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Marine strategy framework directive criterion D11C2 HELCOM pre-core indicator low-frequency continuous noise

Technical Report from DCE – Danish Centre for Environment and Energy No. 204 2021

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Data sheet

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Abstract: The Danish Environmental Protection Agency (Miljøstyrelsen) has a monitoring program for continuous underwater noise in the Danish marine waters. This monitoring program fulfils requirements regarding low-frequency underwater noise of the Marine Strategy (Havstrategien) and the HELCOM monitoring program. Underwater noise was measured on five monitoring stations in the North Sea, Kattegat and Danish Straits in 2019 and 2020, in continuation of previous years' monitoring. Recordings show systematic differences in noise levels between recording stations, consistent with different levels of ship traffic, the main anthropogenic source of low-frequency noise. The time line of monitoring does not extend long enough to allow detection of possible trends in levels.

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Forord

Denne rapport beskriver data indsamlet i indre danske farvande og Nordsøen i 2019 og 2020 som led i Miljøstyrelsens løbende overvågning af undervandsstøj. Denne overvågning foregår som en del af opfyldelsen af Danmarks forpligtigelser i henhold til EU's Havstrategidirektiv (EU Kommissionen, 2008; EU Kommissionen, 2017, kriterium D11C2) og HELCOMs overvågningsprogram (pre-CORE indikator af kontinuerlig undervandstøj). Data er indsamlet på lyttestationer ved Anholt, Hjelm, Lillebælt, Stevns og Horns Rev. To af målestationerne (Anholt og Horns Rev) indgår samtidig i Nordsø-projektet JOMOPANS (Joint Monitoring Programme for Ambient Noise North Sea), finasieret af EU-INTERREG Nordsøen og Miljøstyrelsen.

Denne rapport er alene en afrapportering af de indsamlede data efter kvalitetssikring og grundlæggende dataanalyse i henhold til anbefalinger fra EU (TG-Noise; Dekeling et al., 2014) og HELCOM (EN-Noise / Pressure; HELCOM, 2018) og indeholder derfor ingen tilbundsgående analyse eller syntese af målingerne. Rapporten ligger i forlængelse af tidligere års rapporter (Nielsen et al., 2019; Sørensen, 2019; Tougaard et al., 2017) og årsgennemsnit fra disse tidligere rapporter er angivet, men der er ikke foretaget en egentlig analyse af værdierne og derfor kan forskelle og udviklingstendenser i tallene ikke tillægges nogen statistisk sikkerhed.

Dansk resumé

Havstrategidirektivet (EU Kommissionen, 2008) kræver at EUs medlemslande overvåger og sikrer god miljøtilstand i deres marine områder. Vurderingen af god miljøtilstand er ydermere specificeret på 11 deskriptorer med tilhørende kriterier. Et af disse kriterier, D11C2, vedrører vedvarende lavfrekvent undervandsstøj. Denne rapport beskriver Miljøstyrelsens aktiviteter rettet mod overvågning af lavfrekvent undervandsstøj i 2019, hvilket bestod af målinger på fem stationer i danske farvande.

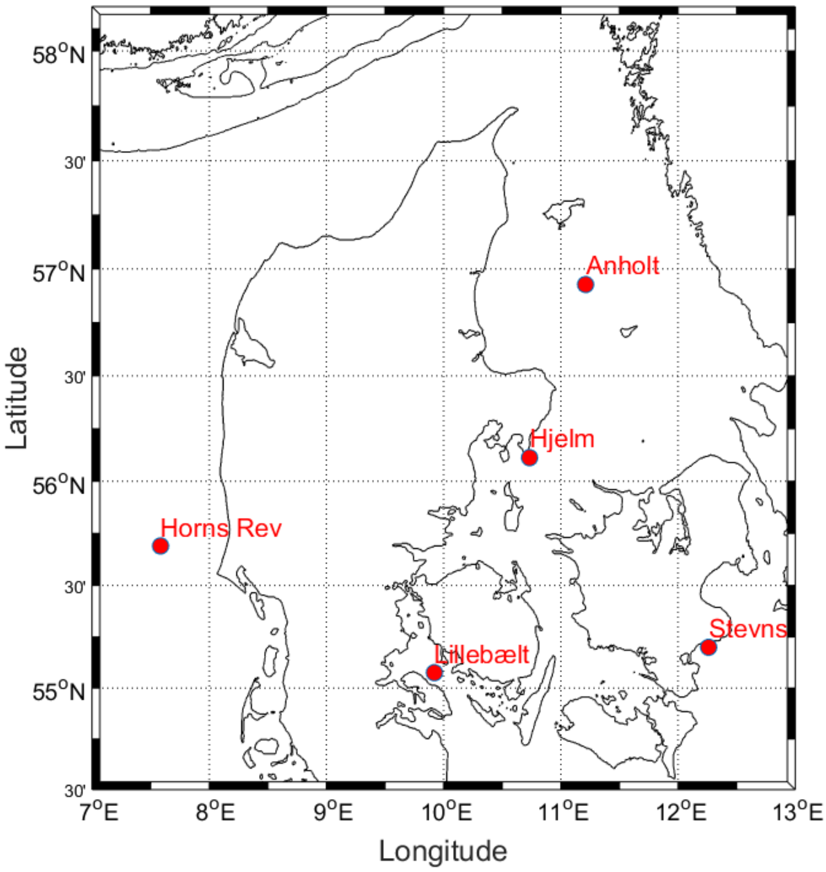
Som noget nyt i HELCOMs overvågningsprogram foreligger der en forpligtigelse til at dele målingerne via HELCOMs nyetablerede database for undervandsstøj. Rapporten indeholder derfor tillige status på aflevering af måledata til denne database.

Målinger i 2019-20

De anvendte metoder følger den tekniske anvisning vedrørende måling af undervandslyd (Tougaard, 2019b), som er afledt af HELCOMs overvågningsmanual (HELCOM, 2018), som igen er afledt af vejledning fra EUs ekspertgruppe, TG-Noise (Dekeling et al., 2014).

Overvågning blev gennemført på fem stationer. To i den marine biogeografiske region Østersøen (Stevns og Lillebælt), to i den marine biogeografiske region Nordsøen (Anholt og Horns Rev), og en (Hjelm) på grænsen mellem de to regioner (nordlige Storebælt). Stationerne er angivet i **Figur 1**.

Figur 1. Kort, der angiver placering af de fem målestationer i 2019.



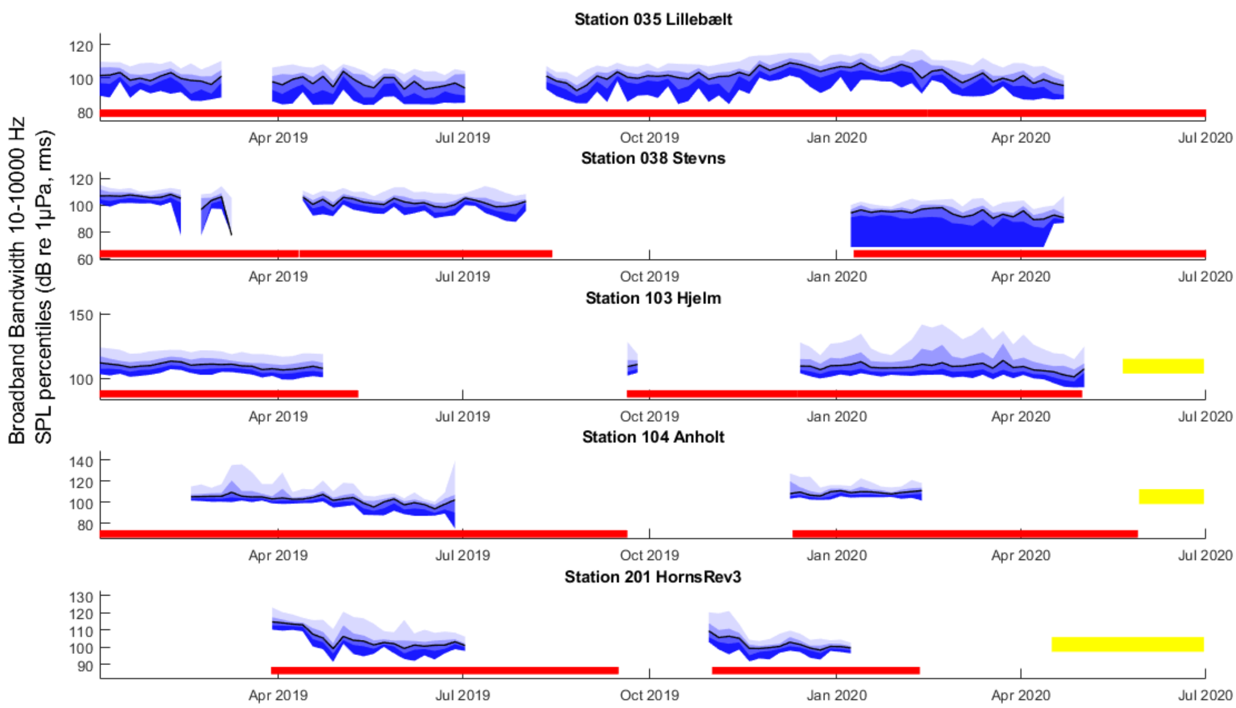
To typer af udstyr blev anvendt: Wildlife Acoustics SM2M dataloggere og den nyere Ocean Instruments ST500. Deres specifikationer er sammenlignelige og de blev programmeret til at optage 30 minutter hver time, for at forlænge batterilevetiden, som typisk er 3-4 måneder. Dataloggerne blev kalibreret i henhold til den tekniske anvisning (Tougaard, 2019b) forud for hver udlægning.

Dataloggerne blev udlagt på bunden forankret til jutesække fyldt med grus. Ved hjælp af en akustisk udløsermekanisme kan grussækken frigøres og udstyret flyder til overfladen.

Dataanalyser

Optagelserne blev analyseret efter samme metoder som tidligere år og i overensstemmelse med den tekniske anvisning (Tougaard, 2019a). Kortfattet beskrevet, så deles optagelserne op i segmenter af 1 sekunds varighed og for hvert segment fremstilles et tredjedels-oktavspektrum. Lydtrykket i de tre bånd centreret omkring 63 Hz, 125 Hz og 2000 Hz afrapporteres i henhold til HELCOMs manual. For hvert bånd kumuleres målingerne for de enkelte segmenter og afrapporteres som percentiler. Der angives således niveauer for de øvre percentiler L_5, L_{25}, L_{50} (median), L_{75} og L_{95}. Den øvre 5. percentil, L_5, angiver det lydtryk, der på den pågældende station overskrides 5% af tiden og er således et mål for de kraftigste støjniveauer på stationen, mens L_{95} angiver det lydtryk, der overskrides 95% af tiden og er derfor et mål for de laveste lydtryk på stationen.

En oversigt over de indsamlede data ses i **Figur** 2, hvor percentiler af totallydtrykket er angivet.

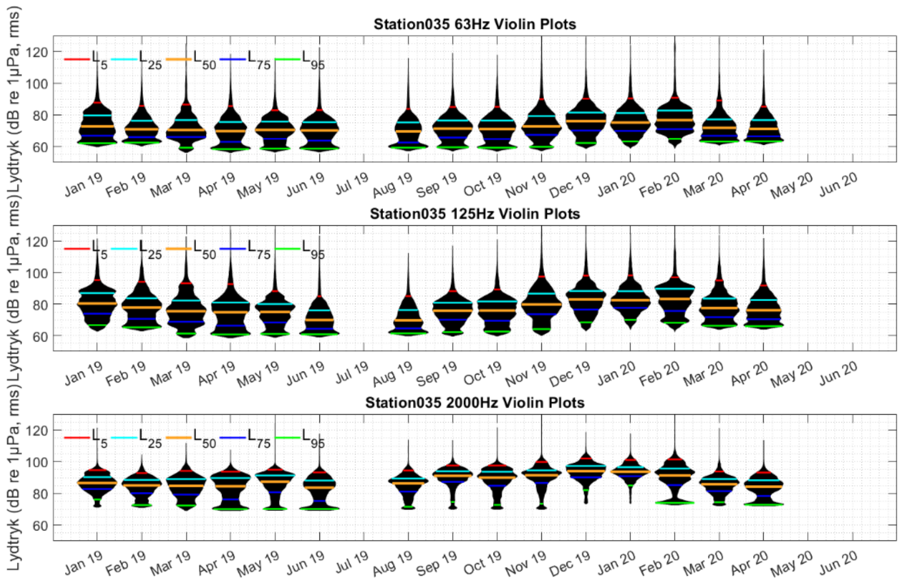


Figur 2. Bredbåndslydtryk (10 Hz – 10 kHz) angivet som percentiler for hver af de fem stationer. Mørkeblåt angiver de nedre percentiler (L_{75}-L_{95}) og de lysere nuancer angiver de øvre percentiler (L_{25} og L_5). Medianen (L_{50}) er angivet som en sort streg. Nederst i hver figur er angivet med rødt den periode hvor udstyr var i vandet på den pågældende station. Gule linjer angiver data, der endnu ikke er analyseret.

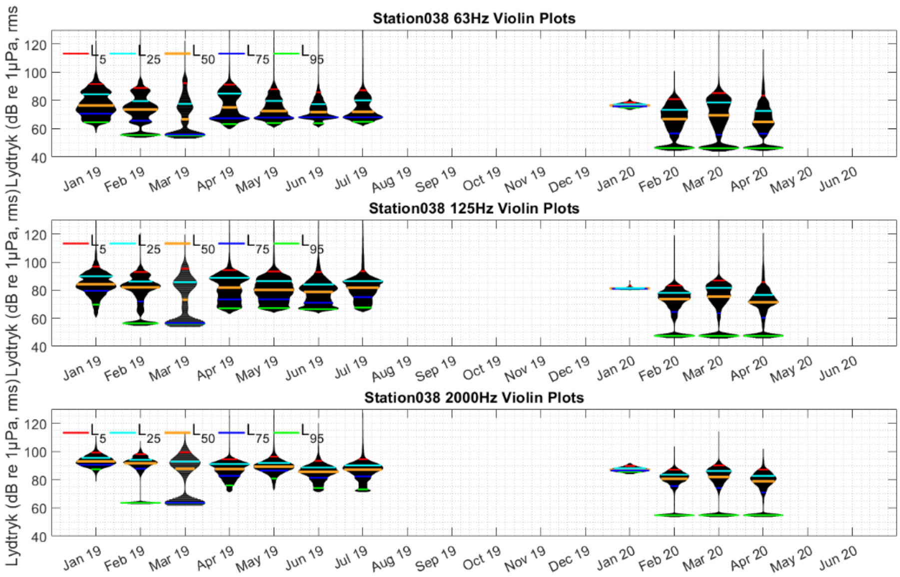
De huller, der er i dataene for 2019 skyldes i overvejende grad tekniske problemer med udstyr, dækkende over mekaniske problemer, fejl i elektronikken og problemer med for kort batterilevetid i forhold til specifikationerne.

Tredjedels-oktavniveauer i 2019-20

De analyserede tredjedelsoktav-niveauer er vist månedsvis som såkaldte violinplot i **Figur 3** til **Figur 7**. Violinplottene angiver fordelingen af lydtryk i den pågældende måned. Bredden af ”violinen” er således et udtryk for hvor ofte det på y-aksen angivne lydtryk forekommer. De forskellige percentiler er angivet som farvede bånd.

