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Scientific Report from DCE – Danish Centre for Environment and Energy No. 539 2023

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Data sheet

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Abstract: A pilot study on passive acoustic monitoring for odontocetes other than harbour porpoises was conducted on two stone reefs in Skagerrak, by means of broadband sound recorders. Analysis of recordings by automated detectors and manual auditing identified numerous likely recordings of vocalisations from an odontocete, most likely white-beaked dolphins, the most common species in the area after harbour porpoises. Other acoustic sounds matching the characteristics of killer whales and pilot whales, two species also observed regularly in the area, were also found. Thus, the pilot study documented the feasibility of passive acoustic monitoring for these species in the North Sea and adjacent waters.

Keywords: Passive Acoustic Monitoring, PAM, SoundTraps, white-beaked dolphins, killer whales, pilot whales, detection and classification, echolocation, whistles.

Front page photo: White-beaked dolphins. iNaturalist/Charlotte Kirchner cc

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Preface

The Danish part of Skagerrak has been monitored as part of the national marine mammal monitoring program NOVANA by annual aerial surveys during summer since 2011. The most commonly observed species is by far the harbour porpoise, but white-beaked dolphins, killer whales, and pilot whales have also been observed. It is, however, at present unknown how often the different species utilize these waters and if there is a seasonal change in their presence.

This report presents preliminary results of a pilot project on development of passive acoustic monitoring (PAM) methods to monitor odontocetes in the Danish North Sea and Skagerrak.

Focus of this report is documentation of the methodology adopted and developed for acoustic detection and classification of non-porpoise vocalizations recorded by wideband acoustic monitoring equipment, alongside established porpoise detection methods. Such recorders were deployed on two deep stone reefs in Skagerrak, as dolphins are commonly observed in these locations by dedicated surveys and opportunistic sightings. The recordings are thus not meant to be representative of the area as a whole, but rather presence/absence of the animals in the monitoring periods. Wider conclusions regarding distribution of the species, including annual variation, will have to await a larger and properly designed monitoring program.

Deployment of data loggers and development of the methodology was funded by the Danish Environmental Protection Agency, through the Wildlife Contract (Vidensopbygning).

Summary

A pilot study was conducted in 2020-2021 to test the feasibility of performing passive acoustic monitoring for odontocetes other than harbour porpoises in the Danish North Sea and Skagerrak. Acoustic monitoring methods for porpoises are already established, but no attempts have previously been made to detect other cetaceans in the Danish North Sea. Four sound recorders (SoundTrap ST500 or ST600), capable of wideband recordings sufficient to capture both whistles and echolocation clicks, were deployed, two on each on the deep stone reefs Store Rev (32-58m) and Gule Rev (29-48m) in the Skagerrak.

Analysis of recordings by means of automated detectors in the software package PAMGuard, assisted by manual auditing, resulted in identification of numerous acoustic events clearly distinct for odonotocetes other than porpoises. Most of these vocalizations matched known echolocation clicks of white-beaked dolphins, assumed from surveys and sightings to be the second most common odontocete in the area after harbour porpoises. Other signals that did not match white-beaked dolphins were also found in the recordings, with lower peak frequency of the echolocation clicks and low first harmonic of whistles, consistent with signals from either killer whales or pilot whales, two species also observed in the area.

Since little is known about the annual occurrence of harbour porpoises in this area, dedicated harbour porpoise detectors (C-PODs) were deployed together with the wideband acoustic recorders. Porpoises were detected at the four stations on 92-100% of days during the deployment period, with most detections from February to May. The recordings covered the full year at Store Rev and from May to October at Gule Rev.

In conclusion, the pilot study has documented the feasibility of passive acoustic monitoring for not only harbour porpoises, but also white-beaked dolphins and other odontocetes in the Skagerrak and North Sea.

Dansk resumé

Der blev i 2020-2021 gennemført et pilotstudie for at undersøge muligheden for at lave akustisk overvågning på andre tandhvaler end marsvin i Skagerrak og Nordsøen. Mens akustiske overvågningsmetoder for marsvin er veletablerede, er der ikke tidligere gjort forsøg på akustisk overvågning af andre tandhvaler i danske farvande. Fire bredbånds lydoptagere (Sound-Trap ST500 eller ST600), der kan opfange både fløjt og ekkolokaliseringslyde fra tandhvaler, blev udlagt på de to dybe stenrev Store Rev (32-58m) og Gule Rev (29-48m) i Skagerrak. Begge rev er udpeget som Natura 2000 områder for stenrev og marsvin.

De akustiske analyser blev foretaget ved hjælp af automatiske detektorer i softwarepakken PAMGuard, suppleret med manuel gennemlytning. Dette resulterede i identifikation af et antal akustiske optagelser af tandhvaler, klart forskellige fra marsvins lyde. De fleste af disse lyde svarede til ekkolokaliseringslyde som beskrevet fra hvidnæset delfin, den mest almindelige tandhval i Skagerrak efter marsvin. Der blev desuden fundet fløjt og andre ekkolokaliseringslyde med lavere frekvensindhold, svarede til signaler fra spækhugger og langluffet grind, to arter der også observeres regelmæssigt i Skagerrak.

Da årsvariationen i forekomsten af marsvin er ubeskrevet for de to revområder, blev også marsvinedetektorer (C-PODs) udlagt sammen med bredbåndsoptagerne. Marsvin blev påvist på 92-100 % af dagene med optagelser, med flest detektioner fra februar til maj. Optagelserne dækkede hele året på Store Rev og fra maj til oktober på Gule Rev.

Dette pilotstudie har dokumenteret anvendeligheden af passiv akustisk overvågning af ikke kun marsvin, men også hvidnæset delfin og andre tandhvaler i Skagerrak og Nordsøen.

