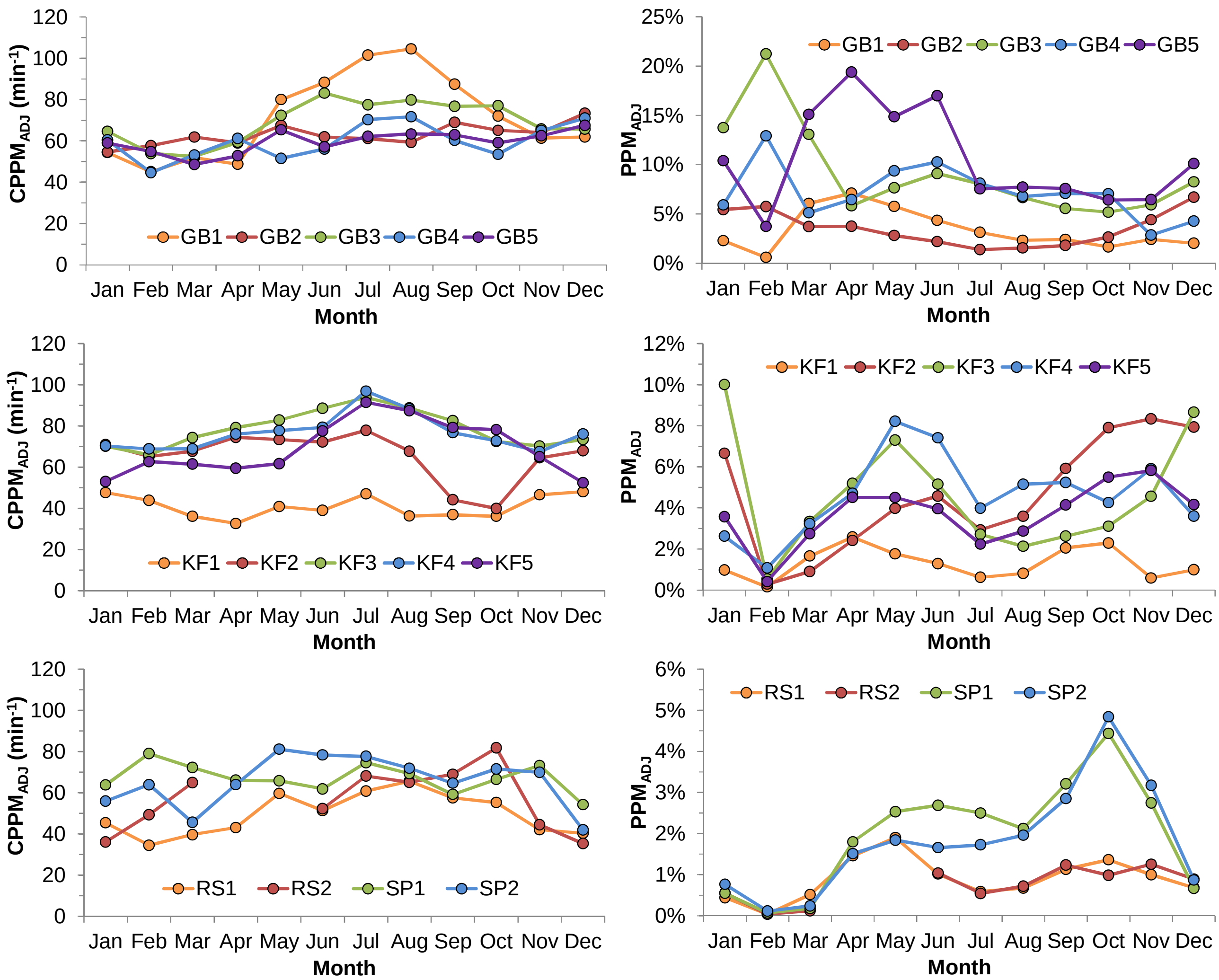


Figure 3.1.2. Monthly averages of CPPM (left panel) and PPM (right panel) extracted from C-POD data collected during the baseline (23 June 2011 to 5 November 2014). Note that the y-aksis in the right panels are different and that Great Belt (GB) and Kalundborg Fjord (KF) includes about 3 years of baseline data, while Reersø (RS) and Sprogø (SP) only include about 2 years baseline.

