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Cetacean passive acoustic network in the Belgian part of the North sea

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In 2016, a design for detecting harbor porpoises (*Phocoena phocoena*) in the Belgian part of the North Sea (BPNS) was developed in the framework of the LifeWatch project using Passive Acoustic Monitoring (PAM) loggers. In 2018, the network of deployments fully matured, and eight locations across the BPNS are presently housed with a C-POD (Chelonia Ltd., UK), a PAM logger moored on the seafloor using a multi-use platform. The PAM logger continuously listens for harbor porpoise click trains, but only stores the click parameters. This paper presents the generated data series of harbor porpoise click trains at a minute-resolution and the details on the individual click trains. The field recordings, methodology and processing are described, along with its data curation, integration and quality control. The data are annually published online in a standardized format, accompanied with the metadata description, and labelled with a digital object identifier for traceability. Data are published under a CC-BY license, allowing the use of data under the condition of providing reference to the original source.

Background & Summary

Harbor porpoises (*Phocoena phocoena*) are widespread, highly mobile animals[1] and the most abundant cetacean species in the North Sea[2]. Despite their almost extinction in the 1960s in the southernmost part[3], the last aerial survey of the North Sea (Small Cetacean Abundance in the North Sea IV; SCANS-IV) showed remarkable estimates of 340,000 to 560,000 individuals (95% C.I.) with a southward redistribution of the population[2,4–6]. The Belgian part of the North Sea (BPNS) presents a unique habitat for the species. It is a shallow (max. 40 m deep) and highly dynamic system, with a mobile subtidal sand bank system[7]. Human activities are intense in the BPNS, from heavily used shipping lanes to offshore wind farms (OWFs)—all of which continuously produce noise pollution[8]. This influences the behavior and presence of harbor porpoises, which can ultimately weaken their survival[9].

Previous non-invasive efforts to monitor the abundance of *P. phocoena* in the North Sea involved aerial surveys (e.g., SCANS; Royal Belgian Institute of Natural Sciences[10]) and monitoring of stranding events[5]. Dependent on good weather and daylight, these surveys took place mainly during the summer (June to August), when harbor porpoises were at their lowest densities in the BPNS. Consequently, the survey's results were not representative of the abundance and habitat use of the species over the entire year in Belgian waters, making observations a partial snapshot of the population at that particular moment.

Communication of odontocete cetaceans can cover various distances, depending on its function. Whether used for communication (whistles or short pulses[11]), or for foraging and navigation (clicks of echolocating odontocetes[12]), their echolocation provides us with invaluable clues of their habitat use, foraging, social structure and behaviour[13]. Passive acoustic monitoring (PAM) presents the opportunity to record the narrow-band high frequency (NBHF) click sequences of porpoises year-round without interfering with the animals' activities, independent of the external weather conditions. However, oceanographic factors (e.g., tides, sediment transport) can be influenced by the weather in certain systems (e.g., sandbanks), and thus affect the quality of the recordings. Additionally, porpoise behavioral states influence the probability of detecting the vocalizing animal, which can lead to over- or underestimations of abundance[14]. Although there is a general risk of knowledge on the behavioral context of these sounds, PAM is proven efficient not only in monitoring distribution (presence/absence), but also in observing behaviors (e.g., foraging, traveling)[15,16] and in estimating absolute abundances of small cetaceans over time and space[17].

As top predators, harbor porpoises play a crucial role in the ecosystems' health and functioning[18]. Their coastal distribution exposes them to direct and indirect anthropogenic stressors such as habitat destruction[19],

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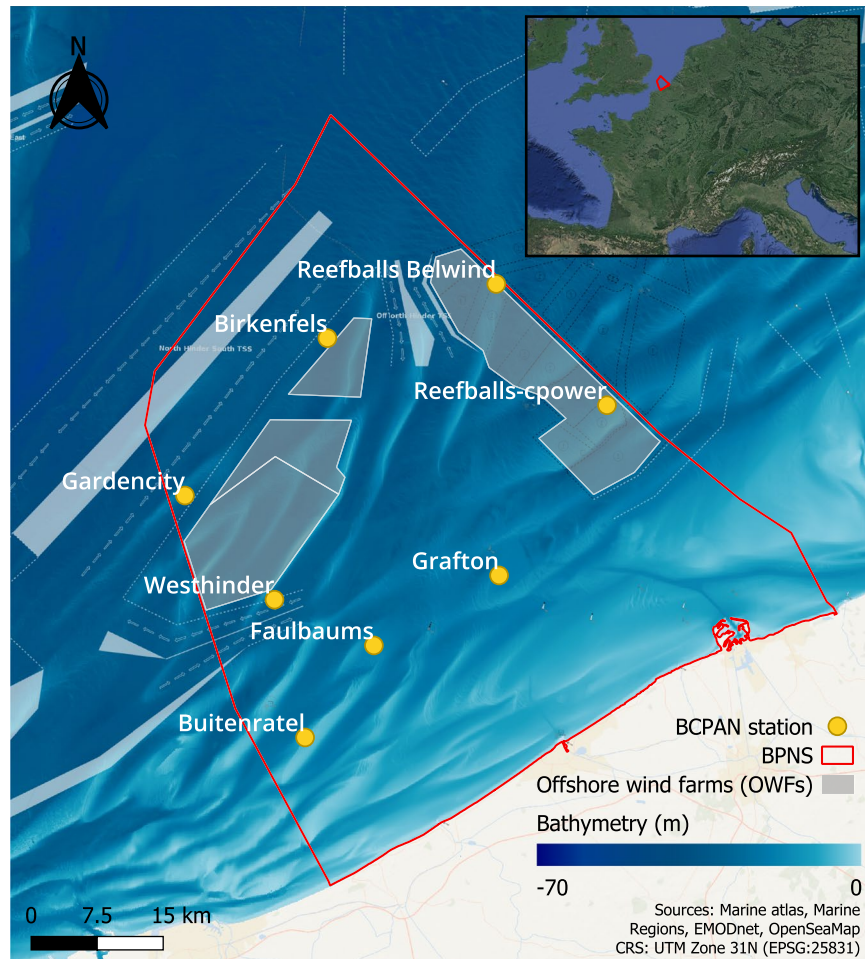
Fig. 1 Overview of the 8 stations (yellow circles) present in the Belgian cetacean passive acoustic network (BCPAN) within the Belgian part of the North Sea (BPNS; red line) and offshore wind energy zones (Offshore Wind Farms, OWFs; grey polygons). Bathymetry (in meters) and the most transited shipping routes (white) are displayed for context[62–65]. The red polygon in the inset map shows the location of the BPNS from a larger map scale.