1 Introduction

Harbour porpoises are by far the most common odontocete in Skagerrak, the body of water between southern Norway and northern Denmark that encompasses the southern hook of the Norwegian Trench (Sveegaard et al. 2018), but other odontocete species are opportunistically sighted (see for example Østrin 1994, Baagøe & Jensen 2007). Presently, the distribution and seasonality of many cetaceans in this region is largely unknown, but it is within the known range for killer whales (*Orcinus orca*), long-fined pilot whales (*Globicephala melas*), bottlenose dolphins (*Tursiops truncatus*), white-beaked dolphin (*Lagenorhynchus albirostris),* minke whales *(Balaenoptera acutorostrata)*, as well as a number of other more occasional visitors, including the Atlantic white-sided dolphin (*Lagenorhynchus acutus*) (See for example Reid et al. 2003, Baagøe & Jensen 2007). The distribution of harbor porpoises (*Phocoena phocoena*), is well known (Sveegaard et al. 2011a, Sveegaard et al. 2018, Hammond et al. 2021) and has benefited from multiple studies on its range and habitat use, although they have never prior to this project been studied by Passive Acoustic Monitoring (PAM) in Skagerrak.

Passive Acoustic Monitoring methods have in the past decades become a very powerful toolkit to detect cetaceans 24 hours a day, year-round without relying on visual observations (e.g. Mellinger et al. 2007), but also to explore distribution and estimate population density (Kyhn et al. 2011, Marques et al. 2013, Carlén et al. 2018, Amundin et al. 2022). In order to properly apply PAM methods to animal populations, however, there needs to be basic knowledge of vocal repertoires of the different species in the area of interest. This has so far only been established for harbour porpoises, although there is information about other species' repertoires from other geographical areas.

Odontocete vocalizations can be grouped into three types: echolocation clicks, burst pulses, and whistles. Echolocation clicks are short (< 1 ms) sonar signals with predominant energy in the ultrasonic range that enable animals to search their environment acoustically and forage. Tonal whistles are communication signals used for social interactions and group cohesion. The third group of signals, burst pulses – rapid click sequences with tonal qualities – is a mix of signals produced for sonar (prey capture events) and for communication (e.g. Sayigh 2014).

A number of studies on odontocete vocalizations are available from northern European waters. For killer and pilot whales (especially in US literature referred to collectively by the whaling name 'blackfish'), their repertoire has been recorded with visual confirmation in Northern Norway (Eskesen et al. 2011, Vester et al. 2017). While there are acoustic differences between the two species, there is significant overlap in their vocalizations so that differentiating between the two is difficult without a suitable sample size. White-beaked dolphins have been recorded with visual confirmation off Iceland (Rasmussen & Miller 2002, Rasmussen et al. 2002) and around the British Islands (Calderan et al. 2013, Yang et al. 2021). The common bottlenose dolphin, as a global, coastal species, is one of the best-studied odontocetes, including the nearby resident population in Scotland, and they produce a variety of sounds as a highly social species. The parameters of a group's whistle repertoire is highly dependent on regional differences, age, and the presence of other conspecifics; mother-calf pairs and bonded partners (Jones et al., 2019).

Atlantic white-sided dolphins have also been encountered in the North Sea, albeit with a more northern distribution than white-beaked dolphins (Reid et al. 2003). It is known from strandings on the Danish west coast (Baagøe & Jensen 2007) but rarely observed alive in the Danish North Sea or Skagerrak. However, the actual overlap in distribution is unknown as most visual surveys combine the two species as they are hard to discern from each other (Calderan 2021). Little is known about their acoustics outside of early recordings from the Faroe Islands (Møhl 1992) and recent recordings obtained off northern Norway (Hamran 2014). From this limited knowledge, they appear to have a fairly similar repertoire to white-beaked dolphins in northern European waters.

Methods for the automated detection and classification of cetacean vocalizations have improved over the decades. However, a substantial effort is still needed to generate baseline information in a new area/species, as species may exhibit variable acoustic parameters in their vocal repertoire in different areas (Oswald et al. 2022). The aim of this study is to create baseline data and tools for assessment of odontocete acoustic activity in Skagerrak and the North Sea.

2 Methods

2.1 Data Collection

This project deployed four broadband recorders along with four porpoise detectors in two Natura 2000 sites, *Store Rev* and *Gule Rev*, in the southwestern corner of the Skagerrak (Figure 2.1). Positions of stations (Table 2.1) were selected based on maps of AIS positions to avoid areas with heavy fishing activity, to reduce the risk of loss of equipment to trawling.

The four stations were deployed as moorings, tethered to the seabed by biodegradable stone bags. The data loggers employed were ST500 & ST600 (Ocean Instruments, Inc.) broadband recorder and C-PODs (Chelonia Ltd., U.K.) porpoise detector. Each C-POD was fixed 2 m above the sea floor, and each broadband recorder at 3.5 m.

Data loggers ST500 were equipped with HTI 96-min hydrophones (High Tech, Inc.), which had a broadband recording range between 20 Hz – 150 kHz, and a sensitivity -165 dB re: 1V/µPa. Our loggers were deployed with a sample rate of 576 kHz, and a duty cycle of 27 minutes on per 90 minutes. Data loggers ST600 have a built in hydrophone, with a broadband recording range of 20 Hz – 150 kHz, and a sensitivity average between -163 and -166 dB re: 1V/µPa. We recorded at a sample rate of 384 kHz with a duty cycle of 30 minutes on per 60 minutes.