3.1 Covariation in echolocation activity among stations

The common seasonal patterns, albeit they are not strong, suggest that the porpoise population in the study area is governed by the same general mechanisms, most likely related to the availability of food. Despite the weak seasonal pattern in $CPPM_{ADJ}$, echolocation activity was mostly positively correlated across the 14 stations (Table 3.1.2). In fact, a significant correlation would only be expected if the temporal patterns at the stations were completely unrelated. However, the weak seasonality in $CPPM_{ADJ}$ reduced the signal-to-noise and resulted in several non-significant correlations. For example, KF1 displayed almost no seasonal pattern (Fig. 3.1.2) and only three correlations were significant. Two negative correlations cropped out for GB3, although the correlation coefficients were not large, and for GB3 only three correlations were significant (Table 3.1.2). These two stations are the deepest and it is possible that porpoises swim with a different angle at depth causing a different reception of clicks at the CPOD. However, this does not imply that pingers will affect echolocation activity differently at these stations, and it is reasonable to assume that responses in $CPPM_{ADJ}$ to pingers will be similar at all stations in the impact area.

Table 3.1.2. Correlation between daily observations of $CPPM_{ADJ}$. Positive and significant (P<0.01) correlations are highlighted in green and negative and significant (P<0.01) correlations are highlighted in red. Stations are ordered from south to north. Note that the correlation matrix is symmetrical around the diagonal.

	GB2	GB3	GB4	SP2	SP1	GB1	GB5	RS2	RS1	KF1	KF2	KF3	KF4	KF5
GB2	1.00	0.07	0.32	0.22	-0.02	0.06	0.37	0.15	0.13	0.08	0.04	-0.01	-0.06	0.06
GB3	0.07	1.00	0.07	0.37	-0.11	0.06	0.04	0.13	-0.20	0.24	-0.02	0.25	0.24	0.33
GB4	0.32	0.07	1.00	0.36	0.09	0.08	0.50	0.34	-0.02	0.08	0.18	0.11	0.19	0.34
SP2	0.22	0.37	0.36	1.00	0.23	0.17	0.36	0.19	0.19	0.28	0.29	0.26	0.19	0.45
SP1	-0.02	-0.11	0.09	0.23	1.00	0.11	0.04	0.26	0.18	0.15	0.07	-0.02	0.18	0.13
GB1	0.06	0.06	0.08	0.17	0.11	1.00	0.14	0.26	0.26	-0.07	0.16	0.29	0.29	0.28
GB5	0.37	0.04	0.50	0.36	0.04	0.14	1.00	0.25	0.10	0.20	0.22	0.05	0.07	0.12
RS2	0.15	0.13	0.34	0.19	0.26	0.26	0.25	1.00	0.31	0.40	-0.05	0.05	0.09	0.42
RS1	0.13	-0.20	-0.02	0.19	0.18	0.26	0.10	0.31	1.00	0.13	0.14	0.00	0.10	0.04
KF1	0.08	0.24	0.08	0.28	0.15	-0.07	0.20	0.40	0.13	1.00	0.11	0.04	0.01	0.05
KF2	0.04	-0.02	0.18	0.29	0.07	0.16	0.22	-0.05	0.14	0.11	1.00	0.28	0.13	-0.04
KF3	-0.01	0.25	0.11	0.26	-0.02	0.29	0.05	0.05	0.00	0.04	0.28	1.00	0.35	0.31
KF4	-0.06	0.24	0.19	0.19	0.18	0.29	0.07	0.09	0.10	0.01	0.13	0.35	1.00	0.38
KF5	0.06	0.33	0.34	0.45	0.13	0.28	0.12	0.42	0.04	0.05	-0.04	0.31	0.38	1.00

Correlations in PPM_{ADJ} were strong and positive for all stations except GB3 and GB4, and to a lesser degree GB2 (Table 3.1.3). In fact, PPM_{ADJ} at GB3 was mostly negatively correlated to temporal variations at the other stations. These negative correlations were mainly driven by inverse patterns of PPM_{ADJ} in winter months (Jan-Mar), where echolocation activity dropped substantially at most of the shallow stations and increased at GB3 and GB4 (Fig. 3.1.1 and 3.1.2). This could suggest that porpoises abandoning the shallower stations and moved to the deeper areas during these particular months and thus, supporting the assumption that it is the same porpoise population occupying the study area.

Table 3.1.3. Correlation between daily observations of PPM_{ADJ}. Positive and significant (P<0.01) correlations are highlighted in green and negative and significant (P<0.01) correlations are highlighted in red. Stations are ordered from south to north. Note that the correlation matrix is symmetrical around the diagonal.