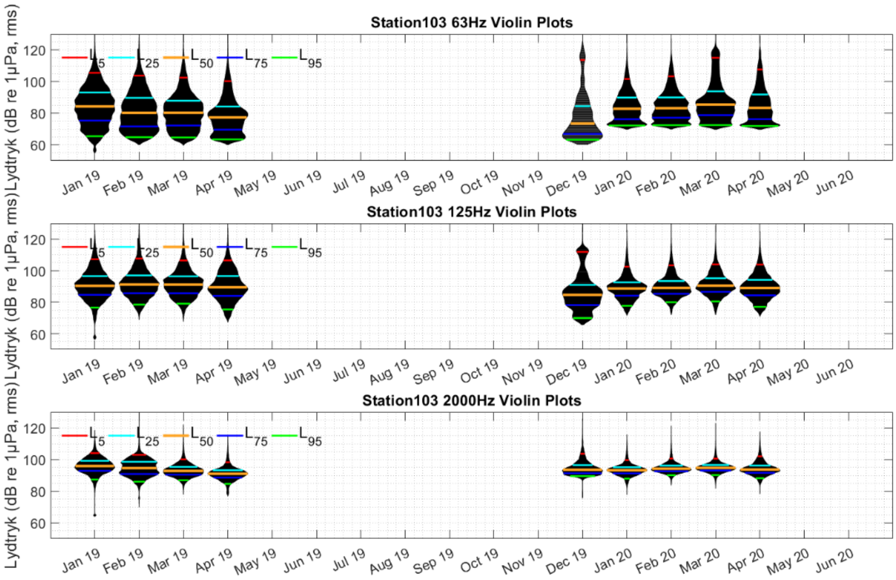


Figur 3. Violinplot månedsvis for målingerne fra Station 035 Lillebælt, med angivelse af percentiler som farvede bånd. Den flade ”fod” i visse måneder, mest tydeligt i 2 kHz dataene, er resultatet af egenstøj i optageudstyret og bevirker at de laveste støjniveauer ikke registreres korrekt. Dette kan betyde at den nederste 5. percentil (L_{95}) overestimeres, men påvirker ikke de højere percentiler. Måneder med mindre end 7 dages data er ikke medtaget.

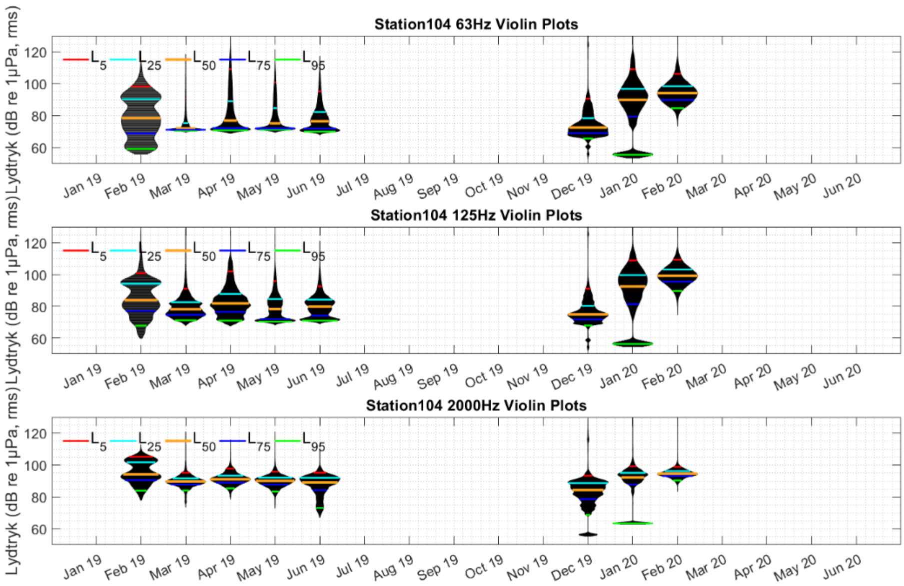


Figur 4. Violinplot månedsvis for station 038 Stevns. Se figurtekst til **Figur 3** for forklaring.

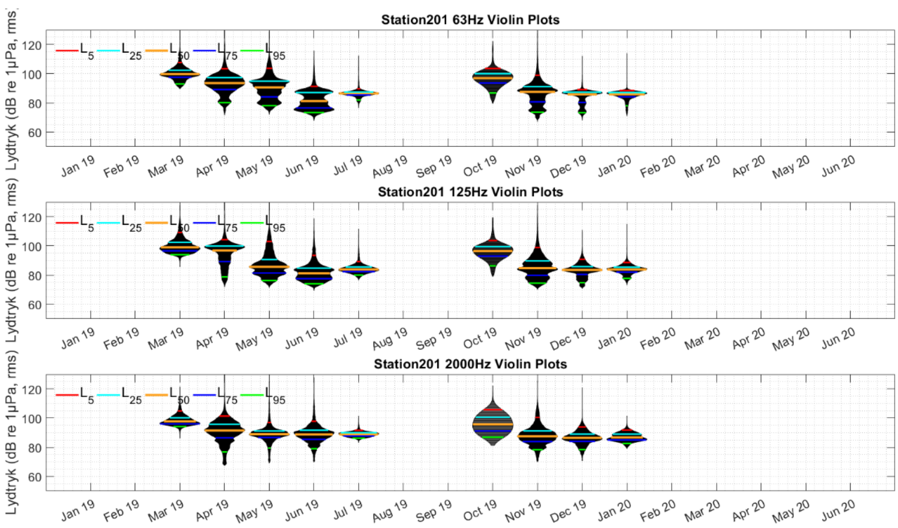
Figur 5. Violinplot månedsvis for Station 103 Hjelm. Se figurtekst til **Figur 3** for forklaring.



Figur 6. Violinplot månedsvis for Station 104 Anholt. Se figurtekst til **Figur 3** for forklaring.



Figur 7. Violinplot månedsvis for Station 201 Horns Rev. Se figurtekst til **Figur 3** for forklaring.



Årsgennemsnit for de fem stationer er angivet i **Tabel 1**. Der er betydelige forskelle i niveauerne mellem de fem stationer, hvilket afspejler deres forskellige lokale omgivelser og især afstanden til større skibsruter. De laveste niveauer i 125 Hz båndet var fra Lillebælt-stationen (76. 7 dB re 1 µPa / tredjedel oktav), i overensstemmelse med resultaterne fra BIAS-projektet (Mustonen et al., 2019) og afspejlende at stationen ligger i et område med meget lidt trafik af større skibe. De større skibe har mest energi ved de laveste frekvenser i undervandsstøjspektret. Middelniveauerne i 2 kHz båndet i Lillebælt var derimod sammenlignelige med niveauerne fra de øvrige stationer i indre farvande, hvilket kan være en afspejling af sammenlignelige niveauer af trafik med mindre både, der har størstedelen af energien i undervandsstøjen ved højere frekvenser. Det markant højeste niveau i 125 Hz båndet (90.6 dB re. 1 µPa / tredjedel oktav) var fra Hjelm, hvilket sandsynligvis afspejler nærheden til både dybvandsruten i Storebælt (T-ruten) og Molslinjen. Ingen af stationerne er dog i nærheden af de maksimumniveauer der blev målt under BIAS-projektet i 2014. Her blev de højeste niveauer i 125 Hz båndet målt i Femern Bælt (115 dB re. 1 µPa / tredjedel oktav) og Storebælt ved Sprogø (109 dB re. 1 µPa / tredjedel oktav).

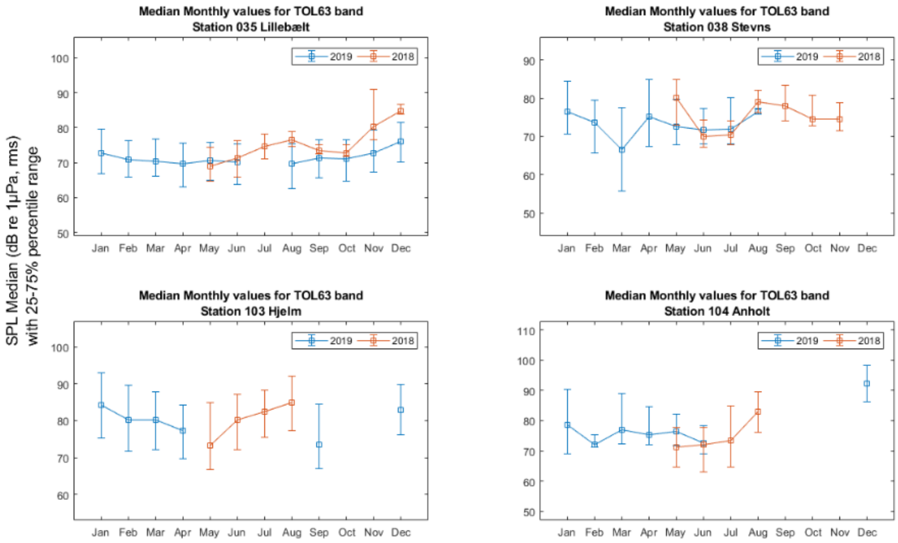
Da der endnu ikke forefindes hverken tærskler for god miljøtilstand eller retningslinjer for vurdering af miljøtilstanden for så vidt angår vedvarende undervandsstøj, kan de målte værdier ikke sættes i relation til miljøtilstand.

Tabel 1. Årsgennemsnit for undervandsstøjen i tredjedelsoktav-båndene 63 Hz, 125 Hz og 2 kHz for årene 2014 (BIAS-projektet), 2018 (Hermannsen (Nielsen et al., 2019) og 2019 (denne rapport) og angivet i dB re. 1 µPa/tredjedel oktav. Da gennemsnittene ikke dækker de samme perioder på året kan de ikke direkte sammenlignes på tværs af år.

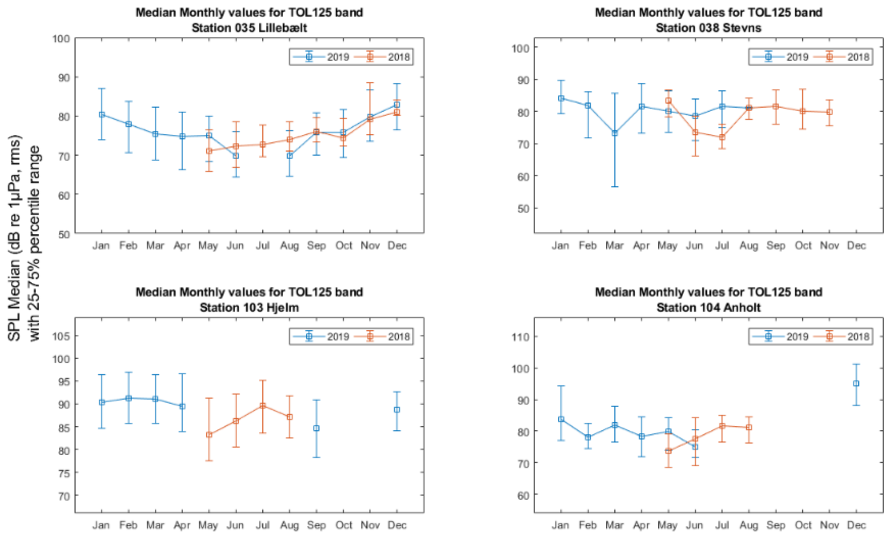
Station	Frekvensbånd	Mean SPL 2014	Mean SPL 2018	Mean SPL 2019
035 Lillebælt	63 Hz	90.1	85.1	72.1
	125 Hz	88.8	83.9	76.7
	2 kHz	89.1	83.6	86.7
038 Stevns	63 Hz	93.1	88.8	74.3
	125 Hz	95.8	96.4	80.2
	2 kHz	93.8	92.3	87.6
103 Hjelm	63 Hz	99.8	100.2	81.9
	125 Hz	101.4	101.7	90.6
	2 kHz	98.9	99.1	93.8
104 Anholt	63 Hz	89.9	88.3	79.0
	125 Hz	91.5	92.4	80.5
	2 kHz	96.6	94.1	88.2
201 Horns Rev	63 Hz	-	-	87.3
	125 Hz	-	-	86.6
	2 kHz	-	-	88.7

Tidsmæssig udvikling i niveauerne

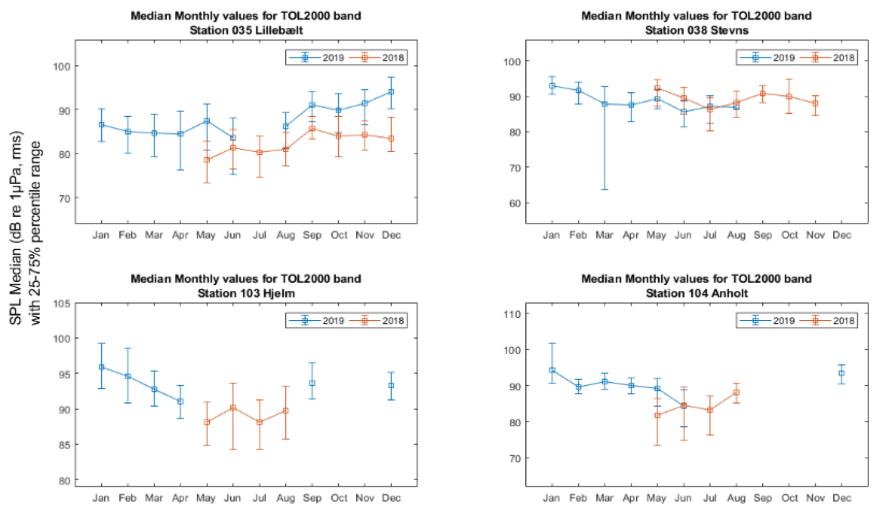
Med overvågningen i 2019 har vi to års data for stationerne i danske farvande (2018 and 2019) ud over BIAS-dataene fra 2014 og data fra Lillebælt i 2016 og 2017 (Nielsen et al., 2019; Sørensen, 2019). Dataene er sammenholdt månedsvis for 2018 og 2019 i **Figur 8** til **Figur 10**. Der er ikke foretaget en statistisk analyse af dataene. Der er indsamlet meget store mængder data for hver station, hvilket betyder at de månedsvise estimater er meget sikre, men tidsseriens længde (6 år) er endnu ikke lang nok til at en tidsmæssig udvikling i niveauerne kan fastlægges. De begrænsede data der findes fra andre områder (østlige Stillehav og Nordatlanten, begge dybt vand) antyder en stigning i den lavfrekvente støj på grund af skibstrafik på omkring 3 dB per tiår (Hildebrand, 2009). En ændring i denne størrelsesorden kan ikke påvises i en tidsserie på kun 6 år, da denne forventede stigning ligger indenfor måleusikkerheden og den naturlige år-til-år variation.