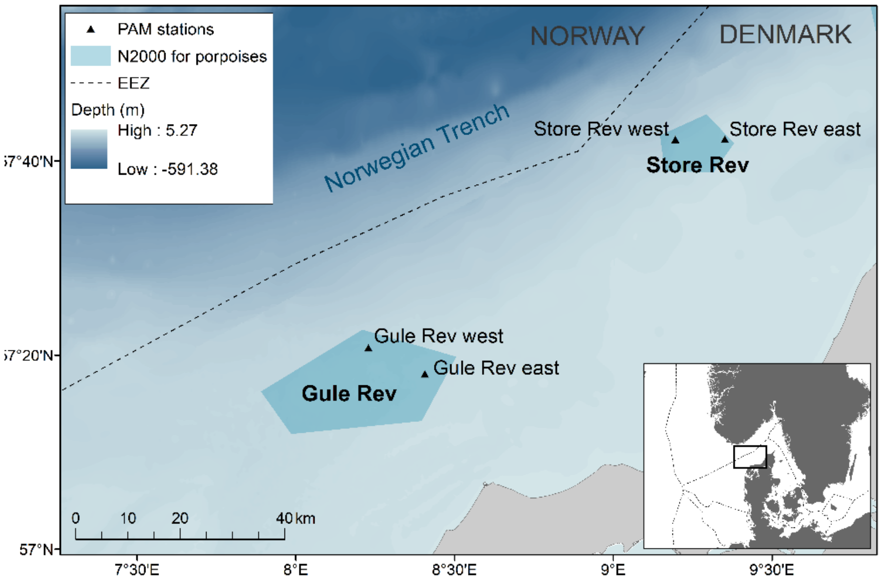


Figure 2.1. Locations of the two N2000 sites and the four deployed PAM stations in Skagerrak.

Table 2.1. Coordinates of the four stations in this study, two at Gule Rev and two at Store Rev.

Station	Location ID	Latitude	Longitude
Gule Rev East	GR_East	8° 24' 03.6"	57° 18' 43.2"
Gule Rev West	GR_West	8° 13' 15.6"	57° 21' 21.6"
Store Rev East	SR_East	9° 21' 28.8"	57° 42' 57.6"
Store Rev West	SR_West	9° 11' 56.4"	57° 42' 57.6"

2.1.1 Collection Effort

The four stations were deployed in September 2020 (Deployment A), with ST500 broadband recorders. All stations were lost at some point, however both stations at Store Rev and the mooring at Gule Rev west were recovered. Gule Rev east remains lost.

Unfortunately, all of the recovered broadband recorders failed during deployment due to a firmware issue. Only the unit at Gule Rev West recorded for a short time period, between 19 and 29 September 2020 (Figure 2.2). Of the C-PODs, station Store Rev east and Store Rev west recorded for the whole period (until May 2021). Gule Rev west contained two months of data. Due to an internal inclinometer on the C-POD, we were able to determine when the mooring was no longer at station.

In May 2021, we deployed four ST600s (Deployment B) alongside the C-PODs. Two recorders collected data from 4 May 2021 until recovery on the 16 August 2021. Gule Rev east only recorded for 2.5 months The two C-PODs at Store Rev and Gule Rev east recorded throughout the period. Gule Rev west station was lost, but recently found. The data has not been analyzed yet.

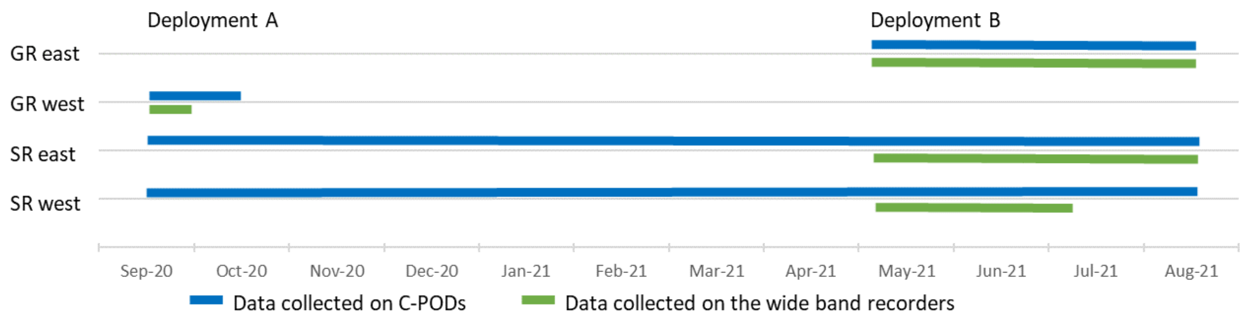


Figure 2.2. Timeline with overview of recording periods for wide band recorders (SoundTraps) and porpoise detectors (C-PODs)

2.2 Data Analysis - Delphinids

All SoundTrap recordings were processed in the software package PAMGuard (Gillespie et al. 2008) using their suite of signal processing tools. To examine sounds, including tonal whistles and burst pulses, the Whistle & Moan Detector module was used. The Click Detector module was used to identify and characterize click sounds (echolocation).

2.2.1 Gule Rev west Deployment A

Since there was only 10 days of data from Gule Rev west in deployment A, this dataset was used to test a previously existing suite of click detection and classification parameters (Keating & Barlow 2013). These settings were normally used in line transect studies, where an array of hydrophones was towed 200 m behind a vessel. The analysis protocol separates clicks into low frequency vs high frequency clicks (i.e. peak frequency above and below 15 kHz), which in our survey area would cover killer and pilot whales (low frequency) vs other dolphins (high frequency). Since these click parameters are used in the presence of constant engine noise, we had hoped they would be useful in the Skagerrak where there is a high level of boating activity due to it being an active commercial and leisure fishing location.

However, this suite of click parameter settings was not as useful as we had hoped, likely because it was developed for a towed array system, where the signal to noise ratio is very different from stationary PAM systems. Our PAM stations experienced a high volume of vessel traffic from a wide variety of vessel types and sizes. The click classifier suite outlined in Keating and Barlow (2013) was designed with one ship in mind; the one towing the array at a known distance from the sensor(s). A manual review of the resulting click detections had a high false positive rate (every ship passing was flagged) and was therefore time consuming. Therefore, this method was not employed in subsequent analyses.