	GB2	GB3	GB4	SP2	SP1	GB1	GB5	RS2	RS1	KF1	KF2	KF3	KF4	KF5
GB2	1.00	0.24	0.12	0.20	0.23	-0.08	0.08	0.18	-0.01	0.02	0.13	0.25	-0.02	0.21
GB3	0.24	1.00	0.28	-0.31	-0.29	-0.06	-0.04	-0.26	-0.40	-0.05	-0.19	-0.13	-0.18	-0.17
GB4	0.12	0.28	1.00	0.12	0.21	0.17	0.00	-0.04	-0.13	0.07	0.02	-0.16	-0.03	-0.02
SP2	0.20	-0.31	0.12	1.00	0.67	0.15	0.04	0.41	0.40	0.28	0.45	0.32	0.28	0.43
SP1	0.23	-0.29	0.21	0.67	1.00	0.13	0.08	0.42	0.46	0.36	0.42	0.22	0.27	0.44
GB1	-0.08	-0.06	0.17	0.15	0.13	1.00	0.34	0.02	0.18	0.33	0.18	0.20	0.29	0.21
GB5	0.08	-0.04	0.00	0.04	0.08	0.34	1.00	0.26	0.27	0.35	0.12	0.27	0.32	0.24
RS2	0.18	-0.26	-0.04	0.41	0.42	0.02	0.26	1.00	0.61	0.32	0.39	0.41	0.31	0.37
RS1	-0.01	-0.40	-0.13	0.40	0.46	0.18	0.27	0.61	1.00	0.35	0.45	0.30	0.32	0.38
KF1	0.02	-0.05	0.07	0.28	0.36	0.33	0.35	0.32	0.35	1.00	0.15	0.22	0.26	0.33
KF2	0.13	-0.19	0.02	0.45	0.42	0.18	0.12	0.39	0.45	0.15	1.00	0.43	0.27	0.42
KF3	0.25	-0.13	-0.16	0.32	0.22	0.20	0.27	0.41	0.30	0.22	0.43	1.00	0.26	0.32
KF4	-0.02	-0.18	-0.03	0.28	0.27	0.29	0.32	0.31	0.32	0.26	0.27	0.26	1.00	0.50
KF5	0.21	-0.17	-0.02	0.43	0.44	0.21	0.24	0.37	0.38	0.33	0.42	0.32	0.50	1.00

Excluding this winter phenomenon from the correlation analysis, a general positive and mostly significant correlation matrix emerged (Table 3.1.4). Correlation coefficients for the three significant negative correlations were generally small, without any systematic pattern. This correlation pattern suggests that for the remainder of the year echolocation activity followed similar patterns across the 14 stations.

Table 3.1.4. Correlation between daily observations of PPM_{ADJ} excluding data from January-March. Positive and significant (P<0.01) correlations are highlighted in green and negative and significant (P<0.01) correlations are highlighted in red. Stations are ordered from south to north. Note that the correlation matrix is symmetrical around the diagonal.

	GB2	GB3	GB4	SP2	SP1	GB1	GB5	RS2	RS1	KF1	KF2	KF3	KF4	KF5
GB2	1.00	0.16	0.06	0.20	0.23	-0.03	0.18	0.18	0.15	0.12	0.23	0.38	0.12	0.34
GB3	0.16	1.00	0.28	-0.10	-0.03	0.17	0.19	0.04	-0.13	0.11	-0.02	0.05	0.10	0.11
GB4	0.06	0.28	1.00	0.14	0.27	0.32	0.18	0.02	-0.02	0.28	0.07	-0.09	0.07	0.12
SP2	0.20	-0.10	0.14	1.00	0.53	0.15	-0.17	0.18	0.13	0.28	0.24	0.07	0.04	0.21
SP1	0.23	-0.03	0.27	0.53	1.00	0.13	-0.08	0.15	0.20	0.36	0.20	-0.06	0.04	0.23
GB1	-0.03	0.17	0.32	0.15	0.13	1.00	0.26	0.02	0.03	0.24	0.11	0.19	0.19	0.11
GB5	0.18	0.19	0.18	-0.17	-0.08	0.26	1.00	0.15	0.18	0.30	0.01	0.17	0.23	0.14
RS2	0.18	0.04	0.02	0.18	0.15	0.02	0.15	1.00	0.41	0.32	0.17	0.18	0.03	0.11
RS1	0.15	-0.13	-0.02	0.13	0.20	0.03	0.18	0.41	1.00	0.16	0.26	0.11	0.03	0.17
KF1	0.12	0.11	0.28	0.28	0.36	0.24	0.30	0.32	0.16	1.00	0.09	0.11	0.13	0.21
KF2	0.23	-0.02	0.07	0.24	0.20	0.11	0.01	0.17	0.26	0.09	1.00	0.25	0.13	0.28
KF3	0.38	0.05	-0.09	0.07	-0.06	0.19	0.17	0.18	0.11	0.11	0.25	1.00	0.13	0.10
KF4	0.12	0.10	0.07	0.04	0.04	0.19	0.23	0.03	0.03	0.13	0.13	0.13	1.00	0.37
KF5	0.34	0.11	0.12	0.21	0.23	0.11	0.14	0.11	0.17	0.21	0.28	0.10	0.37	1.00