Figur 8. Median-lydtryk månedsvis og stationsvis for 63 Hz båndet



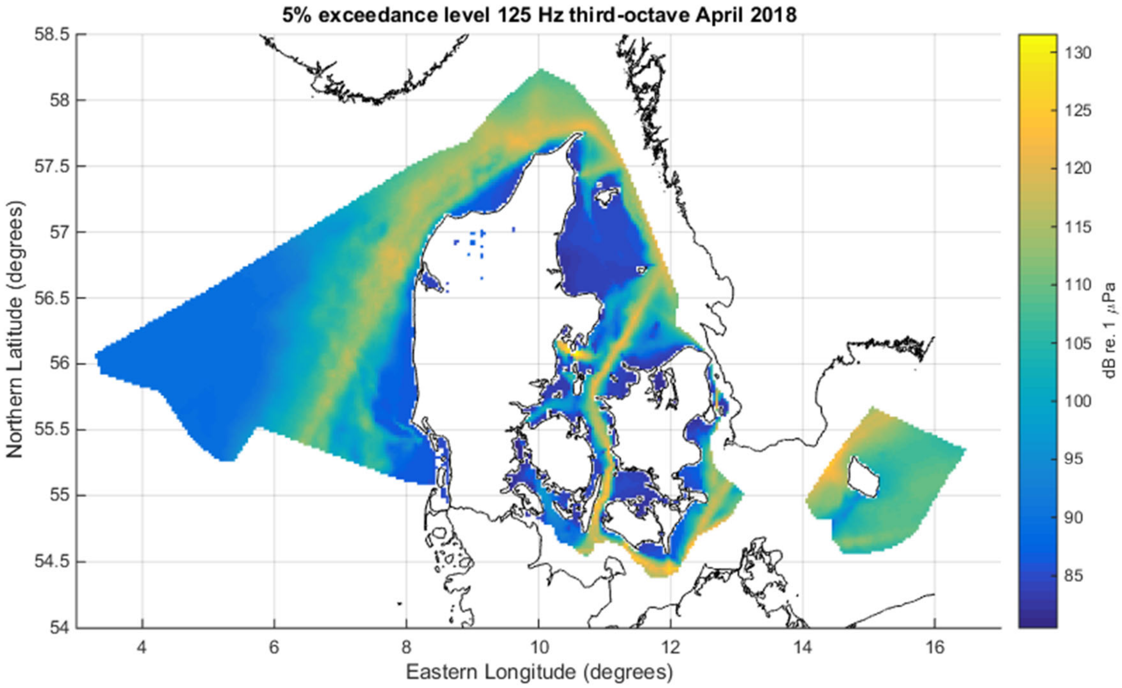
Figur 9. Median-lydtryk månedsvis og stationsvis for 125 Hz båndet



Figur 10. Median-lydtryk månedsvis og stationsvis for 2 kHz båndet

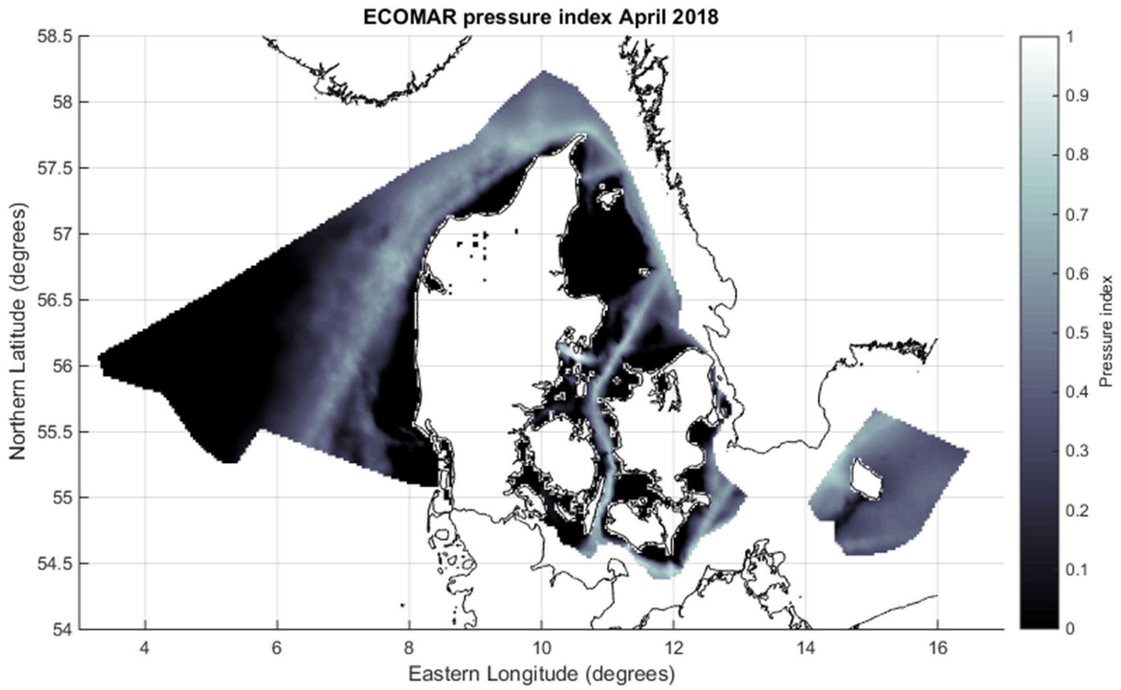
Kort over lydtryk

I forbindelse med projektet Økomar, finansieret af Veluxfonden (Andersen et al., 2020) blev der fremstillet presfaktorkort over undervandsstøj til Økomars integrerede kortværktøj (baseret på principperne beskrevet i Halpern et al., 2012). Selve modelleringen blev foretaget af det franske firma Quiet Oceans og detaljerne i modellen er beskrevet andetsteds (Folegot et al., 2016). Kort beskrevet, så modelleres den naturlige baggrundsstøj (drevet af vind og bølger) ud fra meteorologiske modeller over vindhastighed, mens skibsstøjen stammer fra en særskilt model, Randi3, der beskriver støjen fra skibe som funktion af deres størrelse og sejlhastighed (Jiang et al., 2020). Skibenes positioner kom fra AIS data (Søfartsstyrelsen) og yderligere baggrundsdata om bundsediment og hydrografi fra EMODnet. Baseret på disse informationer kunne støjen fra enkeltskibe propageres ud over de danske farvande og summeres med baggrundsstøjen (**Figur 11**).



Figur 11. Øvre 5. percentil af den samlede undervandsstøj (naturlig baggrundsstøj plus skibsstøj) i 125 Hz tredjedelsoktavbåndet. Fra Økomar-projektet.

Kortet i **Figur 11** viser totalstøjniveauet og er derfor i sig selv ikke udtryk for hvor stort skibsstøjens bidrag er. Til brug for HOLAS II blev udviklet en presfaktor baseret på tilsvarende støjkort for Østersøen (Andersson et al., 2018). Denne presfaktor udtrykker den normaliserede forskel mellem den øvre 5. percentil af et estimat af den naturlige baggrundsstøj (baseret på BIAS-målinger i områder med megen lidt skibstrafik) og den øvre 5. percentil af den faktiske støj, estimeret fra modelleringen. Herved fremkommer et kort, der angiver et indeks fra 0, svarende til meget begrænset skibsstøj, til 1, svarende til meget kraftig og vedvarende skibsstøj. Dette indeks er illustreret i **Figur 12** for danske farvande og for april 2018.



Figur 12. HELCOM HOLAS II presfaktor-indeks for kontinuerlig undervandsstøj estimeret for danske farvande for april 2018 for 125 Hz båndet. Høje værdier af indekset indikerer fremherskende skibsstøj ved 125 Hz, mens lave værdier indikerer forhold, der er tættere på referencetilstanden (naturlig baggrundsstøj uden menneskelige kilder).

Af kortet ses det at indekset for skibsstøj ikke overraskende er højt langs skibsruterne gennem Kattegat og Bælterne, men også langs Jyllands vestkyst og rundt om Skagen. Også farvandet omkring Bornholm, især på nordsiden, har høje niveauer. Også Århus Bugt er påvirket, sandsynligvis på grund af Molslinjen. Omvendt ses det at der er relativt upåvirkede områder i den centrale Nordsø og de lavvandede dele af Kattegat. Indekset gælder for 125 Hz båndet, hvilket er repræsentativt for støj fra større skibe, men ikke for mindre både.

Data til HELCOMs database for undervandsstøj

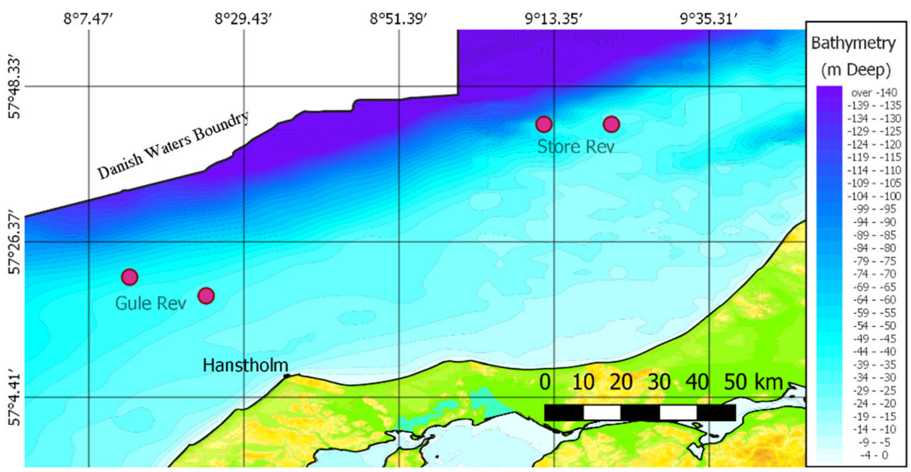
Data for de foregående års overvågning er blevet formateret og afleveret til HELCOMs database for kontinuerlig undervandsstøj, som led i opfyldelsen af forpligtigelserne i henhold til HELCOMs overvågningsprogram, for undervandsstøj. Omfanget af data fremgår af **Tabel 2**.

Tabel 2. Data indrapporteret til HELCOMs støjdatabase, opgjort som antal måneders data per år.

DK Monitering Station	2014	2015	2016	2017	2018	2019	2020	Total
DKMst035 Lillebælt	12	-	6	8	12	10	-	48
DKMst036 Storebælt	12	-	-	-	-	-	-	12
DKMst037 Rønne Banke	12	-	-	-	-	-	-	12
DKMst038 Stevns	11	-	-	-	7	8	-	26
DKMst103 Hjelm	5	-	-	-	6	9	5	25
DKMst104 Anholt	5	-	-	-	7	10	-	22
DKMst105 Frederikshavn	5	-	-	-	-	-	-	5
DKMst201 Horns Rev 3	-	-	-	-	-	8	1	9

Fremtidig overvågning

Overvågningen forventes at fortsætte, for at opfylde kravene i HELCOMs overvågningsprogram og også i forventning om etablering af et fælles overvågningsprogram for Nordsøen (OSPAR region II)(Kinneging and Gersonius, 2020). I den forbindelse foreslås det at etablere en målestation i den nordlige del af den danske Nordsø. AU / DCE gennemfører i øjeblikket et pilotprojekt med overvågning af vågehvaler, hvidnæse og andre hvaler i Natura2000-områderne Gule Rev og Store Rev (Figur 13). Når data fra disse målestationer bliver tilgængelige i første del af 2021 vil det kunne besluttes om der er baggrund for at fortsætte en af disse stationer som en del af støjovervågningen. På forhånd er der størst forventninger til Gule Rev, dels på grund af nærheden til Hanstholm, hvilket vil gøre servicebesøg nemmere og billigere, dels på grund af Gule Revs placering lige under skibsruten langs Jyllands vestkyst og rundt om Skagen.



Figur 13. Placering af målestationer i AU/DCEs pilotprojekt med akustisk overvågning af hvaler på Store Rev og Gule Rev.

For at rumme en ekstra målestation inden for overvågningsprogrammet kan man reducere indsatsen på de eksisterende stationer og derved dække flere stationer for samme midler. Man kan nedsætte optagefrekvensen på stationerne til f.eks. 30 minutter hver 2. time, hvilket vil give længere batterilevetid og dermed behov for færre servicebesøg til stationerne. En sådan nedsættelse af optagefrekvensen vil have minimal betydning for datakvaliteten, da månedsgennemsnit stadig vil være baseret på meget store mængder data. Imidlertid vil risikoen for tab af data stige, da udstyret skal ligge længere ude mellem servicebesøg. Et bedre alternativ er at veksle mellem de forskellige stationer, sådan at der ikke måles på hver station hvert år. Det vil nedsætte mængden af data til rådighed for analyserne, men det er formentlig tidsseriens længde snarere end antallet af målepunkter, der (inden for visse grænser) sætter begrænsningen på mulighederne for at registrere langtidsudvikling i data. Derfor skønnes det at denne form for reduktion i måleindsatsen er at foretrække (Likens and Lindenmayer, 2018), da risikoen for tab af udstyr og dermed data er konstant.

Et forslag til rotation mellem stationerne er at opdele stationerne i par og dermed veksle mellem optagelser på Horns Rev og Gule Rev og mellem Anholt og Hjelm. Stationen i Lillebælt er den mest stabile station og den prioriterede station i sin tid identificeret af BIAS-projektet (Nikolopoulos et al., 2016), og det foreslås derfor at fortsætte med kontinuerlige målinger her, mens der kun optages hvert andet år ved Stevns.

Preface

This report describes data collected in Danish waters in 2019 and 2020 as part of the Danish Environmental Protection Agency's ongoing monitoring of underwater noise. This monitoring is part of fulfilment of Denmark's obligations under the EU's Marine Strategy Framework Directive (EU Commission 2008, EU Commission 2017, criterion D11C2) and HELCOM's monitoring program (pre-CORE indicator of continuous underwater noise). Data were collected on monitoring stations at Anholt, Hjelm, Lillebælt, Stevns and Horns Reef. Two of the measuring stations (Anholt and Horns Rev) are also part of the North Sea project JOMOPANS (Joint Monitoring Program for Ambient Noise North Sea), funded by EU-INTERREG North Sea and the Danish Environmental Protection Agency.

This report is only a description of the collected data after quality assurance and basic data analysis according to recommendations from the EU (TG-Noise; Dekeling et al. 2014) and HELCOM (EN-Noise / Pressure; HELCOM 2018) and therefore does not contain an in-depth analysis or synthesis of the measurements. The report should be seen as a continuation of previous years' reports (Nielsen et al., 2019; Sørensen, 2019; Tougaard et al., 2017) and annual averages from some of these previous reports are provided for reference. No quantitative comparison of the values has been made and therefore differences and trends in the figures are not given any statistical certainty.

The Danish Environmental Protection Agency (Miljøstyrelsen) has commented on a previous draft of the report.

1 Background

The Marine Strategy Framework Directive (EU Commission 2008) requires Member States to monitor, achieve and maintain good environmental status (GES) in their marine waters. Assessment of GES is further specified into 11 descriptors, each with a subset of criteria. One of these criteria is D11C2, continuous, low-frequency noise. The Danish activities related to fulfilling the requirements of the directive's obligation to monitor underwater noise consists of recording of underwater noise at fixed monitoring stations in Danish waters. This report describes and documents the activities of the Danish Environmental Protection Agency's (Miljøstyrelsen) underwater noise monitoring program in 2019 and partly 2020. The monitoring is performed by Aarhus University / DCE and in 2019 and 2020 consisted of recording of underwater noise at five different stations in Danish waters: Hjelm, Anholt, Lillebælt, Stevns and Horns Rev.

As something new, the obligations according to the HELCOM monitoring program (pre-core indicator continuous underwater noise) also includes uploading processed monitoring data to the HELCOM continuous noise database, hosted by ICES. This report therefore also includes information on progress on processing and upload of data to the HELCOM database.