bycatch[20], noise pollution[8], overfishing of prey species[21], toxic chemicals[22,23] and climate change[24]. The number of individuals artificially removed from the population exceeded the maximum sustainable yield (MSY) for several European populations[20], prompting the implementation of special conservation measures in the European Union (EU). They are protected under national and international laws (Annex II, EU Habitats Directive, Appendix II of Convention for the Conservation of Migratory Species of Wild Animals[21]) and included in the EU Marine Strategy Framework Directive (MSFD)[25] and the OSPAR convention[26]. To understand their distribution and presence over time and space in the BPNS, a long-term continuous data series at high spatiotemporal resolution was needed.

In line with this objective, the Belgian cetacean passive acoustic network (BCPAN; Fig. 1) was established within the LifeWatch observatory[27]. Using Cetacean Porpoise Detectors (C-PODs; Chelonia Ltd., UK), or PAM loggers, echolocation clicks of odontocete cetaceans (except for sperm whales) can be recorded. C-PODs continuously listen for high frequency clicks (20–160 kHz), with a high-pass filter of 20 kHz, and stores solely the duration and other parameters (e.g., frequency, sound pressure level (SPL), bandwidth, etc.) of these clicks making it power-efficient. C-PODs were either moored onto a navigation buoy at 3-m below the sea surface or anchored to shipwrecks or artificial hard structures until 2017. However, due to the high number of lost devices and chain and wave breaking noise, it was decided that all C-PODs must be deployed on the seafloor. By summer 2018, this was achieved, and all C-PODs were deployed on a multi-use platform—an in-house developed tripod[28] slightly modified to accommodate a C-POD, which can be moored on the seafloor.

With long-lasting batteries, requiring a small memory capacity and minimal manipulation, this sensor network is key for obtaining long-term data series on porpoise presence. This data series can potentially contribute to climate change research, which relies on decades of background data to obtain significant trends in ecological parameters[15,29]. External environmental factors (e.g., seasonality, daylight, tides and temperature) can also be related in distribution analyses[30,31], potentially leading to the study of climate change effects and trends on the species once baseline parameters are established[30,32]. The entire pathway to obtain and maintain this data series,
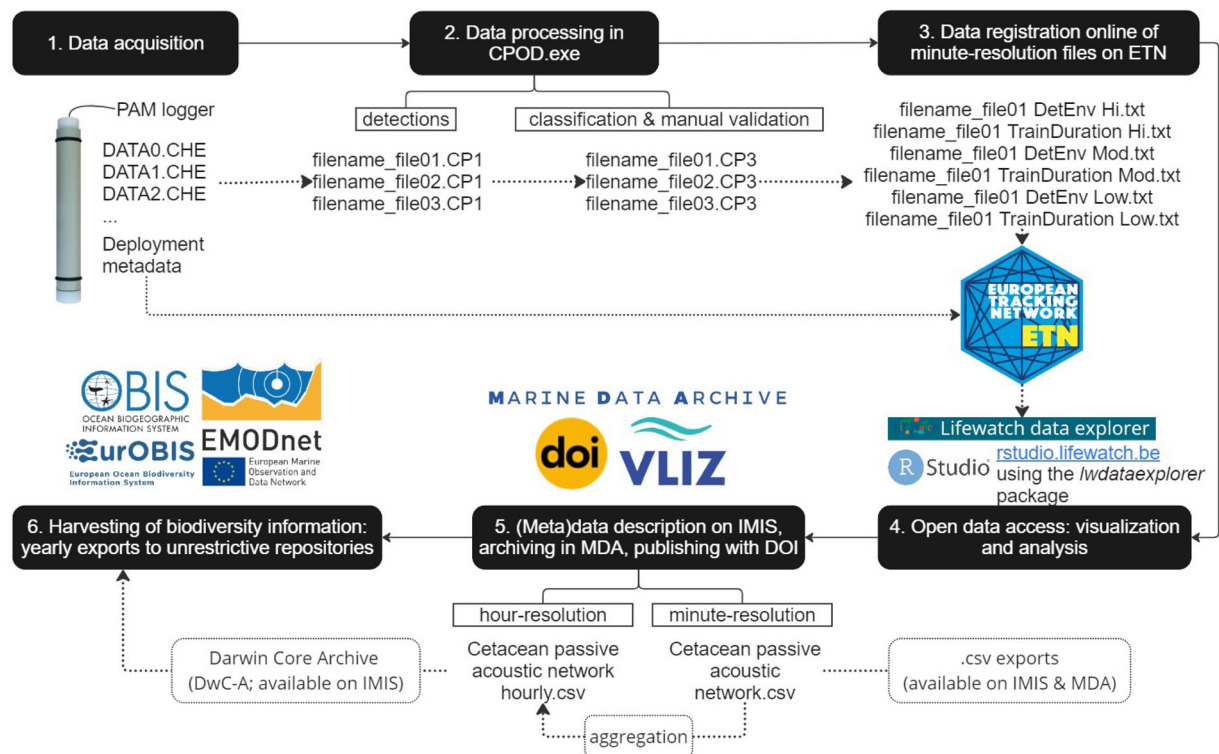
Fig. 2 Schematic overview to obtain and maintain the harbor porpoise data series from data acquisition to harvesting of biodiversity information (solid arrows), and the data files involved in each step (broken arrows). Data read from the PAM loggers (DATA0.CHE, DATA1.CHE,…) are developed into .CP1 files, classified and manually validated as .CP3 files, and exported as (1) Detections and environment and (2) Train duration one-minute resolution text files according to quality class. The text files as well as the deployment metadata are uploaded on the European Tracking Network (ETN[33]) database, which could be visualized and analyzed through the LifeWatch data explorer[36] and the *lwdataexplorer*[38] package accessible in R. Datasets in minute- and hour-resolution are both published yearly with a Digital Object Identifier (DOI) on the Integrated Marine Information System (IMIS[39–47]) and Marine Data Archive (MDA[48]). Datasets in hour-resolution, aggregated from the minute-resolution datasets, are published in a Darwin Core Archive format (DwC-A) on IMIS[49] and in several unrestrictive repositories.