The commonality of the seasonal patterns and the correlation analyses support the assumption that the study area is inhabited by the same porpoise population, which may at times lead to similar patterns across stations and at times to opposing patterns across stations, depending on local features such as depth, food availability and ice formation.

3.2 Variations in echolocation indicators

The seasonal variation in $CPPM_{ADJ}$ was significant, whereas there was no significant difference between the two areas and the seasonal variations of the two areas (Table 3.2.1, Fig. 3.2.1). There was a significant autocorrelation between consecutive days ($\rho = 0.2637$) implying that there were short-term fluctuations (a few days) in the porpoise echolocation activity. The residual variation (V[ε]) was the largest source of random variation, followed by variation between stations within area (V[$station(area)$]), C-POD specific variation (V[$podid$]) and variation between combinations of stations, years and months (V[$station(area) \times year \times month$]) (Table 3.2.2). However, interannual variation (V[$year$]), changes in the seasonal pattern between years (V[$year \times month$]), changes in the seasonal pattern between years and areas (V[$area \times year \times month$]), and changes in the seasonal pattern between stations (V[$station(area) \times month$]) were small and not significant. Overall, this suggests that in addition to the residual variation, variation between stations and C-PODs were most important, and temporal variation in $CPPM_{ADJ}$ was relatively unimportant.

Table 3.2.1. Analysis of variance for fixed effects used to model variations in $CPPM_{ADJ}$ and PPM_{ADJ}.

Fixed effect	**$CPPM_{ADJ}$**				**PPM_{ADJ}**			
	df	**Den df**	**F**	**p**	**df**	**Den df**	**F**	**p**
area	1	3	0.88	0.4165	1	12	0.14	0.7158
month	11	25	8.97	<0.0001	11	50.5	3.55	0.0010
area×month	11	25	0.97	0.4951	11	46.1	1.95	0.0564

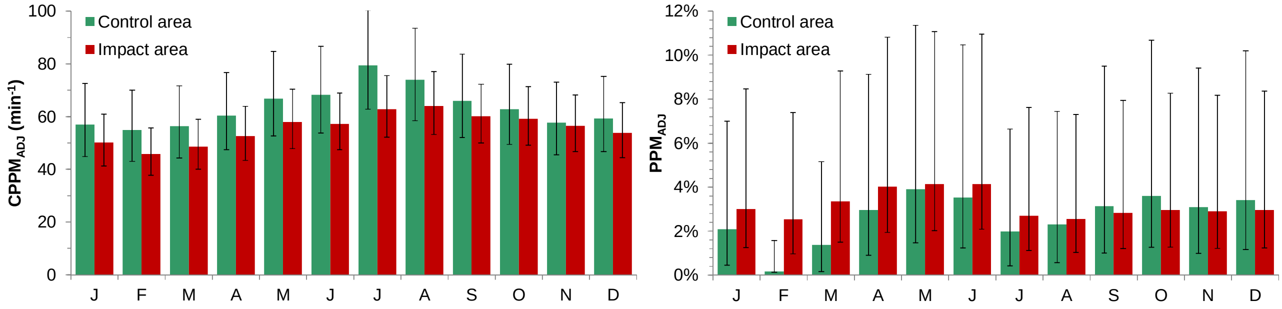


Figure 3.2.1. Monthly means of CPPM (left panel) and PPM (right panel) for the two areas calculated from the statistical model in Section 2.6.2. Error bars show the 95% confidence intervals of the means.

Table 3.2.2. Parameter estimates, their standard deviations and test statistics for the random components of modelling $CPPM_{ADJ}$ and PPM_{ADJ}. Estimates describe the variances of the random components, except for AR(1), which is the parameter describing the correlation between two consecutive days at the same station measured with the same C-POD.