1.1 Terminology and units

Terminology and units in this report strive to follow the ISO standard on underwater acoustics (ISO, 2014) and guidance from EU TG-Noise (Ainslie, 2011; Dekeling et al., 2014).

1.1.1 Sound and noise

There is no universal definition of noise and some confusion relate to the terminology regarding sound and noise. Whereas sound is a neutral term usually describing a pressure wave propagating in a medium, noise is most commonly used to refer to something unwanted and / or detrimental. In the context of this report, noise is used to describe sound, which is potentially detrimental to the organisms living in the marine environment.

1.1.2 Impulsive vs. continuous noise

In management of anthropogenic noise it has turned out to be useful to make a distinction between impulsive noise and continuous noise. This distinction is somewhat arbitrary and some sources can contribute with both impulsive and continuous noise. It nevertheless allows a separation of impulsive sources, such as pile driving, explosions, seismic surveys and sonars, from continuous sources, such as ships and persistent noise from offshore infrastructures (oil and gas platforms, renewable energy installations etc.). While the impulsive sources are usually well-defined in time and space, and impact animals primarily through affecting behaviour, the continuous sources are numerous, persistent and distributed widely, and primarily affects animals by elevation of the ambient noise level. The MSFD criterion D11C2 and this report is concerned with the continuous noise only.

1.1.3 Sound pressure level

Sound consists of pressure fluctuations around the ambient pressure and the amplitude of this deviation is measured in µPascal. For a number of reasons (see for example Tougaard et al., 2015) the instantaneous pressure is not a good predictor of the detrimental effects of the noise. Instead, a time-average should be performed. Such an average is most commonly done as a so-called rms-average, equal to the square root of the mean pressure-squared.

$$L_{p,rms} = 20\log_{10}\left(\sqrt{\overline{p^2}}\right)$$

The log-transform means that the unit of sound pressure level is dB relative to 1µPa.

1.1.4 Third-octave/decidecade band level

Sound pressure level is not sufficient, however, to assess possible impact on marine organisms. Also the frequency of the sound is of importance, typically quantified by means of a frequency spectrum, which maps the intensity of the sound separated into different frequency bands. In analysis of continuous noise with the objective of assessing impact on marine organisms, it is most useful to separate the analysis into one or more narrow bands, each characterized by their centre frequency and bandwidth. The customary bandwidth to use for such an analysis is one-third of an octave, i.e. 23% of the centre frequency. The recommendations regarding D11C2 are that frequency bands centred at 63 Hz and 125 Hz are monitored (Dekeling et al., 2014) and the HELCOM monitoring guidelines further specify that additional monitoring should be performed in the 2 kHz band (HELCOM, 2018).

2 Methods

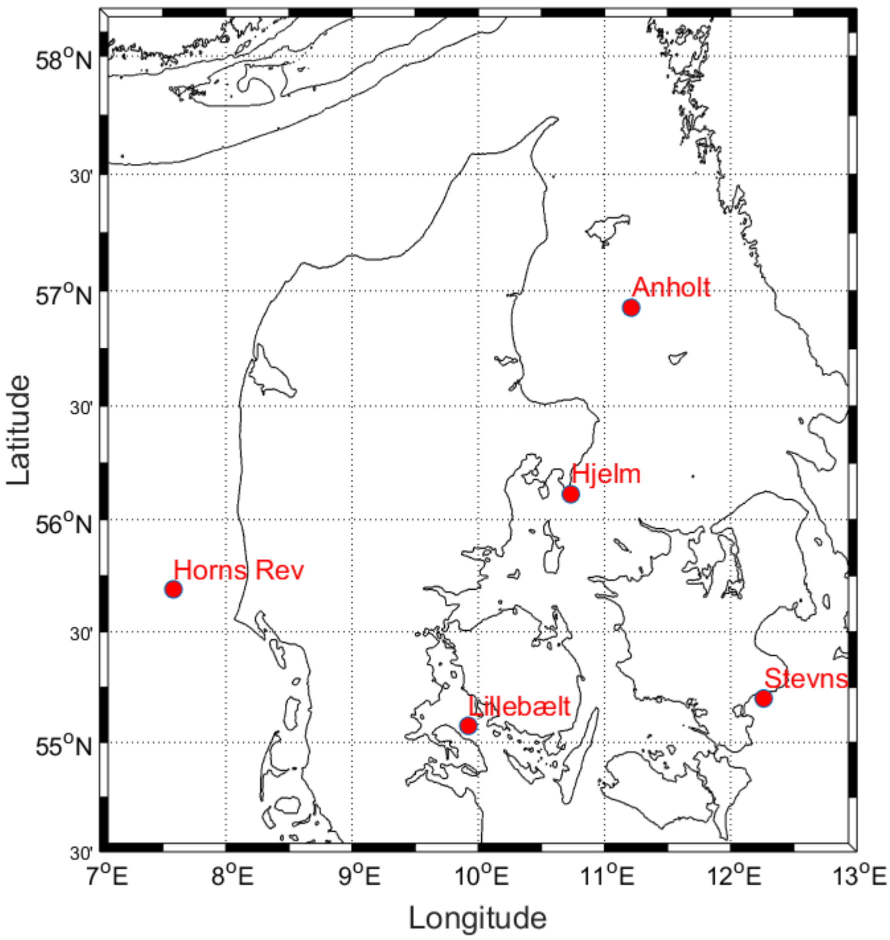
Monitoring follows the technical instructions of the national Danish monitoring program (Tougaard, 2019b), which is adapted from the guidelines for the HELCOM monitoring manual for continuous noise (HELCOM, 2018). The HELCOM guidelines are in turn implementations of the technical advice of the TG-Noise group (Dekeling et al., 2014).

2.1 In field methods

Monitoring was conducted at five different stations in Danish waters (Figure 2.1, Table 2.1). Two of these (Stevns and Lillebælt) are located in the Baltic Marine Biogeographic Region, two (Anholt and Horns Rev) in the North Sea Marine Biogeographic Region, and one station (Hjelm) right on the border between the two regions.

2.1.1 Overview of five Danish noise monitoring stations.

Figure 2.1. Map of the five noise monitoring stations in Danish waters.



The monitoring station at Horns Rev is located within the offshore wind farm, Horns Rev 3. Within this report, references to the station at Horns Rev or HornsRev3 indicate the same location.

Table 2.1. Exact locations, depths, and noise monitoring codes for each of the five stations in Danish waters.

Location	Station Code	Latitude	Longitude	Depth (m)
Anholt	DKMst104	56.924	11.206	12
Hjelm	DKMst103	56.113	10.734	10
Lillebælt	DKMst035	55.074	9.922	25
Stevns	DKMst038	55.199	12.259	11
HornsRev3	DKMst201	55.689	7.586	15

2.1.2 Equipment and Calibration

There are two types of self-contained underwater sound recorders used for the long term deployments: Ocean Instruments ST500 and Wildlife Acoustics SM2M. Each unit is programmed to record on a 30-minute on / 30 minutes off duty cycle, until the memory is full or batteries depleted. This typically takes 3-4 months, after which the units must be recovered and serviced. The specifications for these instruments can be found in **Table 2.2**.

Table 2.2. Key specifications of the two dataloggers used in the Danish monitoring program.

Brand	Model	Sample Rate Used	Data capacity	Sound digitization	Power usage
Ocean Instruments	ST500	36 kHz or higher	1 TB	16 bit	~35 mW
Wildlife Acoustics	SM2M+	32 kHz	512 GB	16 bit	350-500 mW

Both noise logger models have external, attachable hydrophones, making the noise logger board and hydrophone interchangeable between deployments. For both models the HTI96min hydrophone is employed (frequency response: 2 Hz – 30 kHz, nominal sensitivity: -185 dB re: 1V / µPa).

While each noise logger comes with generic factory calibration, individual sound boards and hydrophones may differ between units Therefore we calibrate exact configuration of our noise logger set up prior to deployment, in accordance with the technical instructions (Tougaard, 2019b).

In a calibration, a reference signal of known amplitude is recorded on the datalogger. This is performed in air for convenience, as this can safely be done for low frequencies, below a few kHz (Levin, 1973). The reference signal is generated by a standard sound source (pistonphone, GRAS instruments 42AC), which emits a constant tone at 250 Hz. The hydrophone is placed inside a custom build coupler, into which also a reference microphone is placed. As the sensitivity of the reference microphone is known (and assumed constant), the sound pressure inside the coupler can be calculated from the voltage output of the microphone (U_{rms} [V]), which has a known sensitivity (S [V / µPa]):

$$L_{p,rms} = 20 \cdot \log_{10}(U_{rms}/S)$$

The signal recorded on the datalogger consists of a series of samples (s_i) on a scale from -1 to 1 and from this, the clip level of the recorder can be calculated, i.e. the maximum sound pressure level that the recorder can record without exceeding the dynamic range.

$$L_{clip} = L_{p,rms} + 20 \cdot \log_{10}\left(\sqrt{\frac{\sum s_i^2}{fs \cdot T}}\right)$$

Where *fs* is the sample rate and *T* is the duration of the recording over which the average is performed. This calibration is strictly only valid at 250 Hz, but due to the typically flat frequency response of hydrophones at low frequencies (Levin, 1973) the error committed by calibrating at 250 Hz, while measuring at 63 Hz and 125 Hz is considered smaller than the precision of the calibration itself and hence insignificant. Use of the calibration value at 2 kHz is problematic, however (see for example Hayman et al., 2016), but no standard procedure for calibration at frequencies between about 1 kHz and 10 kHz is available, the measurements at 2 kHz are to be considered less precise than the measurements at 63 Hz and 125 Hz.

Figure 2.2. Examples of our noise monitoring moorings for the ST500 (left) and SM2M (right). The acoustic releaser is attached to the gravel bags and the recorder attached to the releaser. The orange float provides additional buoyancy to assure that the units reach the surface upon release.

2.1.1 Mooring

Noise loggers were moored to the sea bed using two 20 kg biodegradable weights (gravel bags made of jute fibres) and an acoustic releaser, either a Sonardyne LRT or a SubSeaSoncics AR-60. During retrieval, a signal is projected via a transducer to the releaser which initiates the release of the noise logger mooring to the surface. The biodegradable bags are the only part of the mooring left behind. Each noise logger has additional floats attached to ensure the logger has enough buoyancy to come to the surface once released.

2.2 Analysis methods

The recordings were analysed using a Matlab routine (R2017b, Mathworks), developed by the authors of this report, according to the specifications specified by HELCOM (HELCOM, 2018) and the technical instruction (Tougaard, 2019a). The routine was benchmarked against a Matlab routine developed by FOI, Stockholm, as part of the BIAS project (Betke et al., 2015), to ensure the compliance of the newly developed Matlab routine.

Each data file (of 30 minutes duration) was divided into 1-second blocks. For each of these blocks, the total equivalent continuous sound pressure level (L_{eq}: RMS average over 1 second) and the sound pressure in the third octave bands levels (TOL) with centre frequency 63 Hz, 125 Hz and 2000 Hz were calculated. The previously calculated clip level from the equipment calibration was subtracted from these levels to obtain calibrated absolute levels. Third-octave filters were implemented by integrating over the appropriate bands (± 1⁄6 octave around the centre frequency) of a Welsh power spectrum estimate (1 second Hann window, no overlap, see for example Bloomfield, 1976). From the 1-second periods, a 20-second average was then generated, corresponding to the L_{eq} (RMS average) over 20-seconds. Broadband sound pressure values between 10 Hz – 10 kHz were also calculated for every 20 second period.

Based on the values every 20 seconds, the upper percentiles (exceedance levels) L_5, L_{25}, L_{50} (median), L_{75} and L_{95} were calculated. L_5 indicates the sound level that is only exceeded 5% of the time and is thus a measure of the loudest sounds during the measurement period, while L_{95} indicates the level that is exceeded 95% of the time and is therefore a measure of the lowest noise level at the measuring station.

2.3 Soundscape modelling and pressure indicator

Soundscape modelling over the entire Danish EEZ was performed for the 63 Hz and 125 Hz bands as part of the Ecomar project, funded by the Velux Foundation (Andersen et al., 2020). The modelling was performed by the French company Quiet Oceans and the detailed method is described elsewhere (Folegot et al., 2016). Briefly, the modelling combines local estimates of the natural ambient noise, generated by wind and waves, with ship noise combined from all known ships at a given instant in time. The ship positions are obtained from AIS data and the noise from each ship modelled from information about the size and speed of the ship, though the so-called Randi3 model (Jiang et al., 2020). Additional information about bathymetry and sediment properties are included in the model, which then propagates and sums the contributions of all individual ships throughout the modelling area. Propagation modelling is done by the parabolic equation method and parameters of the model are calibrated against actual measurements from the recording stations.

Modelling is performed for a large number of short instants in time (‘snapshots’) and the snapshots are combined into monthly statistical distributions, which can be assessed. By this, a number of exceedance levels L_5, L_{10}, L_{25}, L_{50} (median), L_{75}, L_{90} and L_{95} are available as spatially explicit maps.

For the Ecomar project a pressure indicator was also calculated, to be used in combination with other pressure indicators and ecosystem components in a holistic assessment (Halpern et al., 2012). This pressure index was made in the same way as the pressure index used in the recent HELCOM HOLAS II assessment (Andersson et al., 2018). Briefly, this indicator express the normalized difference between the upper 5th percentile of the estimated natural ambient noise distribution and the actually measured value. This creates an index from 0, expressing a very low level of anthropogenic noise, to 1, expressing high and persistent level of ship noise.

Modelling was performed monthly for the year 2018.

3 Results

3.1 Overview of Data Coverage

In 2019 we had field effort coverage, or a deployed noise logger, at our four original stations (Lillebælt, Stevns, Hjelm, and Anholt) for most days of the year (Figure 3.1, Table 3.1). The Horns Rev station was deployed for the first time on 28 March 2019, and a logger was deployed at that site for 231 days of the remaining days of that year. The gap in 2019 field effort for Horns Rev is because a deployed logger washed ashore before a planned recovery (Supplementary Material: Error Report 4). For the first half of 2020, maximum 181 days, three of the five sites had full field effort coverage. Loggers at Hjelm and Horns Rev washed ashore early before a planned recovery (Supplementary Material: Error Reports 02, 03, & 06).