Table 2.2. Summary statistics of echolocation clicks for odontocetes from North Atlantic waters

Parameter	Killer whale	Long-finned pilot whale	White-beaked dolphin			Bottlenose dolphin
	Orcinus orca	*Globicephala melas*	*Lagenorhynchus albirostris*			*Tursiops truncatus*
Peak Freq. (kHz)	29 (1.7, 16-49)[1]	50 (3.2, 34–94)[1]	106-115[2]	35.3 (11.0, 1.5-46.5)[3]	-	-
Centroid Freq. (kHz)	32 (1.5, 21-56)[1]	55 (2.1; 37–73)[1]	85-98[2]	-	61-80[2]	75 (16, 33-102)[3]
Duration (µs)	49 (3.1, 27-86)[1]	35 (3.0; 20–75)[1]	15-22[2]	-	21-29[2]	23 (8, 12-46)[3]
3-dB Bandwidth (kHz)	25 (1.9; 9–43)[1]	46 (3.4; 24–71; 17)[1]	42-70[2]	5.1(1.4, 3.0-10.5)[3]	14-16[2,4]	34 (6)[4]
Location	Vestfjord, Northern Norway	Vestfjord, Northern Norway	Faxafloi Bay, Island	Halifax, Nova Scotia	Northumber-land coast, UK	Wales
Reference	Eskesen et al. (2011)	Eskesen et al. (2011)	Rasmussen and Miller (2002)	Simard et al. (2008)	Yang et al. (2021)	Wahlberg et al. (2011)

1) Data given as mean (SE, range)

2) Data for three different click sequences. The ranges for feature means/medians are presented.

3) Data given as the mean (SD, range).

4) rms-bandwidth

2.2.2 Pilot and killer whales

In Skagerrak, killer whales are observed regularly and pilot whales seldomly (Kinze et al. 2003). There is much overlap between killer and pilot whale vocalizations. While mean click parameters may be different in shared habitats (Table 2.2), the overlap is too large to allow separation of the species using automated means. Furthermore, the frequency range of whistles produced by these species also overlap considerably, with most of the whistle energy produced below 20 kHz, but both species producing occasional ultrasonic whistles above 60 kHz (Vester 2017). Currently, the automated processes to differentiate between species are all specific to geographic region, and no such process has yet been developed for the North Sea and/or Skagerrak waters. Until such classification tools for this region has been developed, which relies on collection of acoustic data with visual species confirmation, the two species will have to be treated as one group.

Due to the gregariousness of killer whales and pilot whales, as they are social species that live and travel in matrilineal groups (Ford 2002, De Stephanis et al. 2008), we employed the whistle and moan detector (WM) in PAMGuard to find all instances of whistles. The WM detector identifies tonal sounds within the recording via image processing of spectrograms of the sound recording. The detector settings determine how the image processor finds tonal components in each time slice, and how it links components within each time slice together (Gillespie et al., 2013). For pilot and killer whale whistles, we employed more 'connective' settings to help find longer tonal events typical of dolphin whistles (Rankin et al., 2017). The fast-Fourier transform (FFT) length was set to 8192 (21.5 ms), with a 50% overlap and a Gaussian window, which provides very high side-lobe suppression. The whistle and moan detector was set to collect all tonal signals below 37 kHz, with a Connect 8 (sides and diagonals) type, 10 minimum time slices, a total minimum size of 50 pixels, all small stubs removed, calls were re-linked across joins, with a maximum cross length of 5 time slices. As we had one channel per station, no grouping was used. All detections were manually audited twice to verify true odontocete whistle events. All detections were first reviewed by the initial auditor (CM), and timestamps flagged as 'potential delphinid' were reviewed and classified by the senior auditor (ETG).

2.2.3 White-beaked dolphins

There is little information about the vocal repertoire of white-beaked dolphins available in the literature and the parameters reported on their vocal features vary considerably (see summary information in Table 2.2). Off Iceland echolocation clicks were recorded to have a peak frequency above 100 kHz (Rasmussen & Miller 2002, Rasmussen et al. 2006) while off Nova Scotia the peak frequency of echolocation clicks and burst pulses is reported as 35 kHz (Simard et al. 2008). Both studies deployed hydrophones from a small vessel, but whereas the recordings from Iceland were made with an array that could identify on-axis clicks (clicks recorded directly in front of the animal), the recordings from Canada were made with a towed array and likely predominantly contained off-axis clicks[1].

Recordings made from several vessels in UK waters (including Atlantic, North Sea and English Channel waters), found that white-beaked dolphin produce both narrowband and broadband clicks. Narrowband clicks had peak frequencies between 27-37 kHz, with a center frequency at 35 kHz, while broadband clicks predominately had energy above 70 kHz (Calderan et al. 2013). Furthermore, both click types had characteristically notched spectra (referred to as 'banding', due to the distinct spectral peaks and troughs at consistent frequencies, which makes click trains appear with pronounced horizontal bands in spectrograms). Similarly, high amplitude clicks from visually confirmed white-beaked dolphins recorded on stationary moorings along the eastern UK coast, where the broadband recorders were suspended 2 m deep from the sea surface, found banding in over 90% of clicks analyzed, present in both echolocation clicks and burst pulse signals (Yang et al., 2021). Yang et al. (2021) reported a slightly higher peak frequency for burst pulses than Simard et al., (2008a) (39 and 35.3 kHz, respectively) and center frequencies between what Calderan et al. (2013) and Rasmussen and Miller (2002) reported.

In this study, we analyzed a subset of data of recordings for white-beaked dolphins rather than the full deployment due to limitations in processing speed. Timeframes identified by the initial analyst (CM) with potential delphinid activity were collected, and all files 12 hours before and after these timeframes were included in the white-beaked dolphin analyses. This method of selection was employed rather than random selection because it could potentially reveal interactions between larger and smaller delphinids.