Random effect	**$CPPM_{ADJ}$**				**PPM_{ADJ}**			
	Estimate	**StdErr**	**Z**	**p**	**Estimate**	**StdErr**	**Z**	**p**
podnr	0.0400	0.0096	4.19	<0.0001	0.00114	0.00036	3.18	0.0007
year	0.0000	-	-	-	0.00013	0.00015	0.86	0.1949
year×area	0.0036	0.0024	1.48	0.0693	0.00000	-	-	-
year×month	0.0002	0.0007	0.26	0.3988	0.00021	0.00015	1.37	0.0861
area×year×month	0.0000	-	-	-	0.00005	0.00016	0.28	0.3916
station(area)	0.0529	0.0228	2.32	0.0101	0.00545	0.00236	2.31	0.0105
station(area)×month	0.0021	0.0021	0.99	0.1610	0.00130	0.00029	4.50	<0.0001
station(area)×year×month	0.0176	0.0024	7.30	<0.0001	0.00124	0.00021	6.00	<0.0001
AR(1)	0.2639	0.0102	25.79	<0.0001	0.51430	0.00858	59.79	<0.0001
residual	0.0843	0.0011	74.51	<0.0001	0.00703	0.00009	77.15	<0.0001

PPM_{ADJ} displayed a significant seasonal pattern, which could be considered common to both control and impact areas, although the interaction *area×month* was almost significant at the 95% confidence level (Table 3.2.1; Fig. 3.2.1). This difference was mainly driven by low PPM_{ADJ} in the winter months in the control area. The PPM_{ADJ} difference between the two areas was small and not significant. Autocorrelation between consecutive days was larger for PPM_{ADJ} than $CPPM_{ADJ}$, which suggests that the presence of porpoises near a station had fluctuations on the order of several days. The residual variation and spatial variation between stations were the largest random sources of variation for PPM_{ADJ} (Table 3.2.2). Three additional random components also contributed with variation: 1) variation between C-PODs, 2) differences in the seasonal pattern between stations and 3) differences in the seasonal pattern between stations across years. Interannual variations at the level of the entire study are as well as for the control and impact areas were relatively unimportant (*year*, *year×month* and *area×year×month*).

For both indicators the C-POD variation was large (third largest component). Throughout the baseline period C-PODs were rotated between stations for logistic reasons, and this will also be the case during the pinger period. Therefore, this random source of variation will to some extent affect the BACI test, but exactly how cannot be included in the power analyses, since the rotation of C-PODs between stations cannot be determined beforehand for the pinger period. However, to provide a conservative estimate of the effect of C-POD variation, the model above was rerun without the *podnr* factor in order to redistribute this variation on the other factors (Table 3.2.3). For $CPPM_{ADJ}$ the C-POD variation was mainly included into the random factor for $station(area)\times year\times month$, whereas for PPM_{ADJ} the C-POD variation was mainly included into the random factors for $station(area)\times month$ and $station(area)\times year\times month$. The variances in Table 3.2.3 will be used for the power analyses below.

Table 3.2.3. Parameter estimates, their standard deviations and test statistics for the random components of modelling $CPPM_{ADJ}$ and PPM_{ADJ}. Estimates describe the variances of the random components, except for AR(1), which is the parameter describing the correlation between two consecutive days at the same station measured with the same C-POD. This model did not include C-POD specific variation.

Random effect	$CPPM_{ADJ}$				PPM_{ADJ}			
	Estimate	StdErr	Z	p	Estimate	StdErr	Z	p
Year	0.0052	0.0075	0.69	0.2441	0.00022	0.00023	0.95	0.1709
year×area	0.0056	0.0054	1.03	0.1518	0.00000	-	-	-
year×month	0.0000	-	-	-	0.00037	0.00021	1.79	0.0365
area×year×month	0.0000	-	-	-	0.00019	0.00019	1.00	0.1598
station(area)	0.0486	0.0207	2.34	0.0095	0.00491	0.00209	2.35	0.0095
station(area)×month	0.0000	-	-	-	0.00154	0.00031	4.94	<0.0001
station(area)×year×month	0.0504	0.0040	12.71	<0.0001	0.00138	0.00020	6.74	<0.0001
AR(1)	0.2639	0.0102	25.79	<0.0001	0.51430	0.00858	59.79	<0.0001
residual	0.0850	0.0011	74.59	<0.0001	0.00702	0.00009	77.13	<0.0001

The overall conclusion of the analysis of variance for the two indicators is that porpoise presence (PPM) at the different stations has a general seasonal variation, which is common for both control and impact areas. Over time porpoise echolocation activity (CPPM) is quite similar in the two areas, whereas temporal differences are observed at the station level. Thus, in addition to the general seasonal pattern in porpoise presence, the echolocation activity was relatively constant for the entire study area, but shifts in presence occurred at local scale, mostly as shifts from one station to another. This supports the suggestion that the entire study area is inhabited by one large porpoise population.