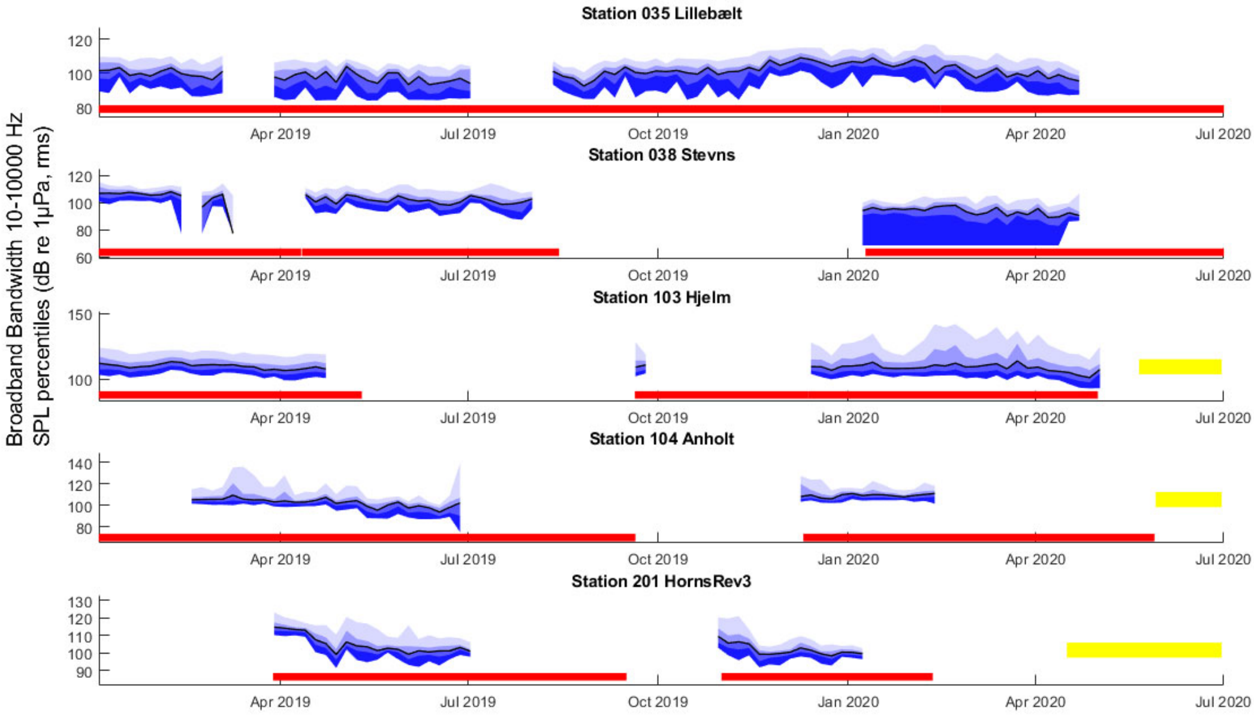


Figure 3.1. Broadband (10 Hz – 10 kHz) percentiles (L05,L25,L50,L75, & L95) for each station averaged over 4 days, times of deployments, and current deployments. Darker blue indicates the lower percentiles (L75-L95), or what SPL each site experiences most of the time. The blue gradient lightens as the SPL percentiles increase (L50, L25, and L05, respectively). The median SPL, or L50, is marked by a blank line in the gradient. At the bottom of each plot the red line represents Field Effort: time when a recorder was in the water at each site. The yellow line indicates current field effort, or current deployments that cannot be incorporated into this report. Data collected in first part of 2020 included for completeness.

Many of the smaller gaps in continuous noise recordings can be attributed to the batteries not living up to expectations regarding endurance or equipment failure. In some cases poor weather conditions and available ship time compromised our ability to retrieve units on schedule.

Hjelm had low coverage (38%) due to equipment problems. The logger deployed at Hjelm between May and September in 2019 experienced a power failure, and nothing but internal noise was recorded (Supplementary Material, Error Report 01). Between September and December of 2019, the logger at Hjelm only recorded four days of data in September, and then failed (Supplementary Material, Error Report 05).

One logger deployed at Stevns (deployed on 9/8/2020) was never retrieved due to an error with the releaser. If eventually retrieved, data between August 2019 and January 2020 may be included in future reports. At the Anholt station, the logger deployed between July – September 2019 experienced a power failure, resulting in no recorded data. Between September and December, 2019, the logger deployed at Anholt recorded for 82 days, however no data was recorded (Supplementary Material, Error Report 04).

Table 3.1. Data collection effort in 2019.

Station	Field Effort (days)	Data days recorded	% Days recorded
Lillebælt	365	304	83%
Stevns	363	176	48%
Hjelm	365	140	38%
Anholt	365	164	45%
Horns Rev	231	160	69%

3.2 Report of TOL levels in percentiles

Third-octave band levels (TOL) are able to give us an overview of what the noise level is at different frequencies. These data are best viewed as percentiles to better understand how the data is distributed. Using violin plots (Figure 3.2) we can get a sense of how loud the noise is at different TOLs.

Here, we present the data from each station between January 2019 and June 2020 for each month as a violin plot (Figures 3.3-3.7). Months that had less than seven days of data are excluded.

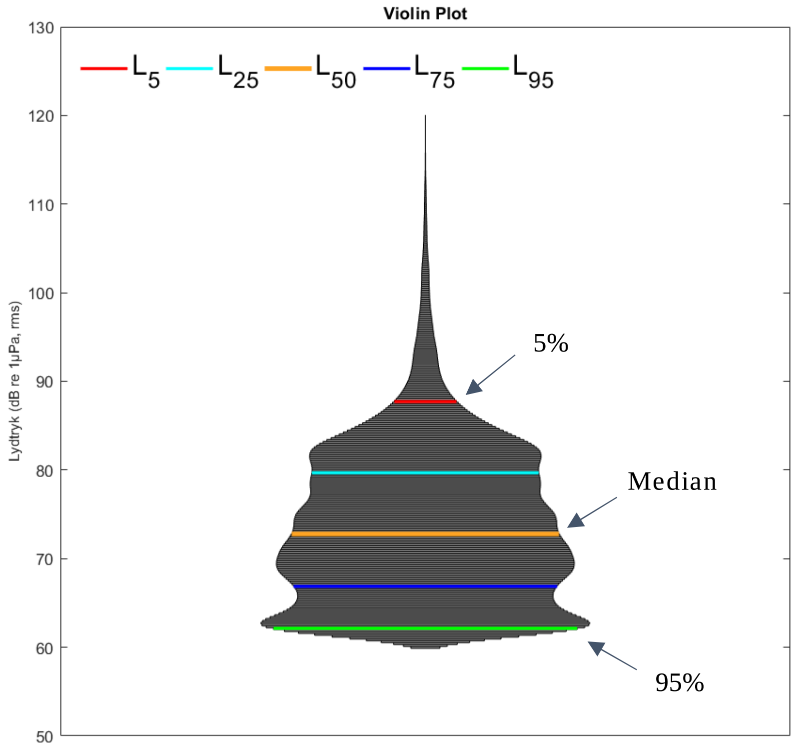


Figure 3.2. Example Violin Plot. Similar to a box plot with probability density data, to show the full distribution of the data. Incorporates known percentiles (here: 5, 25, 50, 75, & 95) which traditionally make up a box plot. Then, using kernel density smoothing, the violin plot shows the density of the data distribution. In this example plot, while the distribution of the Sound Pressure Levels range between ~60-120 dB, most of the collected data is below 90 dB with two modal peaks at ~70 and ~62 dB.

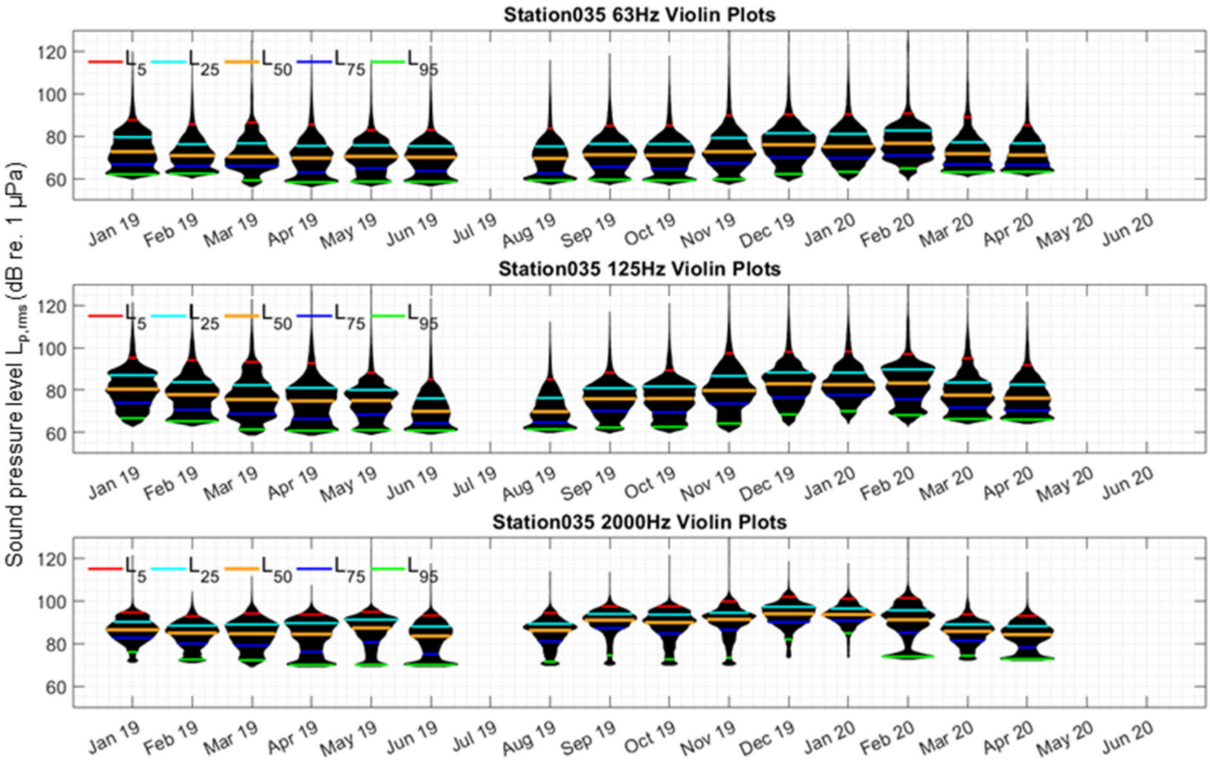


Figure 3.3. Violin Plots for every month of recorded data at Station 035 Lillebælt. The flat 'base' on some plots, especially visible for the 2 kHz data, reflects the internal self-noise of the recording instrument, which prevent levels below to be faithfully recorded. This prevents analysis of the most quiet periods and can lead to an overestimation of the lower 5th percentile (L95), but does not affect the estimates of higher percentiles.

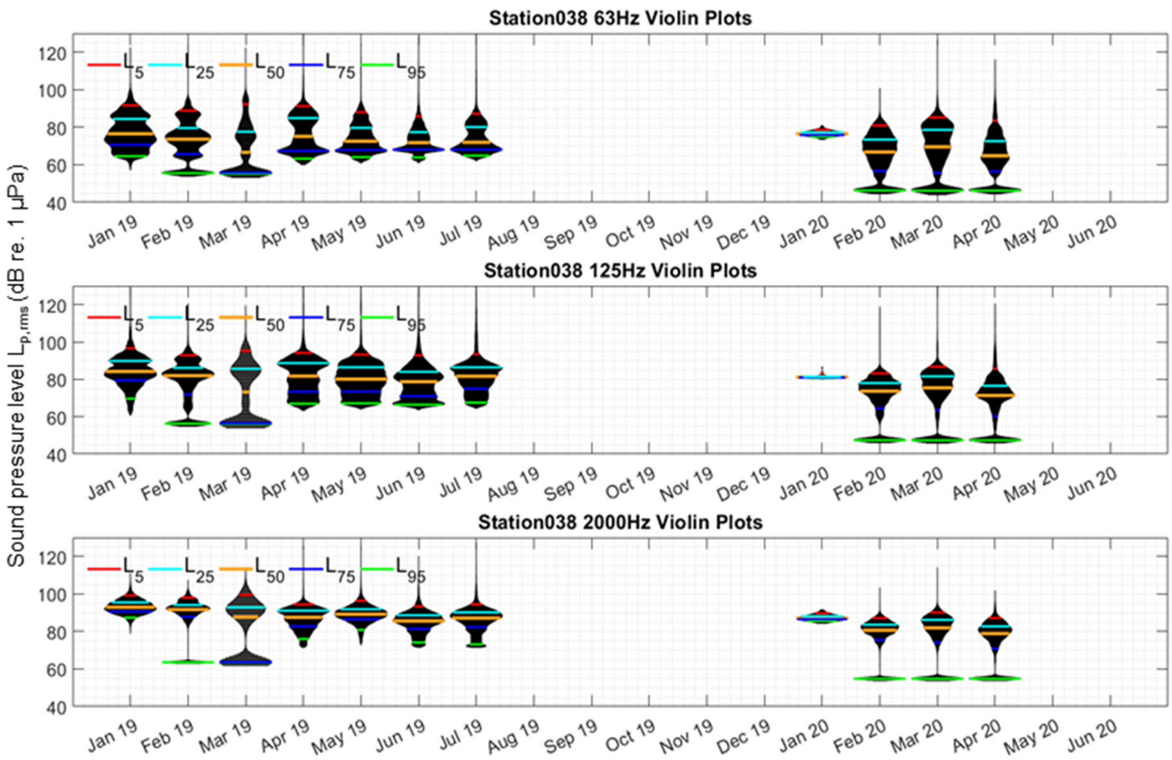


Figure 3.4. Violin plots for every month of recorded data at Station 038 Stevns.