from data acquisition towards online data accessibility, is described in this paper along with its data curation, integration and quality control (Fig. 2).

Methods

Setting up C-PODs. C-PODs (Chelonia Ltd., UK) store clicks and the parameters of these clicks on a pre-programmed SD card. A maximum of 4096 clicks can be stored per minute to prevent high battery consumption and to avoid the SD card from being filled up with noise. A battery pack of 10 D-cell alkaline batteries provides enough power to record for 4 to 6 months. The default setting of logging was applied, wherein the C-POD does not log data when lying horizontally. The C-POD is therefore maintained in a horizontal position until it is deployed to avoid unnecessary consumption of battery power and memory space.

Deployment, retrieval and maintenance of C-PODs. Since the summer of 2018, all C-PODs, or PAM loggers, have been deployed on a multi-use platform (Fig. 3) across the ten stations of the BCPAN. The multi-use platform is an in-house developed tripod frame[28] with a floatable collar (Deepwater Buoyancy Inc.), which was primarily designed to deploy acoustic receivers with an acoustic release system for fish telemetry purposes. The platform was slightly modified to fit a C-POD in a fixed vertical position in the floatable collar next to the acoustic receiver with an acoustic release system (Vemco VR2AR or Thelma Biotel TBR800). The floatable collar is connected to the tripod with a rope, of length 1.5 to 2 times the depth of the water column of the specific station, carefully coiled inside the central canister. The acoustic release holds the floatable collar tight to the tripod and allows the retrieval of the entire platform (details of design and deployment protocol were outlined[28]). The equipped tripod is lifted by the A-frame of the RV Simon Stevin using the deployment eye, lowered into the water column to the seafloor, and disconnected using a quick release. The design of the tripod assures its upright position on the seafloor ensuring the full-time recording of the sensors.

About every 4 months, the stations of the BCPAN (Fig. 1) are revisited for data acquisition and redeployment. The platform is retrieved through the acoustic release system by establishing a connection between the hydrophone of the deck unit at the surface and the acoustic release on the tripod. Once acoustic release
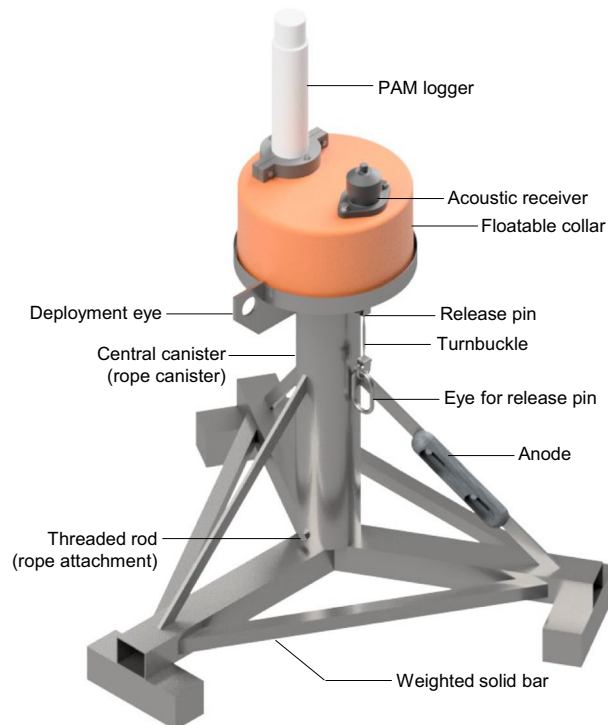
Fig. 3 Technical drawing of the multi-use platform—a galvanized-steel tripod frame with a floatable collar, that can hold both a PAM logger and an acoustic receiver, attached with a rope carefully coiled inside the central canister. The rope is attached to the bottom of the tripod through a threaded rod. The acoustic release pin is connected to the tripod's eye with turnbuckles. Weighted horizontal bars give additional weight to the tripod, while the anode protects the tripod from corrosion. The deployment eye is used to lift and lower the entire platform into the water column.