[1] The frequency spectrum of broadband echolocation clicks is strongly affected by the directionality of the sound beam, which is much stronger for higher frequencies. A downward shift in peak frequency is therefore both expected and observed as the recording position is moved increasingly off-axis. See Au et al. (1987) for an example from Belugas.

As reported across multiple studies, white-beaked dolphins appear to produce different click types and burst pulses, each with variability in reported center frequencies. Therefore, a series of detectors were used, and detections had to meet multiple classification criteria to be considered a potential dolphin encounters. To identify white-beaked dolphins in our data, a combination of the click detector and the WM detector was employed at an FFT length of 2048 (5.33 ms) with a 50% overlap. The first step was to find instances of delphinid echolocation. With the detection threshold set at 12 dB, the *Basic Click Classifier* was selected to find both echolocation clicks and burst pulses: Search Range between 15-180 kHz, Peak Frequency Range between 25-60 kHz. The peak frequency range was selected based on common peak ranges reported by other studies (Simard et al. 2008a, Calderan et al. 2013, Yang et al., 2021) and because lower frequencies disappate slower. The Click Length Range was between 0-0.02 ms, measured over 15% of the total energy, as the clicks reported were much shorter in duration than other species in the area.

The second step was using the WM detector to find burst pulses. By selecting less 'connective' settings we could find burst pulse events (Rankin et al. 2017). Informed by the results in Simard et al. (2008), we employed an investigation range between 25-110 kHz, a Connect 4 (sides only) type, 7 minimum time slices, a total minimum size of 10 pixels, small stubs kept, calls were re-linked across joins, with a maximum cross length of 20 time slices. For more information about these settings' definitions, please see Gillespie et al. (2013).

For the third step, output from this process was exported to R using the PamBinaries software package (Sakai & Oswald 2022). Click detections and whistle and moan detections were collated per second. Seconds which both included at least 5 clicks classified as white-beaked dolphin and where the percentage of clicks classified as white-beaked dolphin within that second was ≥ 30% were included in further analysis. Next, collected seconds with 3 or more burst pulse detections from the Whistle and Moan Detector, and/or had 80% or more of clicks classified as white-beaked dolphin were considered potential white-beaked dolphin events. The recordings containing these identified seconds were manually audited (ETG) for white-beaked dolphin events.

It is worth noting that any of these detections found by the white-beaked dolphin detector could potentially be from other medium-sized dolphin species, in particular white-sided dolphins, as the vocal repertoire for the two species may overlap considerably. However, the occurrence of other dolphins is very low in this area and the likelihood that there are other species erroneously classified as white-beaked dolphins is assessed to be low.

2.2.4 Bottlenose dolphins

Though usually rare in Danish waters, a group of 3-7 bottlenose dolphins (with known origin from the Scottish population in Moray Firth) have recently established themselves in the waters around Thyborøn, on the Danish west coast. These animals support a small dolphin watching business, and have been traveling south into the Danish straits as far as Aarhus Bay, Great Belt and Svendborg Sund (Fisker 2022). However, this is a very small group of animals, and it is not expected that they would commonly visit the study area. The likelihood that they were picked up by our recorders is therefore very low. Additionally, both the killer whale and pilot whale, as well as the white-beaked dolphin detection algorithms would pick up whistle and clicks from bottlenose dolphins if present. The manual audit of detections will determine if bottlenose dolphins are within our dataset. Therefore, no dedicated detection method was employed.

2.3 Data Analysis - Harbour Porpoise

The C-POD data were processed in cpod.exe using the same method as for the national monitoring data (Hansen & Høgslund 2019). Broadband recordings were not analyzed for harbour porpoise vocalizations.

3 Results and Discussion

For Gule Rev west, Deployment A, all click detections were manually reviewed. There was one verified detection of white-beaked dolphin echolocation activity, and no detections of pilot and/or killer whales.

In Deployment B, all data from the WM detector was manually analyzed, and instances of potential odontocete activity were flagged and audited for killer and pilot whales, and other less common odontocetes. For the white-beaked dolphin analysis in Deployment B, a subset of 20-29% of the data from each recovered station was analyzed (Table 3.1).

Table 3.1. Overview of data available for analysis. WBD = White beaked dolphin.

Location	Data Starts	Data Ends	Number of files	Files in WBD analysis	Percent of files included in WBD analysis
Gule Rev West	19 Sept 2020	29 Sept 2020	176	176	100%
Gule Rev East	4 May 2021	16 Aug 2021	2496	722	28.9%
Store Rev West	4 May 2021	16 Aug 2021	2505	513	20.5%
Store Rev East	4 May 2021	06 Jul 2021	1517	430	28.3%

Despite the limited dataset, white-beaked dolphins were detected on recordings from all four stations, and killer/pilot whales were detected at all stations analyzed except Gule Rev west (Table 3.2).

Table 3.2. Overview of killer/pilot whale and white-beaked dolphin detections

Station	Classification	Date	Start time (UTC + 2)	Duration
Gule Rev West	White-beaked dolphin	25 Sep 2020	10.05.20	8s
Gule Rev East	White-beaked dolphin	4 May 2021	20.51.57	1m10s
Store Rev West	White-beaked dolphin	5 May 2021	12.34.17	4m17s
Store Rev West	White-beaked dolphin	6 May 2021	00.44.33	8m54s
Store Rev West	White-beaked dolphin	6 May 2021	16.44.35	2m22s
Store Rev West	White-beaked dolphin	6 May 2021	18.42.10	2m35s
Store Rev West	White-beaked dolphin	6 May 2021	21.25.28	29m58s
Store Rev East	White-beaked dolphin	10 May 2021	09.06.28	12s
Gule Rev East	Killer/pilot whale	31 May 2021	19.29.42	30m
Store Rev West	Killer/pilot whale	20 Jun 2021	19.25.54	30m
Gule Rev East	White-beaked dolphin	23 Jun 2021	00.23.07	24m2s
Gule Rev East	White-beaked dolphin	25 Jun 2021	02.23.51	27m5s
Store Rev East	Killer/pilot whale	2 Jul 2021	05.56.13	30m
Store Rev West	Killer/pilot whale	2 Jul 2021	06.26.02	30m
Store Rev East	Killer/pilot whale	2 Jul 2021	08.00.10	1h

3.1 Pilot and killer whales

Of the 76 events flagged for potential odontocete activity by the initial analyst (23 at Gule Rev east, 22 at Store Rev east, and 31 at Store Rev west), on five separate occasions whistles characteristic of killer and/or pilot whales were detected: four on Store Rev and once on Gule Rev. Other detections were concluded to be harbor porpoise (66) or not biological in origin (5) by the senior analyst.