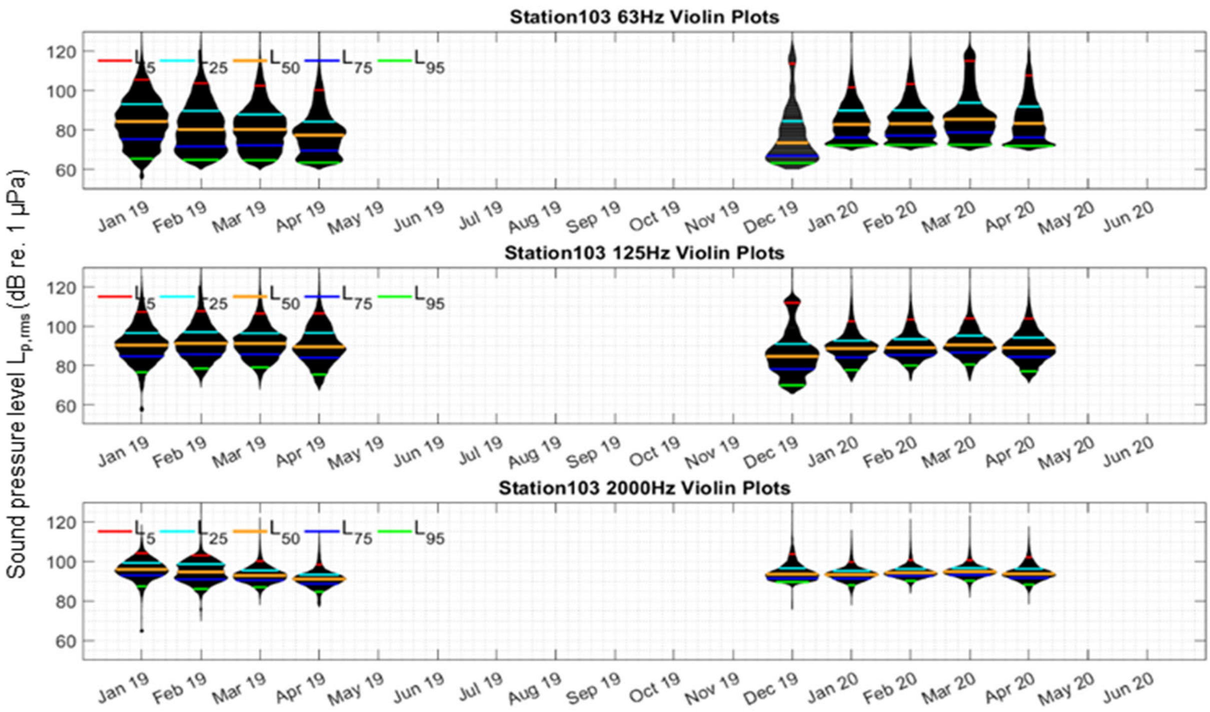


Figure 3.5. Violin plots for every month of recorded data at Station 103 Hjelm

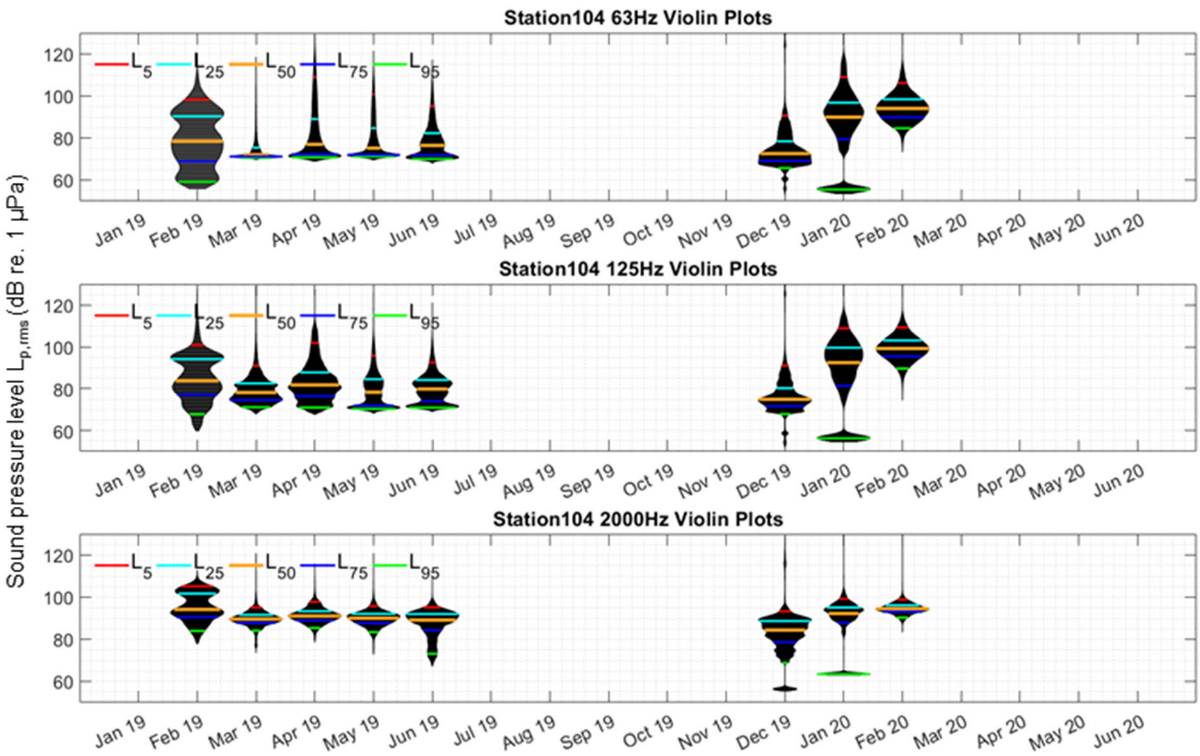


Figure 3.6. Violin plots for every month of recorded data at Station 104 Anholt.

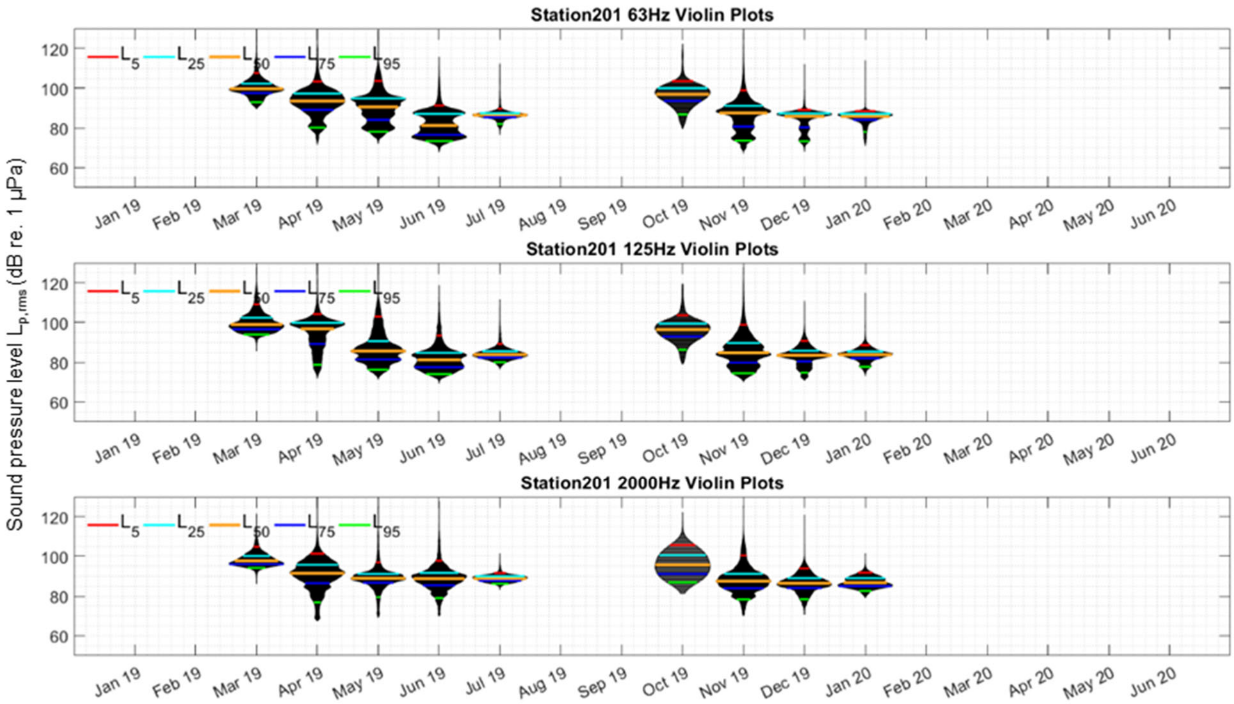


Figure 3.7. Violin plots for every month of recorded data at Station 201 Horns Rev.

3.3 Temporal coverage and comparison to previous years

At the writing of this report, we had collected six years of noise monitoring data at station Lillebælt, four years of noise monitoring data at stations Stevns, Hjelm and Anholt, and most of two years of noise monitoring data for the new station, Horns Rev (**Table 3.2**). This provides the foundation for a long term dataset which will be used to generate statistical averages and estimates 8of noise in Danish waters in the future.

Table 3.2. Annual averages for 2014, 2018-2019 for the five measuring stations, divided into the three analysed frequency bands. Mean TOL measured in dB re 1 µPa. Numbers given below do not indicate there was data for the entire year. The mean SPL for 2019 comes from the data available outlined earlier in this report. Data from 2014 comes from the BIAS project (citation). In 2018 there is some data missing from every station (Hermannsen et al., 2020).

Station	TOL band (Hz)	Mean SPL 2014	Mean SPL 2018	Mean SPL 2019
035 Lillebælt	63	90.1	85.1	72.1
	125	88.8	83.9	76.7
	2000	89.1	83.6	86.7
038 Stevns	63	93.1	88.8	74.3
	125	95.8	96.4	80.2
	2000	93.8	92.3	87.6
103 Hjelm	63	99.8	100.2	81.9
	125	101.4	101.7	90.6
	2000	98.9	99.1	93.8
104 Anholt	63	89.9	88.3	79.0
	125	91.5	92.4	80.5
	2000	96.6	94.1	88.2
201 Horns Rev	63	-	-	87.3
	125	-	-	86.6
	2000	-	-	88.7

Generally, mean sound pressure levels (SPL) appear to be lower in 2019 than in previous years. As there are gaps in the time series of each year, the means are not computed over exactly the same time of year, however, and are therefore not directly comparable. Looking at the median SPL every month, rather than every year, can give us better insight into these trends. Figures 3.8-3.10 examine the difference in the median monthly SPL (dB re 1 µPa) from 2018 and 2019 at each station, where available. Months with less than seven days of data are excluded. Horns Rev was removed from this review because no data was collected in 2018 at that location.

It is clear from the figures that at least on some stations there is a substantial variation with season, generally with lower levels in summer months. This is likely due to higher wind-generated noise contributions in winter. The gaps in the time series means that they are not completely overlapping and therefore also that the means listed in **Table 3.2** do not cover the same periods. Differences in annual means within the same station is therefore not in itself indicative of an actual difference in recorded noise levels. As additional data from coming years are accumulated it will be possible to build a statistical model that can include month to month variation and thereby allow for a statistical comparison of annual means. A visual inspection of the curves in **Figure 3** to **Figure** does not indicate large differences from 2018 to 2019, with the exception of the 2 kHz band for the Lillebælt station, where levels in 2019 appears consistently about 5 dB higher than the levels in 2018. However, as there is a larger and presently unquantifiable uncertainty on the 2 kHz measurements, due to possible influence of the presence of the measuring instrument itself on the sound field (see section 2.1.2), this difference cannot yet be taken as evidence of a genuine difference in the sound levels between 2018 and 2019.

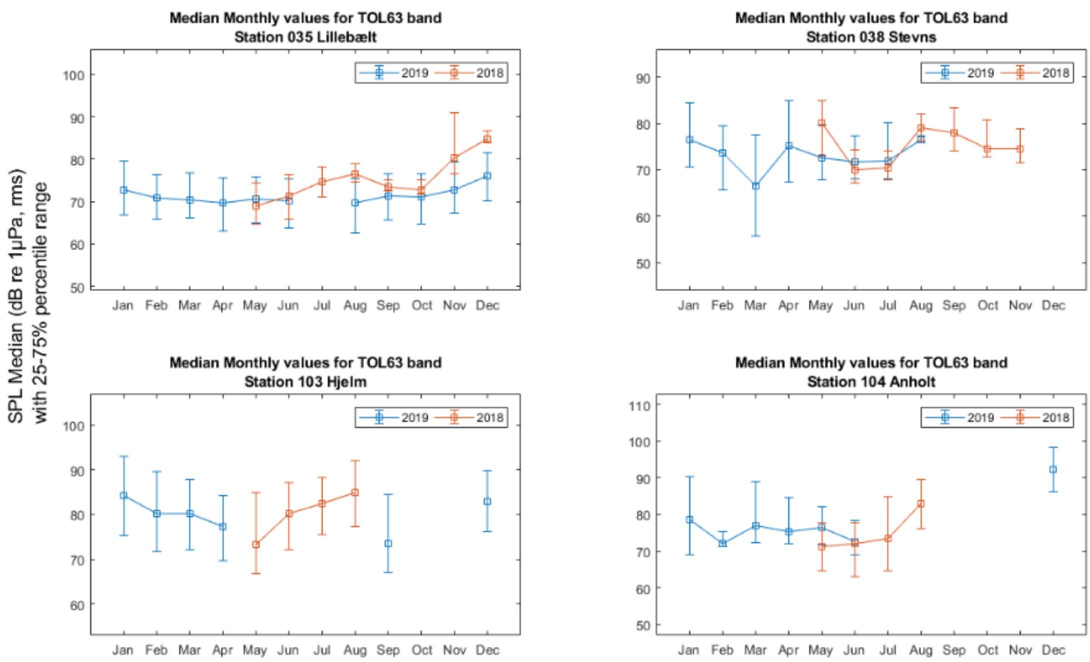


Figure 3.8. Median monthly SPL 63 Hz in 2018 and 2019 for each station.

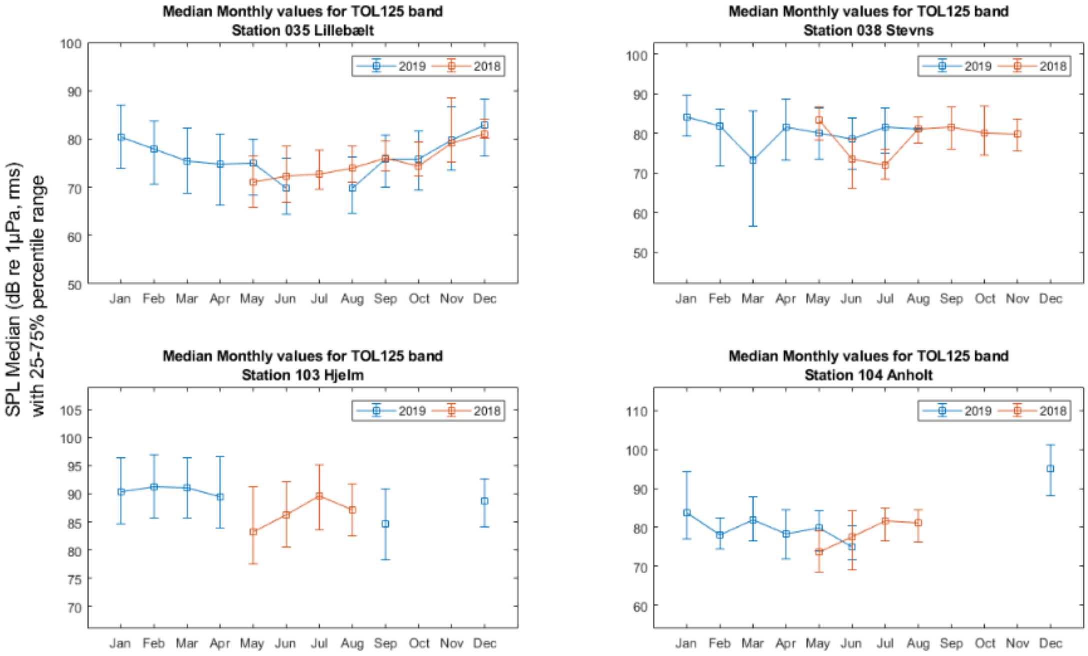


Figure 3.9. Median monthly SPL 1Hz in 2018 and 2019 for each station.

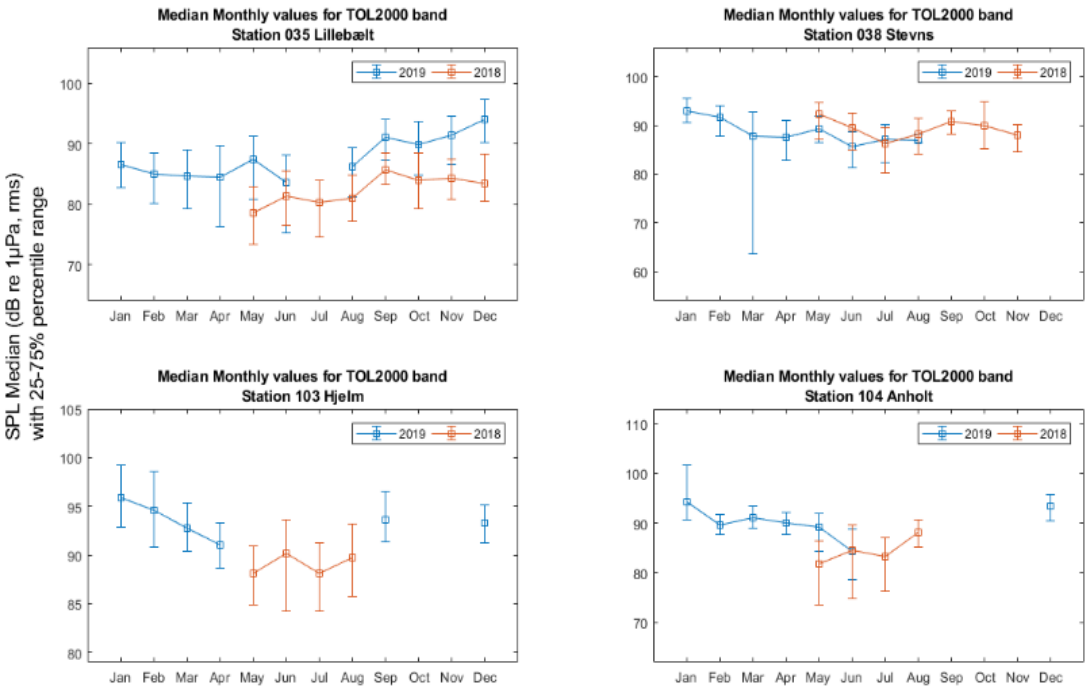


Figure 3.10. Median monthly SPL 2 kHz in 2018 and 2019 for each station.