A. Detections and environment text file	
Variable	**Description**
File	Name of the input file
ChunkEnd	End in date (dd-mm-yyyy) and time (hh:mm:ss) format of the click trains exported from the file
Minute	Number of minutes since the start of the year 1900. Used for the calculation of the time of recording
Temp	Average daily temperature range (°C) of the POD
Angle	Angle (°) to vertical at which the C-POD was oriented
MinutesON	Total duration in minutes for which the POD was active and collecting data in a vertical position
DPM	Detection positive minutes or the number of minutes in which a click train of the selected species was recorded
Nfiltered	Number of clicks in trains passing through the chosen filter per minute
Nall	Total unfiltered number of clicks found in the .CP1 file for the same period
%TimeLost	Percentage of time in periods when the POD reached the maximum logging limit for a minute. Since the unit in this case was minutes, it is the percentage of minutes lost.
SonarRisk	Risk of sonar presence if identified (0- absent, 1-present)
kHz_continuous_noise	The frequency (kHz) of any continuous noise identified
LandmarkSeq_total	Sequences of trains showing a linear decrease in inter-click interval (ICI), which occur as porpoises approach a landmark, which in this case is either the POD or other structures nearby or beyond the POD.
B. Train duration total text file	
Variable	**Description**
File	Name of the input file
ChunkEnd	End in date (dd-mm-yyyy) and time (hh:mm:ss) format of the click trains exported from the file
Millisecs	Sum of the duration of trains logged (milliseconds)
Nfiltered	Number of clicks in trains passing through the chosen filter per minute
Nall	Total unfiltered number of clicks found in the .CP1 file for the same period
MinsOn	Total duration in minutes for which the POD was active and collecting data in a vertical position

Table 1. Description of the variables in the Detections and environment (A) and Train duration total (B) text files extracted from CPOD.exe after manual validation[61].

|	Format	Repository	Description
Data record 1	R data frame object	LifeWatch data explorer[36], lwdataexplorer[38] R package	Merged results in minute-resolution from the Train duration total and Detections and environment text files uploaded on ETN[33]. The period and quality of data can be selected by the user using the *getCpodData* function in RStudio from the *lwdataexplorer*[38] package.
Data record 2	Cetacean passive acoustic network *year*.csv	IMIS[39–47], MDA[48]	Published dataset of merged results in minute-resolution per year (Table 3). Only high- and moderate-quality click trains are published.
Data record 3	Darwin Core Archive (DwC-A)	OBIS[53], EurOBIS[52], EMODnet[50], GBIF[51], IMIS[49]	Harvested biodiversity information from the hourly yearly export, aggregated from the minute-resolution datasets (Data record 2[39–47]).

Table 2. Various data records of processed C-POD data published online through several public repositories such as the Integrated Marine Information System (IMIS[39–47,49]), European Marine Observation and Data Network (EMODnet[50]), Global Biodiversity Information Facility (GBIF[51]), European Ocean Biodiversity Information System (EurOBIS[52]) and the Ocean Biodiversity Information System (OBIS[53]).

Variable Name	Description
Coordinate variables	Contain information of the location and timestamps of recorded data
Projectname	Name of the project
Station	Name or code of sampling station or receiver code
Zone	Name or code of sampling station or receiver code (no longer in use)
Latitude	Centre latitude in decimal degrees, WGS84.
Longitude	Centre longitude in decimal degrees, WGS84.
Datetime	Date (dd/mm/yyyy) and time (hh:mm:ss; 24 h, UTC) at the beginning of sample time bin
Primary data variables	Contain data quality metrics derived from the acoustic device primary measurement
Species	Harbour porpoise (*Phocoena phocoena*)
Milliseconds	Duration of click trains in the specified time bin
Number_clicks_filtered	Recognized number of click trains in the specified time bin
Number_clicks_total	Total number of recorded clicks in the specified time bin
Lost_minutes	Number of minutes in which the number of clicks was more than 4096
Recorded	Number of minutes that the C-POD was actively recording in a fixed position underwater
DPM	Number of Detection positive minutes (DPM); that is, a porpoise click train was detected in that minute.
Angle	Angle (°) at which the C-POD was oriented
Technical variables	Describe the technical properties of the equipment or the dataset
Mooring_type	Location of the recording device in the water column: Surface-buoy or bottom mooring
Receiver	Serial number of the C-POD
Quality	Hi = high; Mod = moderate
Deployment_fk	Link to the deployment metadata in the European Tracking Network (ETN[33]) database

Table 3. Description of the variables from the yearly published dataset (Data record 2[39–47]) at the Integrated Marine Information System (IMIS[39–47]) of VLIZ. Variables are grouped into three classes: coordinate variables, primary data and technical variables. Only high- and moderate-quality click trains are published in the yearly exports.

is activated, the floatable collar holding the C-POD and the acoustic receiver surfaces and is retrieved on the rigid-hulled inflatable boat (RHIB). The rope connecting the floatable collar to the tripod is disconnected from the floatable collar and attached to the A-frame of the main Research Vessel for a full recovery of the tripod. The tripod and floatable collar are cleaned, rope is stored back in the rope canister and the data of the C-POD and the acoustic receiver are downloaded, new batteries are switched and both sensors are reactivated for a new deployment at sea to start a new recording cycle. The deployment metadata which includes the coordinates of the station and the date and time (UTC) of C-POD activation, deployment and retrieval are manually logged in the European Tracking Network (ETN[33]). While C-POD activation is defined as the date and time that the C-POD was activated, the deployment timestamp is logged at the time that the platform is fixed on the seafloor, and the retrieval timestamp immediately prior to the activation of acoustic release to retrieve the platform. Any abnormality in the deployment, hardware or data are stored in the 'Comments' section of ETN[33].