Note: The WM detector did not pick up porpoise echolocation events, only the initial analyst made note of all echolocation activity opportunistically spotted.

One example of killer/pilot whale vocal activity is shown in Figure 3.1, which contained both echolocation clicks and whistles, recorded 8 minutes apart on the 20. June 2021 on Store Rev west.

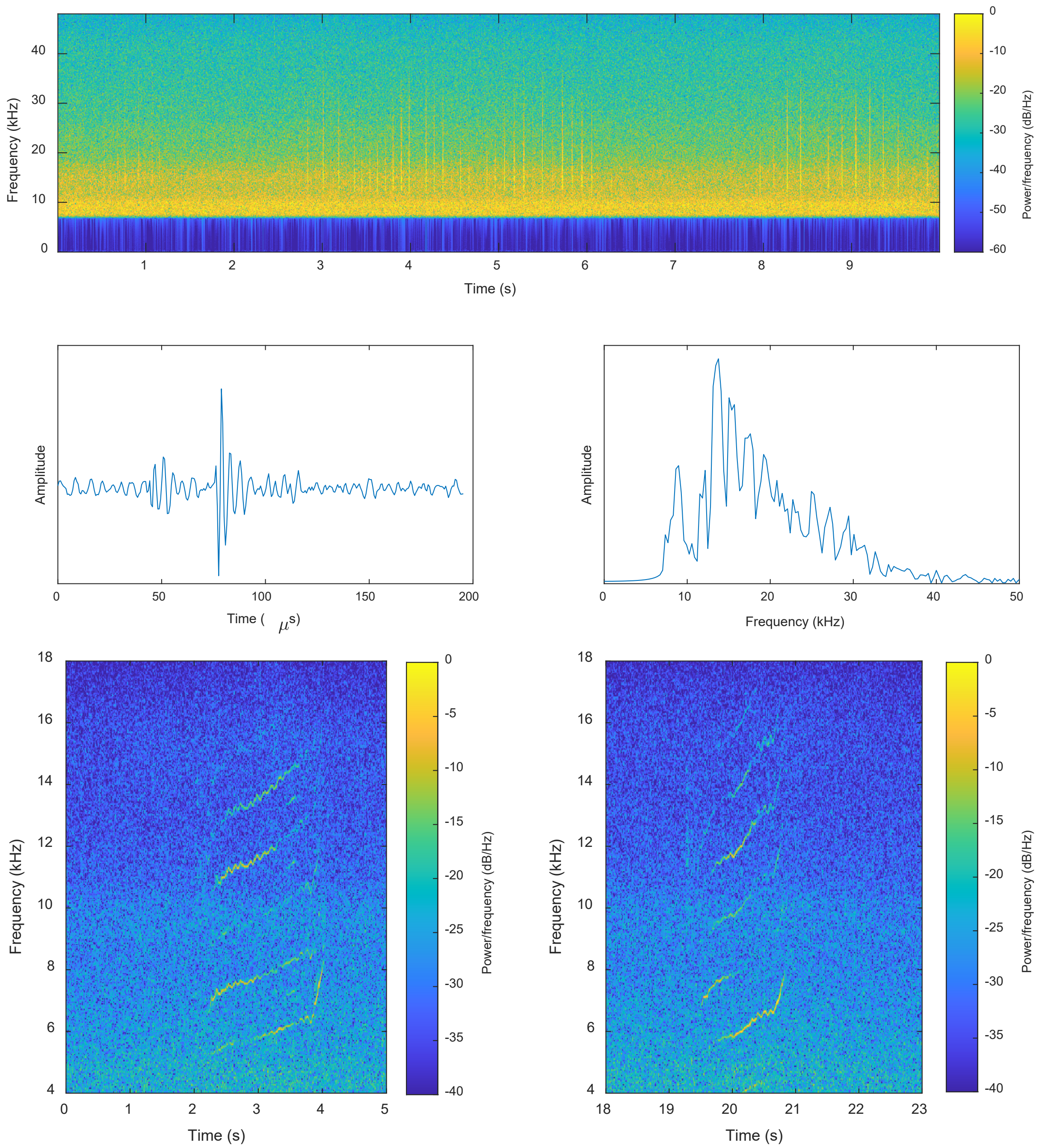


Figure 3.1. Top: Example of a 10 second recording with echolocation clicks not classified as white-beaked dolphins. Middle: example waveform and frequency spectrum of a single click from the sequence above, illustrating the low peak frequency of the clicks. Bottom: Spectrograms of two examples of whistles, recorded 20 seconds apart.

The echolocation clicks have very low peak frequencies (example above exhibits a peak frequency of 15 kHz), consistent with a large odontocete, such as killer whale or pilot whale and in contrast to the higher-frequency white-beaked dolphins. Also the whistles have very low first harmonics again consistent with a larger odontocete and in sharp contrast to the higher frequencies of white-beaked dolphin whistles (Rasmussen et al. 2006). Whistles recorded demonstrated variable inflection points and loops, as is typical with killer/pilot whales in Norway (Vester, 2017). The characteristics match the characteristics of both killer whales and pilot whales and as both species are observed in the area, it seems likely that the signals are from one or both of these species. Of course, some of the whistle repertoire does overlap with the common bottlenose dolphin, however, peak frequencies for *T. truncates* echolocation clicks can range between 40-120 kHz (Wahlberg et al., 2011, Jones et al., 2019). None of the whistles detected matched characteristics of published white-beak dolphin whistles.