3.3 Power analysis

Correlation between consecutive days was larger for PPM_{ADJ} than for $CPPM_{ADJ}$ (Table 3.2.2), which resulted in standard errors of 0.026 and 0.069 for monthly aggregated values, respectively (compared to 0.015 and 0.053, if correlation was not accounted for). For $CPPM_{ADJ}$ changes in the interannual variation between the two areas ($area\times year$) was the largest variance contribution to the BACI effect, whereas variations between stations, year and month ($station(area)\times year\times month$) was the largest variance contribution to the BACI effect for PPM_{ADJ}. This implies that for $CPPM_{ADJ}$ it is important to have a monitoring program with many years, whereas for PPM_{ADJ} many combinations of station, year and month will improve the power of the BACI test.

The standard error of the BACI effect decreased with the number of years included in the pinger period (Table 3.3.1). Moreover, the standard error contributions of the four means were of similar magnitude with three years of data in the pinger period, because the amount of data used to calculate the means for the baseline and after periods were then similar. It is possible with a power of 80% to detect a 42% change in $CPPM_{ADJ}$ and a 22% change in PPM_{ADJ} with one full year of monitoring in the pinger period. With four years with pinger monitoring the relative changes that can be detected is reduced to 25% and 14%, respectively.

Table 3.3.1. Estimated standard error contribution for the four means to the BACI effect and the standard error of the BACI effect with 1-4 years of data in the after period. The bottom row shows the relative change in the two indicators to be detected with a probability of 80% using a confidence level of 95%. Note that the standard error contribution for the BC and BI means are constant, since they have been determined from the amount of data collected during the baseline.

Standard error and	**$CPPM_{ADJ}$**				**PPM_{ADJ}**			
relative change	**N_y=1 year**	**N_y=2 year**	**N_y=3 year**	**N_y=4 year**	**N_y=1 year**	**N_y=2 year**	**N_y=3 year**	**N_y=4 year**
SE[BC]	0.04130	0.04130	0.04130	0.04130	0.00391	0.00391	0.00391	0.00391
SE[BI]	0.03988	0.03988	0.03988	0.03988	0.00309	0.00309	0.00309	0.00309
SE[AC]	0.08023	0.05485	0.04426	0.03810	0.00620	0.00367	0.00278	0.00230
SE[AI]	0.07787	0.05399	0.04379	0.03779	0.00531	0.00331	0.00256	0.00216
SE[BACI]	0.12568	0.09602	0.08469	0.07859	0.00957	0.00702	0.00626	0.00590
%change	42.2%	30.9%	26.8%	24.6%	22.4%	16.2%	14.3%	13.5%

An optimal BACI design aims at balancing the monitoring effort in all four combinations of area versus period. Hence, the power improves considerably up to 3 years of monitoring in the after period, whereas the gain of adding an additional year of monitoring becomes relatively smaller. Therefore, to get the best statistical power, it is recommended to monitor the 14 stations for three years after the pinger are employed. This will make it possible to detect changes in $CPPM_{ADJ}$ and PPM_{ADJ} of 27% and 14% with sufficient power, respectively.

4 Conclusion

The baseline monitoring of the 14 C-POD stations have provided a strong dataset for the evaluation of the pinger introduction to the Great Belt expected to start in 2015. Ten stations (Great Belt and Kalundborg Fjord) have provided data since summer 2011, while additional four stations (Reersø and Sprogø) were deployed a year later in summer 2012. Five of the stations constitute a control area, whereas the remaining nine stations constitute an impact area, where pingers will be employed on fishing nets. The baseline monitoring is continuing until the pinger program is introduced, and additional baseline data may be harvested from the C-PODs. Therefore, this report should be seen as a status report only reporting on a part of the baseline period.

Analyses of recorded porpoise clicks in relation to the signal / noise level have revealed that the occurrence of porpoise clicks (PPM) decreased and the number of clicks recorded (CPPM) increased with decreasing signal / noise levels. This is most likely due to porpoise clicks, particularly those emitted from longer distances, being masked when the signal / noise level is low. However, a calibration model has been developed by which the two porpoise echolocation indicators can be adjusted to provide comparable values over time.