Data acquisition and processing. Using the CPOD.exe software, data recorded by a C-POD is read from the SD card, stored at the internal server of VLIZ (Vlaams Instituut voor de Zee - Flanders Marine Institute), processed, classified and manually validated (Fig. 2). Data read from the SD card (DATA0.CHE, DATA1.CHE,…) are developed into .CP1 files containing all detected clicks. From the .CP1 files, the click trains originating from porpoise clicks (narrow-band high frequency clicks) are automatically detected using the built-in KERNO classifier
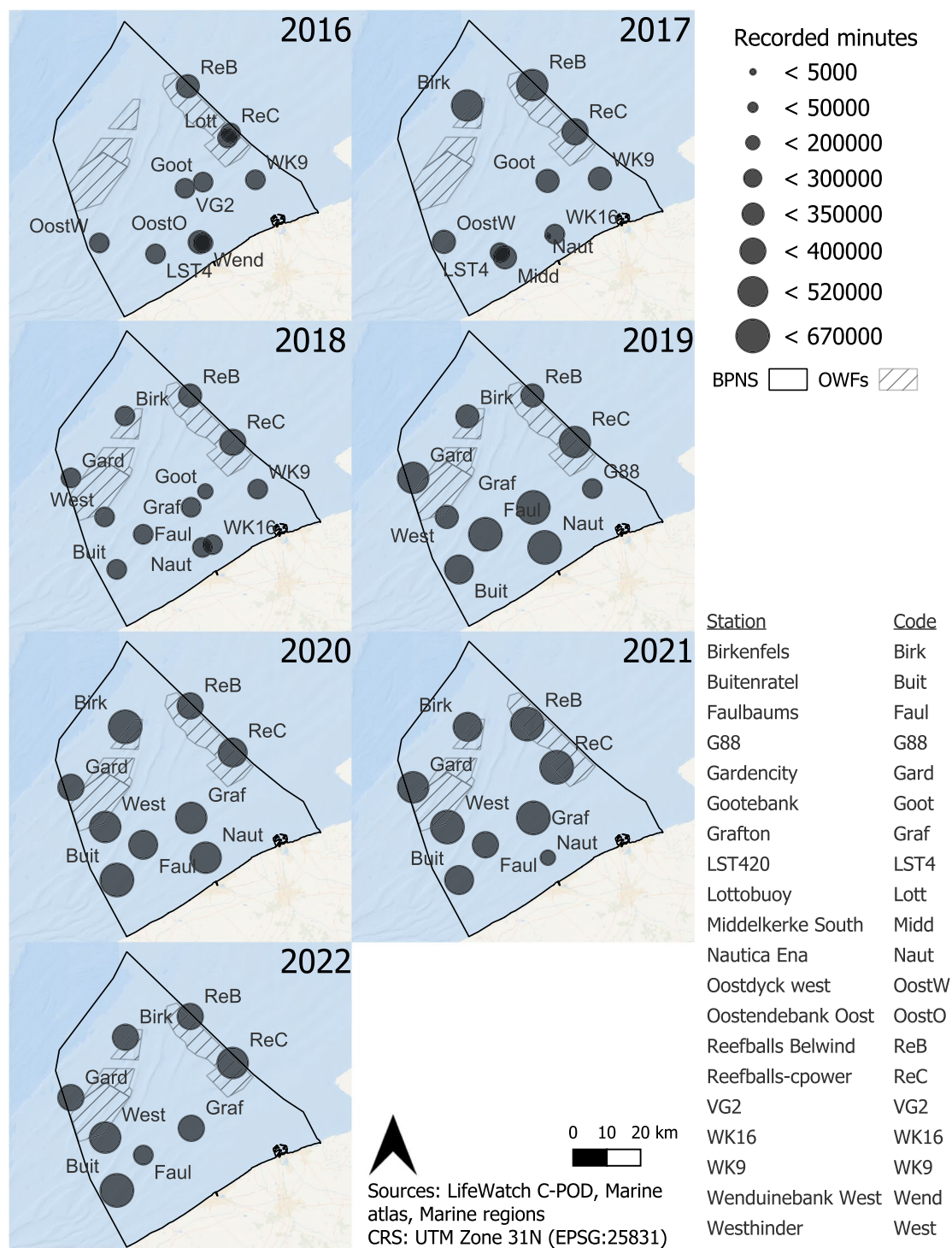
Fig. 4 Summary of total recorded minutes for each station obtained over the course of the LifeWatch Belgian cetacean passive acoustic network per year (BCPAN; 2016–2022) in the Belgian Part of the North Sea (BPNS). The size of circles corresponds to the total recorded minutes per station. Label codes for each of the stations are provided in the table. Offshore wind energy zones (Offshore Wind Farms; OWFs) in the BPNS are shown (striped polygons)[62,63].