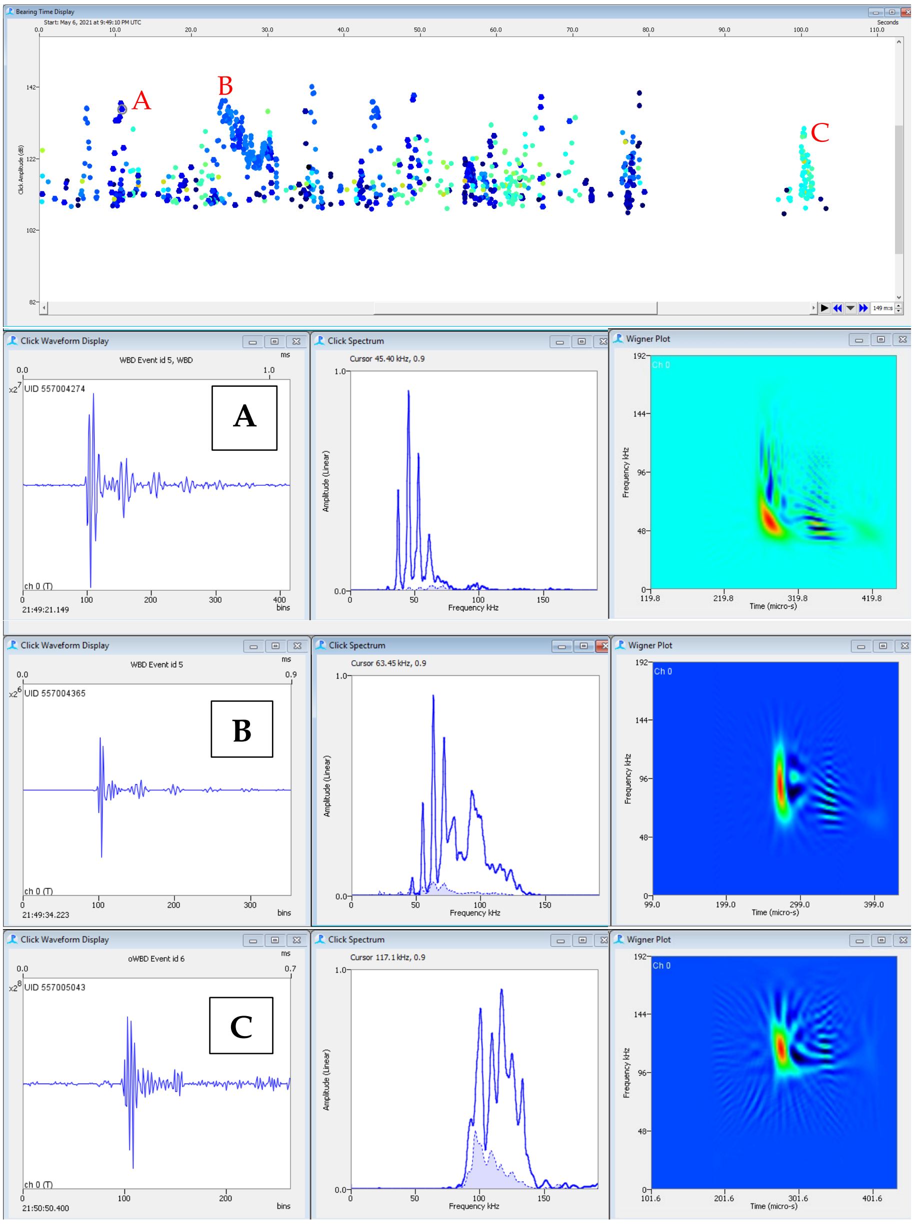
3.2 White-beaked dolphins

Within our subsampled data, we did find examples of both the narrowband and broadband white-beaked dolphin echolocation clicks described in Calderan et al. (2013). While most of the clicks were narrowband and lower in frequency, broadband clicks were often found within larger events. For example, from Store Rev West, on 6 May at 21:49 many of the clicks had a peak frequency around 44-45 kHz (Figure 3.1, panel A), which is what triggered the PAMGuard Click Detector to classify the click as a white-beaked dolphin. However, there were many clicks with a much broader bandwidth, spanning between 45-100 kHz, with a peak frequency around 63-64 kHz (Figure 3.1, panel B). Within identified events broadband clicks were also found, as defined by Calderan et al. (2013), where most of the energy was above 70 kHz and a highly variable peak frequency ranging between 95-117 kHz (Figure 3.1, panel C). Based on these preliminary results, using the terms narrowband and broadband may not be the best way to describe our clicks, as all clicks had broadband characteristics despite their peak frequency.

What is also noticeable in these detections is the deeply notched spectra (‘frequency banding’) of all clicks. Due to the nature of our data, it is not possible to separate clicks into on-axis and off-axis. Since the majority of clicks recorded from autonomous recorders are likely to be off-axis, further work is needed to determine how stable the notches in the spectra are, and thereby whether it can be used to refine our classification tools. Stable notch patterns from wildlife recordings have been independently documented for multiple species with a similar cranial morphology (indicating that the origin could be internal reflections in the head of the animals), and have been used as a species diagnostic tool (Soldevilla et al. 2008, Calderan et al. 2013) and to categorize types of delphinids from passive acoustic recorders (Palmer et al. 2017).

While burst pulse detection was used to help find white-beaked dolphin events, no further analysis was completed to characterize these signals; only that the pulses detected matched parameters outline in Simard et al. (2008). In all white-beaked dolphin detected events, it was visually confirmed that no whistling was present.