The seasonal patterns in the study area are significant and common to the control and impact areas, albeit not as strong as observed in other studies from the region. Over the four years with baseline data echolocation activity (CPPM) has remained relatively constant over the entire study area, but there have been shifts in porpoise presence (PPM) between stations, most pronounced in the winter period, where porpoises are suggested to move from shallower stations to the deeper in the Great Belt. Overall, the analyses suggest that the study area is inhabited by one large population of porpoises, which has not changed in numbers over the four years, but these porpoises utilise different areas at different times of the year. These results increase the confidence in that changes in the impact area different from those in the control area are linked to the employment of pingers.

If the employment of pingers has an effect on porpoise echolocation activity then continuing the current monitoring program for three years when pingers are implemented would allow for detecting relative changes of density (PPM) of around 14, with a probability of at least 80%. On the other hand, reducing the monitoring program during the employment of pingers to one year would allow for detecting relative changes of density (PPM) around 22% and echolocation behaviour CPPM around 42%. It would be optimal to continue the monitoring efforts during the pinger employment period for three years to obtain the similar amount of data as collected during the baseline.

5 Acknowledgements

A sincere thanks to Torben Vang, Lars Renvald, Anders Galatius, Lonnie Mikkelsen, Mikkel Villum Jensen and the brave ship, Thyra, who gave invaluable help during field work. The Danish Maritime Authority has given permission to the deployment of the C-PODs. The C-POD data from the marine NOVANA programme was made available from the Nature Agency and DCE. The project is financed by the Danish AgriFish Agency under the Ministry of Food, Agriculture and Fisheries with constructive help from Anja Gadgård Boye.

6 References

Akamatsu, T., Teilmann, J., Miller, L.A., Tougaard, J., Dietz, R., Wang, D., Wang, K., Siebert, U. & Naito, Y. (2007). Comparison of echolocation behaviour between coastal and riverine porpoises. - Deep-Sea Research Part II 54(3-4): 290-297.

Carlström, J., Berggren, P. and Tregenza, N.J.C. (2009) Spatial and temporal impact of pingers on porpoises. Canadian Journal of Fisheries and Aquatic Science 66: 72-82.

Carstensen, J., Henriksen, O.D. and Teilmann, J. (2006). Impacts on harbour porpoises from offshore wind farm construction: acoustic monitoring of echolocation activity using porpoise detectors (T-PODs). Marine Ecology Progress Series, vol 321: 295-308.

Cressie, N. A. C. (1993) Statistics for Spatial Data. Revised edition. New York: John Wiley and Sons.

Culik, B.M., Koschinski, S., Tregenza, N., Ellis, G.M. (2001) Reactions of harbor porpoises *Phocoena phocoena* and herring *Clupea harengus* to acoustic alarms. Marine Ecology Progress Series, 211: 255-260.

Green, R.H. (1979). Sampling Design and Statistical Methods for Environmental Biologists, Wiley, Chichester.

IWC. 1994. Report of the workshop on mortality of cetaceans in passive fishing nets and traps. . Rep Int Whal Comm Spec Issue 15:6-57.

Kraus, S.D., Read, A.J., Solow, A., Baldwin, K., Spradlin, T., Anderson, E., Williamson, J. (1997) Acoustic alarms reduce porpoise mortality. Nature 388: 525.

Kyhn, L.A., Tougaard, J. Thomas, L., Poulsen, L.R., Steinbæk, J. Desportes,G., Amundin, M. and Teilmann, J. (2012) From echolocation clicks to animal density – acoustic sampling of harbour porpoises with static dataloggers. Journal of the Acoustic Society of America 131(1): 550-560.

Kyhn, L.A., Jørgensen, P.B., Carstensen, J., Bech, N.I., Tougaard, J., Dabelsteen, T. nad Teilmann, J. (in press). Pingers cause temporary habitat displacement of harbour porpoises (*Phocoena phocoena* L.). Marine Ecology Progress Series.

Linnenschmidt, M., Teilmann, J., Akamatsu, T., Dietz, R. and Miller, L.A. (2012). Biosonar, dive and foraging activity of satellite tracked harbour porpoises (Phocoena phocoena). Marine Mammal Science 29(2): E77–E97, DOI: 10.1111/j.1748-7692.2012.00592.x.