algorithm of CPOD.exe and stored as .CP3 files. KERNO uses multiple hypothesis testing to test multiple features from the raw data to isolate trains that come from one of the so-called species classes (harbor porpoise, other cetaceans or sonar), and then classifies each train[34,35]. KERNO also classifies trains according to quality class (high, moderate and low) where high-quality trains have the lowest risk of false positives and vice versa.
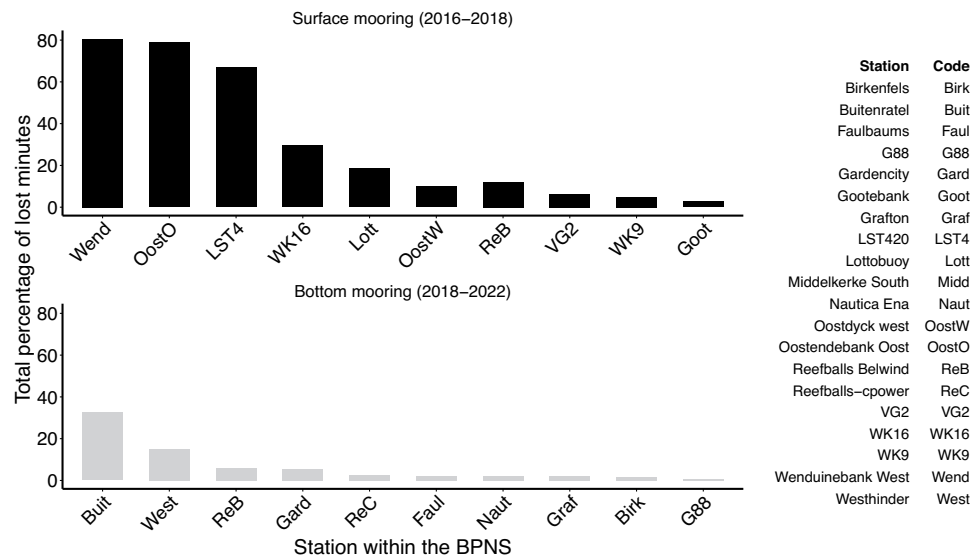
Fig. 5 Percentage of lost minutes per station over the course (2016–2022) of the LifeWatch C-POD network in the Belgian part of the North sea (BPNS) by the type of mooring used for deployments. Data were extracted from the *lwdataexplorer*[38] package with the *getCpodData* function in rstudio.lifewatch.be.
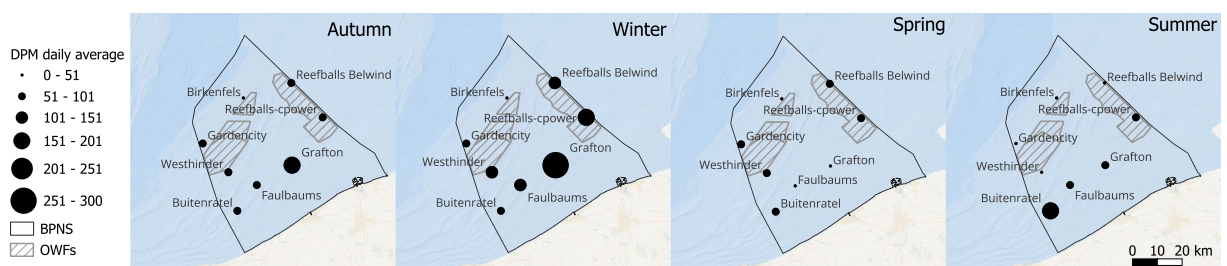

Fig. 6 Average of daily Detection positive minutes (DPM; black circles) of harbor porpoises per station. Seasons were based on the exact astronomical dates of equinoxes and solstices in the northern hemisphere (spring equinox: ~20 March, summer solstice: ~21 June, autumn equinox: ~22 September, winter solstice: ~21 December). Offshore wind farms (OWFs) are indicated by striped, grey polygons. Data were extracted from the *lwdataexplorer*[38] package with the *getCpodData* function in rstudio.lifewatch.be. Shpfiles were sourced from marineatlas.be and marineregions.org.

High-, moderate- and low-quality click trains are then visualized in CPOD.exe, wherein a maximum of 100 randomly selected click trains per deployment are manually validated according to their features (see Technical Validation). Data per minute is exported as (1) Train duration total and (2) Detections and environment text files (Table 1) separately for high-, moderate- and low-quality click trains.

Data registration and visualization. The ETN[33] online web application, component Underwater Acoustics, was developed in-house to store all metadata and output files of the C-PODs. In addition to the deployment metadata (activation, deployment and retrieval date and time in UTC) of each C-POD deployment, valid date and time until which the C-POD was actively recording on the seafloor are registered on the ETN[33] database to consider the occasional termination of recording prior to retrieval due to battery power or memory loss. The latter is checked after processing the data through the CPOD.exe software and defines the end time of data collected at sea. This information is crucial as the C-POD is not equipped with an internal clock. Only data between the timestamps of deployment and until which the C-POD was actively recording on the seafloor are registered on the ETN[33] database to ensure that all data stored on ETN[33] were exclusively recorded while the C-POD was fixed underwater. All metadata timestamps are important to keep track of sensor maintenance and performance.