Figure 3.2. Example of a white-beaked dolphin detection event from Store Rev west on 6 May 2021 at 21:46. Duration of recording is about 2 minutes. Y axis indicates received click amplitude, while colour indicates peak frequency (dark blue – lower, cyan – higher). Lower panels show details of individual clicks, labelled A, B and C in the top panel. The three subparts show, from left to right: Click Waveform, Click Spectrum and Wigner Plot of the click, which shows the time-frequency structure of the click, with warmer colors indicating higher amplitude.

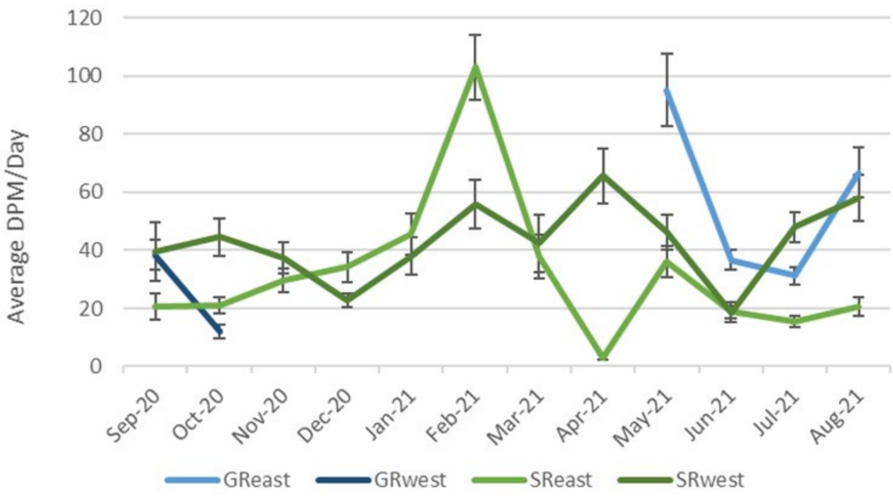


3.3 Harbour porpoise

Porpoises were detected on 92-100% of the days during the deployment period. The recording period covered the full year at Store Rev and from May to October at Gule Rev.

The monthly average number of harbour porpoise detection positive minutes per day (minutes where harbour porpoises have been detected, DPM) per station varied between 10 to 100 DPM per day in most month (Figure 3.3).The highest level of detection (approx. 100 DPM ≈ 7% positive minutes per day) and lowest (3 DPM ≈ 0.2%) were both recorded at the station Store Rev east in February 2021 and April 2021, respectively. A higher level of detections (90 DPM ≈ 6%) was also recorded in May 2021 at Gule Rev east. The data show that porpoises were present at the reefs throughout the year, but with a tendency of higher numbers during February to May on Gule Rev.

Figure 3.3. Detections of harbour porpoises at the four stations in Skagerrak from September 2020 to August 2021. DPM = detection positive minutes. Error bars illustrate standard error of mean.



3.4 Conclusion

The pilot project succeeded in recording cetacean vocalizations from species other than porpoises, thereby for the first time documenting these species acoustically from Danish waters. Comparisons of our data with recordings of white-beaked dolphins from other areas of northern Europe, and the development of a preliminary classification routine indicate that after harbour porpoise, the second most commonly acoustically detected species in our study was the white-beaked dolphin, with additional detections of either killer whales or pilot whales.

This is the first study acoustically documenting the presence of harbour porpoises year round at the Danish reefs in Skagerrak. Harbour porpoises were detected on 92-100 % of days with a tendency for more porpoise detections from February to May at Gule Rev. At Store Rev, most detections were recorded in May 2021 and August 2021, but unfortunately no data is available at Store rev from November to April, so porpoise presence in the winter remains unknown. That harbour porpoises are detected on most days was expected as harbour porpoises are common in Skagerrak and since results from satellite tracked porpoises have shown that porpoises in Skagerrak prefer the slopes of the Norwegian Trench where water depth increase from 100 m to 700 m and where our study areas are located (Sveegaard et al. 2011b),

It is important to note that there may be more white-beaked dolphins signals in our data, since only a subset was examined, and that other odontocete species may be present in the recordings as well (either missed entirely, or erroneously classified as white-beaked dolphins).

These difficulties are to be expected, however, as this is a pilot study. From this data, we can continue to develop more robust classifiers now that we have the means to identify timespans in our autonomously collected data that has odontocete vocalizations present. As there are limited species present in Skagerrak, detected signals can only belong to a few species. Additionally, these difficulties do not prevent the design of more rigorous monitoring programs, with better temporal coverage, allowing for description in annual patterns of abundance, and better geographical coverage, allowing for detection of patterns in distribution. It is important to get better recordings from the Skagerrak and North Sea of white-beaked dolphins, killer whales and pilot whales with visual confirmation, such that detectors and classifiers can be optimized.

However, as long as the aim of a monitoring program is to quantify occurrence and distribution of white-beaked dolphins, assumed from visual surveys to be the most common odontocete after harbour porpoises in Danish waters, then the errors committed by falsely including a few individuals of other species is unlikely to be a significant problem.

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ACOUSTIC DETECTIONS OF ODONTOCETES IN SKAGERRAK

Investigation of clicks and whistles from delphinids at Gule Rev and Store Rev

A pilot study on passive acoustic monitoring for odontocetes other than harbour porpoises was conducted on two stone reefs in Skagerrak, by means of broadband sound recorders. Analysis of recordings by automated detectors and manual auditing identified numerous likely recordings of vocalisations from an odontocete, most likely white-beaked dolphins, the most common species in the area after harbour porpoises. Other acoustic sounds matching the characteristics of killer whales and pilot whales, two species also observed regularly in the area, were also found. Thus, the pilot study documented the feasibility of passive acoustic monitoring for these species in the North Sea and adjacent waters.

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