3.4 Soundscape modelling

Soundscape modelling is included here as an example from the Ecomar project (Andersen et al., 2020). Figure 3.11 shows an example for April 2018 and illustrates the upper 5th percentile levels in the 125 Hz third-octave band. The shipping routes around Skagen and into the Belts are clearly visible as bands of increased noise levels. Also the waters around Bornholm has generally elevated levels, whereas other areas, most notably the central Kattegat and Central North Sea are comparatively quiet.

Based on the map in Figure 3.11, the pressure index used in HOLAS II was estimated for the entire Danish EEZ. The principle is illustrated in Figure 3.12, copied from the description of the pressure index (Andersson et al., 2018). The green bars represent an estimate of the natural ambient noise without ships, measured in a quiet part of the Baltic Sea, which serves as reference condition. The upper 5th percentile of this distribution was 92 dB re. 1 µPa, which is used as the natural reference level for calculation of the index. The blue bars illustrate modelled noise levels in a part of the Baltic with heavy shipping. The increase in the upper 5th percentile caused by ship noise is normalized, to achieve a dimensionless index between 0 (very low ship noise) and 1 (very high ship noise). This pressure index was developed for the Baltic Sea for the HOLAS II assessment and based on the BIAS data, which only covers the Baltic Marine Biogeographical Region. Application of the index to the North Sea and Kattegat areas therefore constitutes an extrapolation outside the original area to which the index was developed and may be associated with significant uncertainty. However, at the time of the Ecomar project this method was the best available. Further development of methodology, in particular as part of the JOMOPANS project, has led to significant improvement in assessment methods and development of a new pressure index, which will be applied in future modelling efforts.

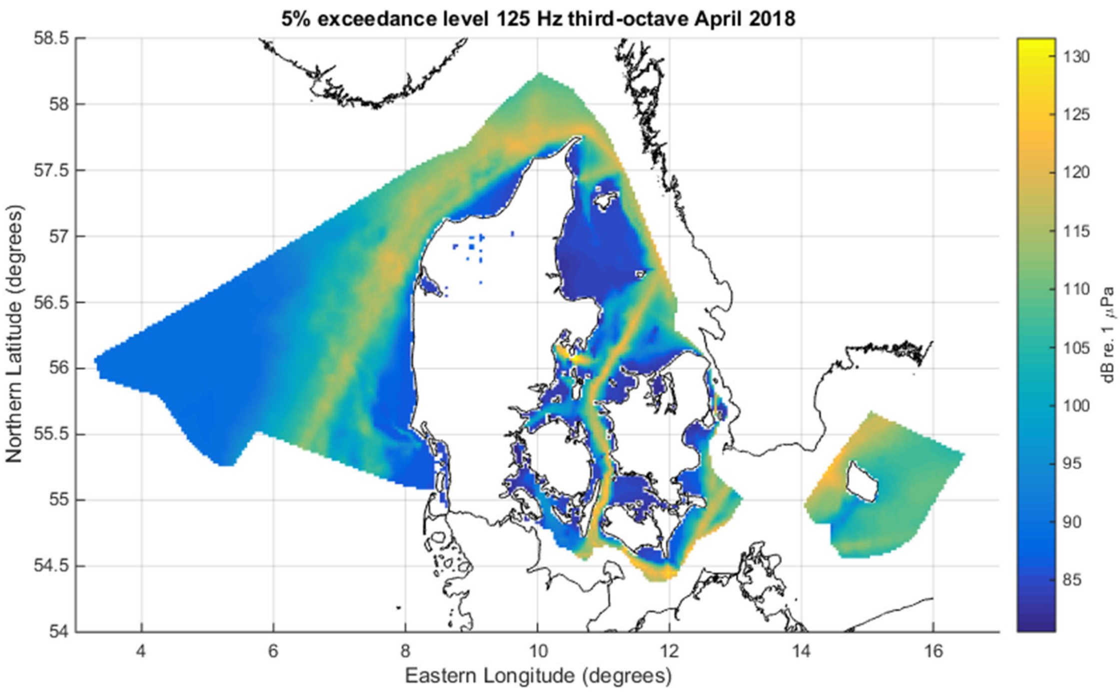
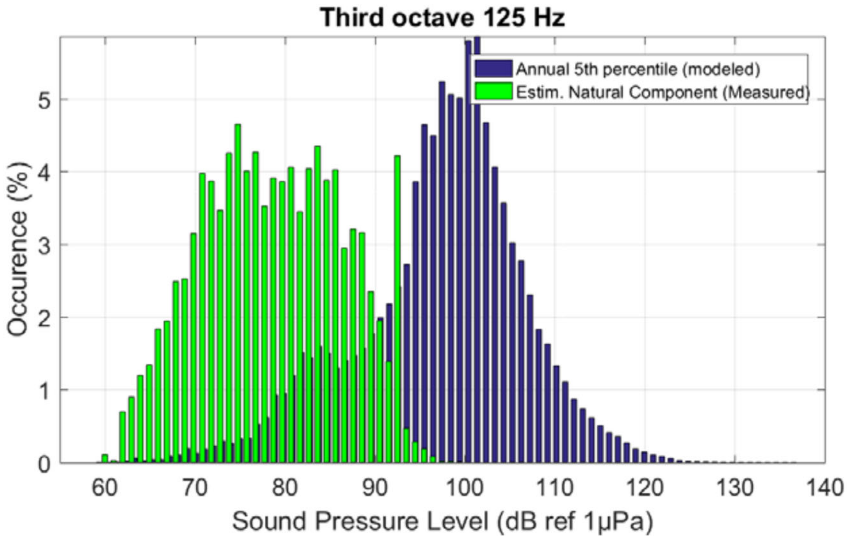


Figure 3.11. Upper 5th percentile of the total noise (natural wind and waves plus ships) in the 125 Hz third-octave band. From the Ecomar project.

Figure 3.12. Illustration of the difference between the distribution of sound pressure levels measured in a remote part of the Baltic (green) and the modelled noise level in an area with intense shipping (blue). The normalised difference between the distributions constitutes the HOLAS II pressure index for continuous noise. From Andersson et al. (2018).



The index was calculated for all grid cells in the map and the result is shown in Figure 3.13. The pressure index is high in the shipping routes, in Skagerrak and around Bornholm, whereas the shallower areas in Kattegat, with relatively little ship traffic, has a low index. Note also the high index in Aarhus Bay, due to the fast ferry (Molslinjen).

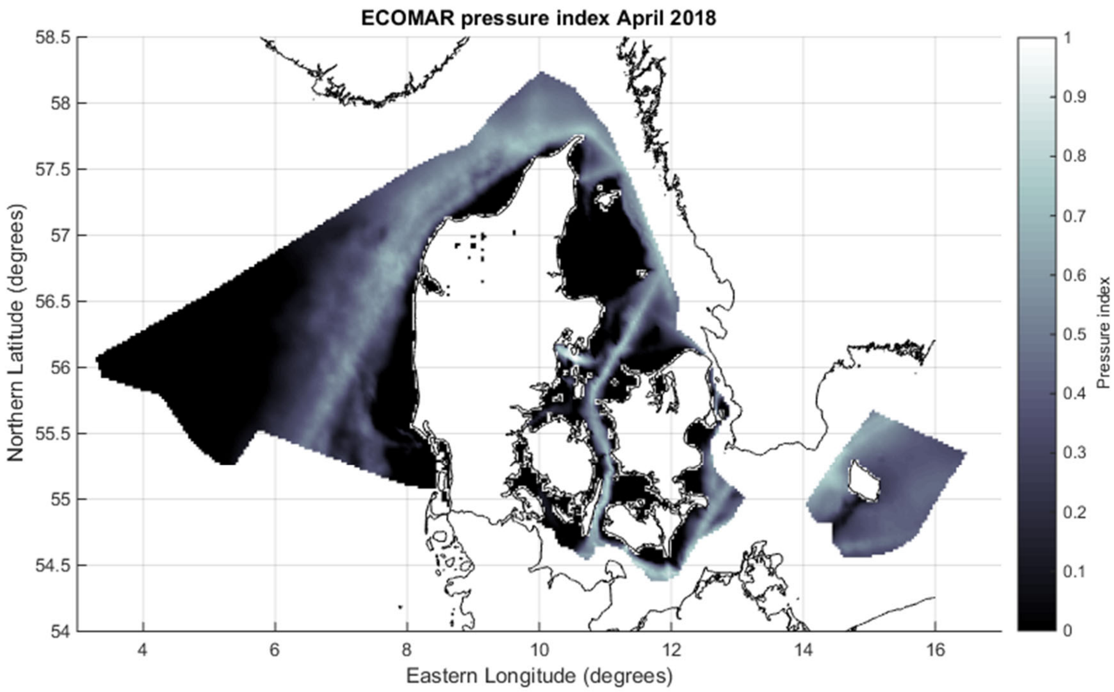


Figure 3.13. HELCOM HOLAS II pressure index for continuous underwater noise estimated for April 2018 throughout all Danish waters.

3.5 HELCOM Upload

For the past year we have been working with ICES team to upload our backlog of data into the HELCOM database. This includes data from three out-of-use noise monitoring stations: Storebælt, Rønne Bank, and Frederikshavn, dating back to the BIAS project (Sigray et al., 2016). Data which has been uploaded is outlined in Table 3.3.

Table 3.3. Data at each station, by year and number of months, available to be uploaded to the HELCOM database

DK Monitering Station	2014	2015	2016	2017	2018	2019	2020	Total
DKMst035 Lillebælt	12	-	6	8	12	10	-	48
DKMst036 Storebælt	12	-	-	-	-	-	-	12
DKMst037 Rønne Banke	12	-	-	-	-	-	-	12
DKMst038 Stevns	11	-	-	-	7	8	-	26
DKMst103 Hjelm	5	-	-	-	6	9	5	25
DKMst104 Anholt	5	-	-	-	7	10	-	22
DKMst105 Frederikshavn	5	-	-	-	-	-	-	5
DKMst201 Horns Rev 3	-	-	-	-	-	8	1	9

4 Discussion

Measurements of underwater noise constitutes the basis for assessing Good Environmental Status (GES) in Danish waters. While the assessment framework for continuous noise still awaits guidance from EU (TG-Noise) and continuous noise indicators for HELCOM and OSPAR monitoring are still not fully developed, the measurements can be obtained in fulfilment of this part of the requirements of the Marine Strategy Framework Directive. Measurements are not evaluated here and neither is GES status of the Danish waters assessed. This process awaits the full development of the indicators, likely to happen in 2021-22, as part of preparation for the HELCOM HOLAS III and OSPAR Quality Status Report assessments, due in 2023. The measurements reported here will form an important basis for the spatial modelling of underwater soundscapes, anticipated to be a key element of these assessments.

4.1 Absolute noise levels at the four stations

There are considerable differences between the average levels at the five stations. This is not surprising, given their different local environments and distance to shipping lanes. In the 125 Hz band the lowest average levels were from the Lillebælt station (76. 7 dB re 1 µPa / third octave), consistent with results from the BIAS project (Mustonen et al., 2019) and with the location of the station in an area with very little traffic from commercial ships, which have peak noise energy in the low part of the frequency spectrum. The mean noise level in the 2 kHz band at Lillebælt was comparable to the levels at the other stations in Kattegat and the Baltic, which could be a reflection of comparable levels of traffic with smaller recreational vessels, which tend to have peak energy at higher frequencies. By far, the highest average level of noise in the 125 Hz band (90.6 dB re. 1 µPa / third octave) was from Hjelm, likely a reflection of the proximity to both the deep water shipping route through Storebælt (Route T) and the fast ferry (Molslinjen). None of the stations are close to the maximum levels measured in 2014 during the BIAS project, however. In 2014, the highest average levels in the 125 Hz band were measured in Femern Bælt (115 dB re. 1 µPa / third octave) and Storebælt (109 dB re. 1 µPa / third octave).

As no guidance is yet available regarding assessment of GES based on measurements of low frequency underwater noise, there are no thresholds or targets to compare the measurements with at present.

4.2 Identifying trends in the average noise levels

With this report we have two consecutive years of noise monitoring data from four stations in Danish waters (2018 and 2019). This adds to the data from 2014 from the BIAS project and two additional years of monitoring on the station in Lillebælt in 2016 and 2017 (Nielsen et al., 2019; Sørensen, 2019). No statistical analysis of possible trends in the recorded levels has been attempted. The amount of data collected for each station and year is very large, providing very good description of the soundscape at these stations, but the duration of the monitoring program as a whole (6 years, not data from all years), means that insufficient statistical power is available to detect even large trends in the data. The sparse historical data from other areas (deep water Atlantic Ocean and Eastern Pacific Ocean) suggest an increase in low-frequency continuous noise of around 3 dB per decade (Hildebrand, 2009). The accuracy of the measurements in the Danish monitoring program is on the order of a few dB. Calibration of the equipment itself is accurate to within 1 dB (Tougaard, 2019c) and the field procedure is likely to add at least another one dB, due to variation in deployment position, effects of biofouling (Urick, 1983). On top of this comes natural variation from year to year in natural ambient noise due to differences in weather and hydrography, which is likely to add several dB on top of the measurements uncertainty. It is therefore highly unlikely that a trend of 3 dB per decade would be detectable as statistically significant in a time series of only 6 years. As more measurements are collected over the coming years, the variation due to weather and hydrography can be described and included in a statistical model, which will increase the statistical power. This will add to the simple increase in statistical power simply from accumulating more samples and the associated gradual averaging out of the random measurement errors.

4.3 Quality control and issues with recorders

The monitoring program achieved nearly full field effort in 2019, meaning that noise recorders were deployed on all stations almost all of 2019. However, we still experienced gaps in the data collected, due to either equipment malfunction, equipment loss, or deployed equipment prematurely running out of power or memory before we were able to service the station. All losses of data has been described in the failure reports in the appendix. Some of the recurring problems are discussed below.