Data Records
The Train duration total and Detections and environment text files (Table 1) uploaded and merged on the ETN[33] database can be visualized on the LifeWatch data explorer[36] and downloaded after registration on the platform (Fig. 2). The LifeWatch R package (*lwdataexplorer*; Data record 1[37,38]) also provides open access to this minute-resolution dataset; i.e., observations per minute (detection positive minutes, DPM). Using the
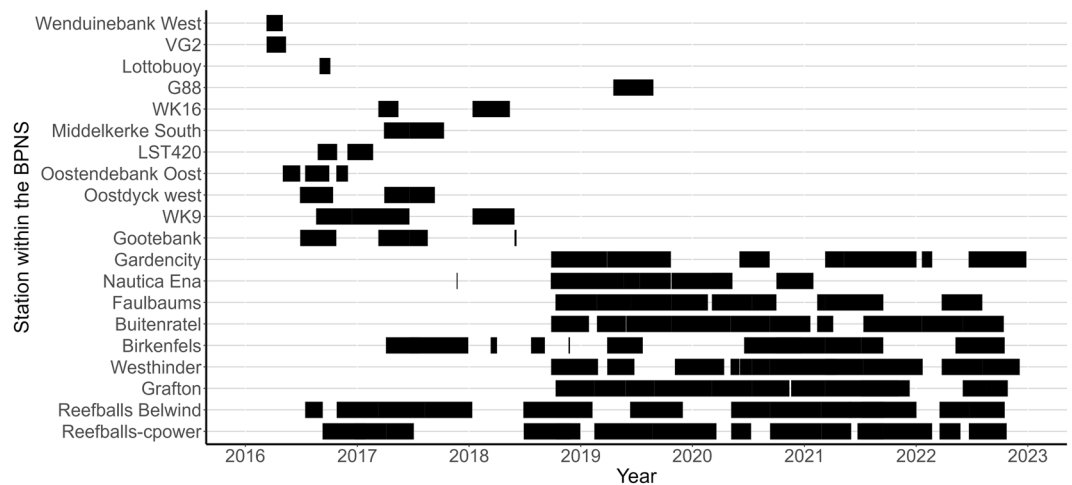
Fig. 7 Belgian cetacean passive acoustic network (BCPAN) data availability per station from 2016 to 2022. Data were extracted from the *lwdataexplorer*[38] package using the *getCpodData* function in RStudio.

lwdataexplorer[38] package, datasets of a selected period and quality can be viewed in an R data frame object with the *getCpodData* function.

Yearly exports of high- and moderate-quality data from the entire minute-resolution dataset are published as a .csv file (Data record 2[39–47]): station names, species name and date and time are standardized, and minutes when the C-POD was not working are excluded. These yearly datasets in minute-resolution are published with a Digital Object Identifier (DOI) along with their metadata on the Integrated Marine Information System (IMIS[39–47]) and archived in Marine Data Archive (MDA[48]).

Subsequently, datasets in minute-resolution of high- and moderate-quality are aggregated into hour-resolution datasets and presence/absence information from these datasets are stored in a Darwin Core Archive (DwC-A), a standardized format for sharing biodiversity data (Data record 3[49]). The resulting archive is published with a DOI and is accessible on IMIS[49] and in several unrestrictive online repositories—the European Marine Observation and Data Network (EMODnet[50]), Global Biodiversity Information Facility (GBIF[51]), European Ocean Biodiversity Information System (EurOBIS[52]) and the Ocean Biodiversity Information System (OBIS[53]) (see Fig. 2).
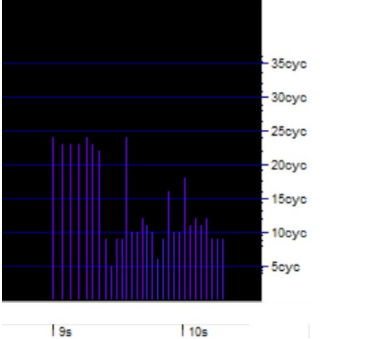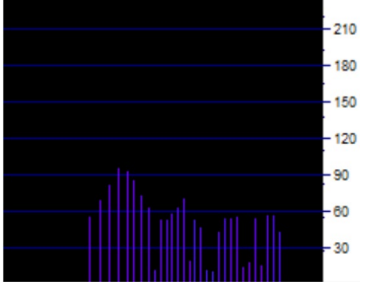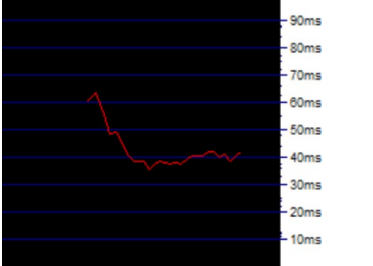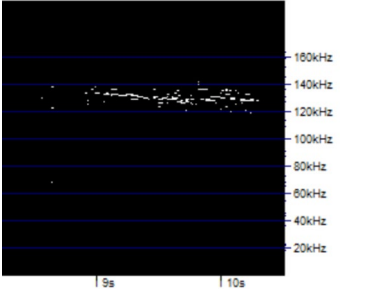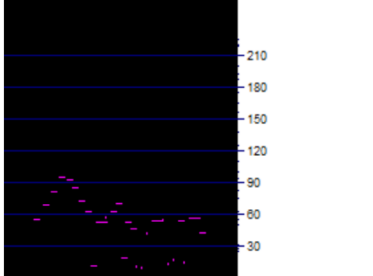
These data records generated from the data processing and published online through several public repositories are summarized in Table 2. Details of variables of the yearly published datasets (Data record 2[39–47]) include the coordinate variables, metrics derived from the acoustic device and the technical properties of the acoustic recorder (Table 3). Original exports from the C-POD loggers (e.g., .CP1, .CP3, Detections and environment and Train duration total text files) are stored in the internal server of VLIZ but can be made available upon request.