Northridge, S., D. Sanderson, A. Mackay, and P. Hammond. 2003. Analysis and mitigation of cetacean bycatch in UK fisheries. DEFRA, Project MF0726.

Read, A. 1994. Interactions between cetaceans and gillnet and trap fisheries in the Northwest Atlantic. Rep Int Whal Comm Spec Issue 15:133-147.

Scheidat, M., Tougaard, J., Brasseur, S., Carstensen, J., van Polanen Petel, T., Teilmann, J., Reijnders, P. (2011) Harbour porpoises (*Phocoena phocoena*) and wind farms: a case study in the Dutch North Sea. Environmental Research Letters 6: 025102, doi:10.1088/1748-9326/6/2/025102.

Sveegaard, S., Galatius, A. and Teilmann, J. (2014) Overvågning af sæler og marsvin. In Hansen, J.W. & Petersen, D.L.J. (red.) 2012: Marine områder 2012. NOVANA. Tilstand og udvikling i miljø- og naturkvaliteten. Aarhus Universitet, DCE - Nationalt Center for Miljø og Energi. - Videnskabelig rapport.

Sveegaard, S. (2011) Spatial and temporal distribution of harbour porpoises in relation to their prey. Ph.D. Thesis. National Environmental Research Institute, Aarhus University, Denmark.

Teilmann, J., Tougaard, J. and Carstensen, J. (2009) Baseline monitoring of harbour porpoises -Rødsand 2 Offshore Wind Farm. NERI Commissioned Report to E.ON Vind Sverige. Aarhus University, Roskilde, Denmark. 58 pp.

Tougaard, J., Carstensen, J., Wisz, M.S., Jespersen, M., Teilmann, J., Ilsted Bech, N., Skov, H. (2006) Harbour porpoises on Horns Reef: Effects of the Horns Reef Wind Farm. Final Report to Vattenfall A/S. NERI, Roskilde, Denmark.

Underwood, A.J. (1994). On beyond BACI: sampling designs that might reliably detect environmental disturbances, Ecological Applications 4: 3–15.

Verfuß, U.K., Miller, L.A., Pilz, P.K.D. and Schnitzler, H.U. 2009. Echolocation by two foraging harbour porpoises (*Phocoena phocoena*). Journal of Experimental Biology 212, 823-834.

Vinther, M. 1999. Bycatches of harbour porpoise (*Phocoena phocoena* L.) in Danish set-net fisheries. J. Cetacean Res. Manage 1:123-135.

[Blank page]

PORPOISE MONITORING IN PINGER-NET FISHERY

Status report

Harbour porpoises are part of the assignment of 16 Natura 2000 areas in Danish waters and Denmark are obliged to monitor and protect the species. The harbour porpoise faces the threat of entanglement in gill nets but by using acoustic alarms, so-called “pingers” placed on the nets, bycatch can be reduced. Pingers may, however, scare the porpoises out of important areas such as the Natura 2000 areas. This project aim to examine if porpoise density will change in the Great Belt, when mandatory use of pingers in all set net fisheries are enforced during a limited time period from mid-2015. By comparing the presence of porpoises before, during and after pingers are introduced in the Great Belt, with a control area in Kalundborg Fjord, we will be able to estimate the effect of pingers on porpoises in relation to density and acoustic behaviour. Porpoise presence is examined by deployment of acoustic data loggers (C-PODs) that can detect echolocation sounds emitted almost continuously by porpoises during foraging, communication and orientation.

This report covers the baseline period from July 2011 to October 2014 for the 14 C-POD stations that have listened for porpoises more or less continuously during this period. The porpoise detections were analysed as PPM (Porpoise Positive Minutes) and CPPM (no. of clicks during each PPM. This may be interpreted as a measure of acoustic behaviour). Both are aggregated as average values per 24 hours. The results show that the seasonal patterns in the study area are significant and common to the control and impact areas. Over the four years with baseline data, echolocation activity (CPPM) has remained relatively constant over the entire study area, but there have been seasonal shifts in porpoise presence (PPM) between stations, most pronounced in the winter period, where porpoises apparently move from shallower stations to the deeper stations. Power analysis show that the current baseline data and a continuation of the monitoring program during the employment of pingers for one year, would allow for detecting relative changes of density (PPM) around 22% and echolocation behaviour (CPPM) around 42%. If monitoring continue for up to four years the relative changes that can be detected is reduced gradually to 14% and 25%, respectively.

ISBN: 978-87-7156-145-6
ISSN: 2245-019X