The acoustic recordings from 2016 to 2022 across all stations contained a total of 19,889,836 recorded minutes with 993,062 minutes where porpoises were present (Fig. 4). Every minute with a number of clicks exceeding the maximum number (4096 clicks) that the SD card can store per minute is classified as a "lost minute." Throughout this period, there were a total of 1,924,544 (9.68%) lost minutes. Lost minutes are directly related to the noise of the C-POD's environment and can be either due to natural sources (e.g., tides and sediment transport) or the type of mooring, which influences the stability of the PAM logger. Surface- and bottom-moored C-PODs had an average of 19.76% and 7.88% lost minutes of the recorded data respectively (Fig. 5). After 2018, when the deployment of the multi-use platform was standardized following a pilot period, stations Middelkerke South, Oostdyck west, LST420, WK16, WK19 and Gootebank were no longer operational (Fig. 4). Stations G-88 and Nautica Ena were discontinued in 2019 and 2021 respectively, leaving 8 stations currently monitored (Figs 1 and 6). As of 2022, there had been a total of 127 C-POD deployments. The largest number of deployments were at the 8 stations annually monitored since 2018, and the discontinued Nautica Ena (Fig. 7). Unavailable data between deployments were either due to the malfunctioning of the C-PODs (i.e., loss of data from malfunctioning of the SD card or battery) or unforeseen weather circumstances preventing access to the site.

Technical Validation

A first check of the data is performed in CPOD.exe, confirming the activation and deployment timestamps and until which the C-POD was actively recording in a fixed position underwater. High-, moderate- and low-quality click trains classified by the built-in KERNO classifier of CPOD.exe are quality controlled through visual validation[54] of 100 randomly selected click trains per deployment. Since cetaceans mostly produce trains continuously[11,14], a click train coming from a particular source should have similar characteristics within successive clicks (i.e., sound pressure level profile is evenly spread), a quiet background where random unrelated clicks before, during and after a train are few to none, and a temporal association with other trains[54]. Specific features of each click train are then assessed for comparability to a harbor porpoise click train (NBHF) as described by Chelonia Ltd., UK (Table 4).

Feature	Train characteristic of an NBHF species
Duration (number of cycles)	Long, often greater than 15 cycles
Amplitude profile	Often smooth with initial rise and fall
Inter-click interval (ICI)/click rate	Less than 250 ms
Frequency	120–139 kHz
Temporal association	Trains grouped over 2 minutes or more
Bandwidth	Typically low

Table 4. Features of click trains used to validate porpoise clicks (narrow-band high frequency, NBHF) classified by the built-in KERNO classifier of CPOD.exe[54].

In addition to visual validation of click trains, the Train duration total and Detections and environment text files (Table 1) are quality checked. A positive number of milliseconds in the Train duration total should always correspond to a DPM of 1 in the Detection and environment text file. Coordinates logged together with the deployment date and time are verified in the data as an extra check of sensor performance. Temperature is also checked, since a sudden drop or rise in temperature values is associated with a shift in data; that is, the data on the SD card can suddenly shift to data from the previous deployment.

Usage Notes

The function *getCpodData* from the *lwdataexplorer* package[37,38] allows the retrieval of PAM data from the LifeWatch observatory[55]. To boost query performance, up-to-date PAM data can also be accessed via https://rstudio.lifewatch.be/ upon registration[38] In the LifeWatch project data portal[36], it is possible to browse and visualize the data and select specific parameters, such as the timeframe, its quality (level of processing) and a sample period. The annual exports of minute- and hour-resolution PAM data can also be downloaded without login requirements via IMIS[39–47,49].

LifeWatch observatories continuously generate various biodiversity data which may be used in conjunction to the PAM data. Ecological studies in the BPNS involving porpoises may be furthered through integration of relevant data such as abiotic parameters (temperature, salinity, nutrients), phytoplankton, zooplankton and fish telemetry data. For example, data streams from PAM and acoustic telemetry were already combined in a recent species co-occurrence study[56] of the European seabass, Atlantic cod, harbor porpoise and dolphins in the BPNS using presence-absence matrices (see Code Availability).

During the LifeWatch data analysis workshop[57] held in VLIZ from the 5th to the 6th of October 2017, research ideas and questions on the use of PAM data generated by BCPAN were formulated. This includes the correlation of PAM data to abiotic variables, sensor network analyses, dealing with background noise, effects of bottom versus surface moorings and comparisons with aerial observations (see Code Availability).

LifeWatch needs to be cited if any of the data are used and acknowledged: "Flanders Marine Institute (VLIZ), Belgium; (2023): LifeWatch observatory data: permanent Cetacean passive acoustic sensor network in the Belgian part of the North Sea. Marine Data Archive. https://doi.org/10.14284/639".

Code availability

Scripts written in R (https://www.r-project.org/) to produce Figs. 5 and 7 are publicly available on GitHub[58]. Other scripts available to process PAM data, as mentioned in the Usage Notes above, can be found on the following GitHub pages: species co-occurrence study[59] and LifeWatch data analysis workshop on the use of PAM data[60].

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Author contributions

A.C. led the writing of the manuscript. P.N.G. and E.D. contributed to writing. E.D. and K.D. elaborated and led the maintenance of the monitoring network. E.D. developed the deployment design. E.D., J.M. and A.C. contributed to managing and cleaning datasets. J.M. published the yearly exports to unrestrictive repositories. P.N.G., A.C. and E.D. wrote scripts publicly available to process PAM data. FH co-authored the *lwdataexplorer* R package. F.H. and K.D. managed the funding and related projects. All authors critically revised the drafts and approved the final manuscript.

Competing interests

The authors declare no competing interests.

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