4.3.1 Loss of equipment

When deploying equipment on the seabed for extended periods of time there is always an associated risk of losing the equipment, either because it is unintentionally damaged by trawls or other fishing gear, or through failure of the equipment, which prevents recovery. While we have taken reasonable precautions against this, in selection of deployment locations and addition of extra buoyancy to equipment, some loss of data is unavoidable. It frequently happens that equipment is lost from the stations, most likely due to bottom trawling, but in many cases the lost equipment washes up on the beach and is recovered that way. Deployment in new environments is particularly risky, which is seen by the equipment deployed at Horns Reef being lost several times. However, the addition of a satellite tracking device (GPS and Iridium satellite phone link) has on two occasions alerted us within hours of a detachment of equipment and allowed us to start immediate recovery operations. See illustrations in **Figure 4.1** from the error reports. We will increase the use of GPS tracking devices in the coming years, as this has proved a very reliable way of recovering lost equipment and minimize the time between loss of equipment at a station and replacement.

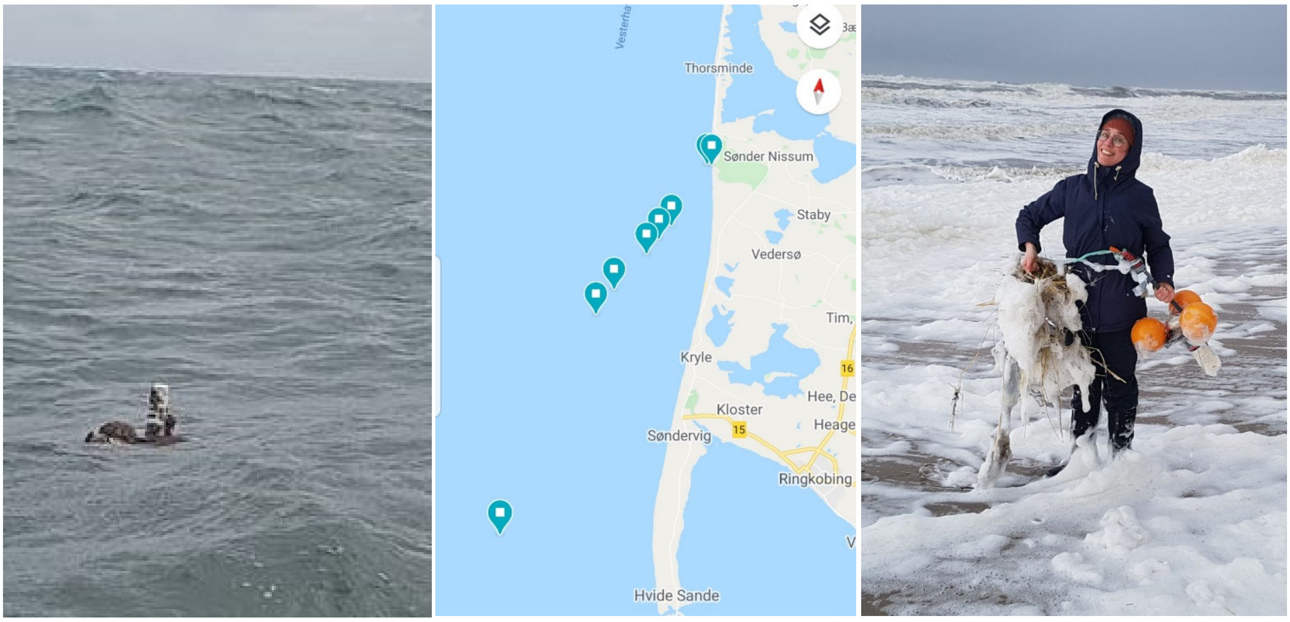


Figure 4.1. Datalogger floating in the surface with GPS/Iridium beacon visible (white vertical cylinder); track of equipment from time where it was ripped of the mooring at Horns Reef (bottom left) in a storm until it beached at Sønder Nissum about a day later; and recovery of the unit on the beach the following morning.

4.3.2 Equipment malfunction

A major source of data loss has been malfunction of equipment in various ways. The SM2M data recorders have been extremely reliable over the years, but have now reached the end of their functional lifetime and are increasingly plagued by mechanical and electrical failure. Data collection by these logers will be discontinued as new equipment is purchased.

The replacement datalogger, the Soundtrap ST500, has not fulfilled expectations. On several deployments it failed to perform according to producer specifications regarding battery capacity and have failed due to untraceable firmware and/or hardware errors. The producer, Ocean Instruments, New Zealand, has acknowledged these issues and has discontinued production of the datalogger. A new and improved model ST600 has been announced and we have placed orders for these units, to be delivered in spring 2021.

4.3.3 Reduction of data loss

Within the current monitoring program we continuously improve deployment rigs and protocols for check of equipment before deployment, in order to minimize loss of data. Further security in data collection can be achieved by increasing the number of service visits to stations (assuring quick replacement of a lost or faulty logger) and ultimately by tandem deployment of two independent recording systems at each location. Both strategies are efficient, but costly, and the gain must be balanced against this extra cost. The overall purpose of the monitoring program is twofold: provide long time series of accurate measurements to allow evaluation of trends in the noise levels, and provide measurements useful for calibration of sound propagation models used in soundscape modelling. For both purposes, it is desirable to have complete time series, but not essential and the current loss of data is not considered to compromise the objective of the monitoring program.

4.4 Future monitoring

The monitoring is expected to continue, in fulfilment of the HELCOM monitoring program and also in anticipation of a joint monitoring program for the Norths Sea (OSPAR area II) (Kinneging and Gersonius, 2020). This includes a proposal for establishing a new monitoring station in the Northern North Sea.

4.4.1 Proposal for station on Store Rev or Gule Rev

For several reasons it is desirable to include a monitoring station in the northern part of the Danish North Sea. This area is different biogeographically from both Kattegat (covered by Anholt and Hjelm stations), and the southern North Sea (covered by the Horns Reef station) and contains several important Natura2000 areas, in particular Store Rev and Gule Rev. It is also an area where white-beaked dolphins (Galatius et al., 2013) and minke whales (Hammond et al., 2017) are frequently encountered, and it is one of the busiest areas with respect to ship traffic in Danish waters.

AU/DCE is currently conducting a pilot project on monitoring of minke whales and white-beaked dolphins on Gule Rev and Store Rev (**Figure 4.2**), where four dataloggers were deployed in September 2020. The dataloggers will be recovered in early 2021, and the usefulness of the deployment sites for noise monitoring can be assessed once the data has been recovered. The tentative proposal, however, is to establish underwater noise monitoring with one station on Gule Rev, essentially continuing the monitoring once the pilot project ends in 2021. The reasons why Gule Rev is preferred over Store Rev is the shorter distance to Hanstholm, reducing expenses for servicing, and location right in the main shipping route from the southern North Sea around .Skagen.

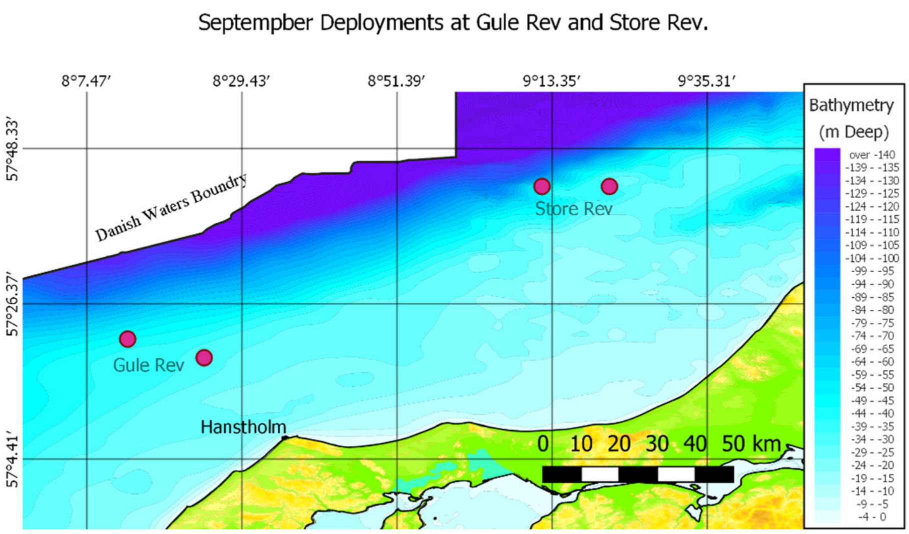


Figure 4.2 Location of the monitoring stations on Store Rev and Gule Rev in the AU/DCE pilot project on passive acoustic monitoring of cetaceans.

4.4.2 Long term duty cycling between stations

In order to reduce costs of the monitoring program one can increase the monitoring time at each station by duty cycling recordings (for example 30 minutes every 2 hours), which will reduce the number of service visits to each station. Such duty cycling will have little consequences for the quality and usefulness of the data for assessment of GES, but comes with an increased risk of loss of data, due to loss of equipment or equipment failure. A better alternative to reducing costs is therefore to duty cycle the effort between stations, such that not all stations are monitored every year. This will decrease the amount of data available for trend analysis, but as the main issue with trend analysis is likely the total duration of the time series and not the number of data points (within reasonable limits), such duty cycling is considered better than duty cycling within each station (Likens and Lindenmayer, 2018), as the risk of losing data due to equipment failures remain constant.

A tentative proposal for duty cycling between stations, presuming a station is established in northern North Sea, is to group the stations into an annual rotation between Horns Rev and Gule Rev, an annual rotation between Hjelm and Anholt, and biannual monitoring at Stevns. Since Lillebælt is our oldest and most reliable station, and furthermore the preferred station for a long-term monitoring program identified by the BIAS project (Nikolopoulos et al., 2016), we propose to maintain continuous recordings at this location.

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AARHUS UNIVERSITY

Survey failure report 2019-1

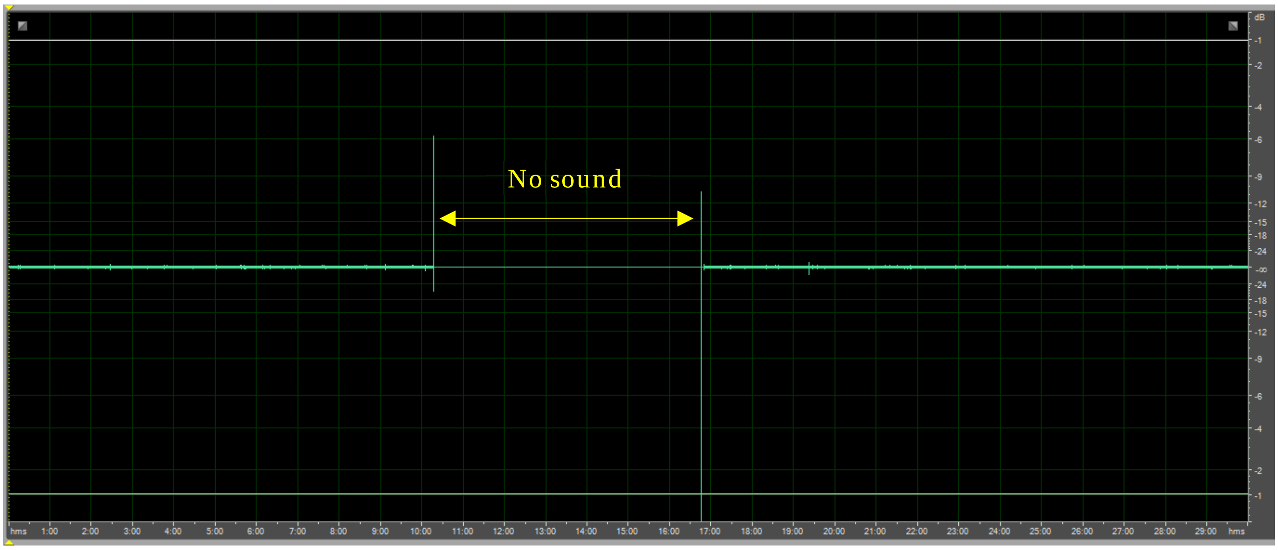
Date:	*September 2019*	**Point of contact:**	*Jakob Tougaard/Line Hermannsen*

Description of survey failure: Power loss to hydrophone

Problem: Power to hydrophone of logger AU6 deployed at Hjelm station during May-September 2019 began failing in beginning of June (around 8th, see picture below), resulting in continued (showing that batteries to recorder were still working), but empty recordings without any sound from June 11th and onwards.

Affected data: June-September 2019

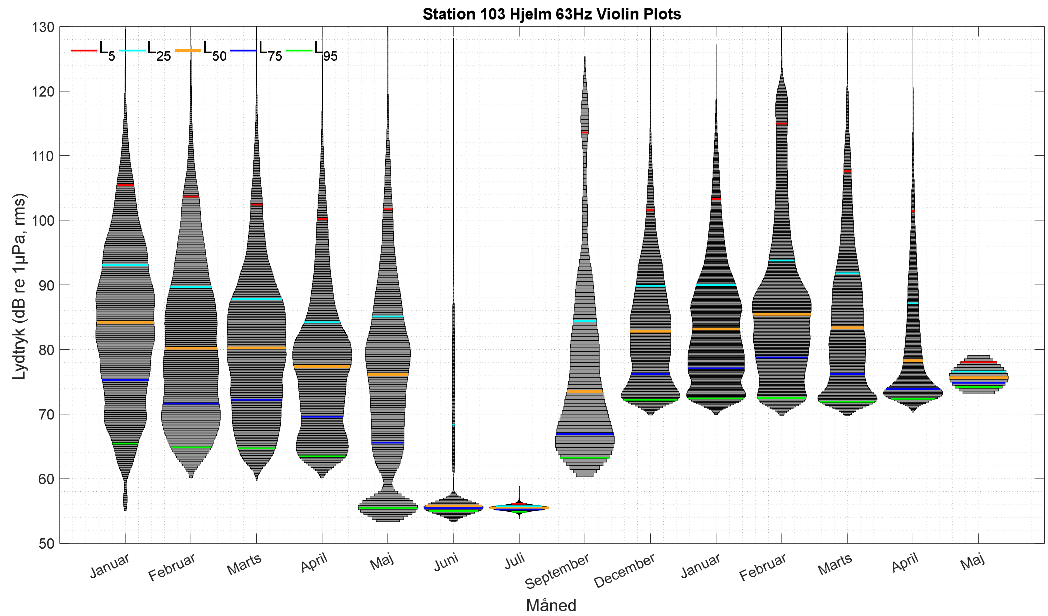
Solution: Unknown why power to hydrophone failed, but always ensure that the hydrophone cable is intact and correctly attached to motherboard, and that hydrophone batteries are of good quality and full upon deployment.



Addition: (October 2020 – by Emily T. Griffiths)

Further inspection of the data indicates that this entire deployment should not be used in analysis. The quality of the recordings prior to the battery failure are low, and likely inaccurate. Please see figure below of all Hjelm data between January 2019 and June 2020. This deployment clearly sticks out as atypical.

Affected data: May - September



Survey failure report 2019-2

Date:	*23 September 2019*	**Point of contact:**	*Jakob Tougaard*

Description of survey failure: Lost data because of battery failure.

Problem: ST500 sound recorder (ID: AU08, 671670302, hydrophone ST-1038) deployed at *Horns Rev* (DK) stopped prematurely, after approx. 3 months of recording (from March 29th to July 4th 2019), due to low battery (1.1 V), which is also registered in the log file. Batteries were 9 x Energizer Industrial, which we have had good experience with, and all batteries were new (March 12th 2019).

Affected data: Data missing from July 4th to end of September 2019.

Solution:

Survey failure report 2019-3

Date:	*September 2019*	Point of contact:	*Jakob Tougaard*

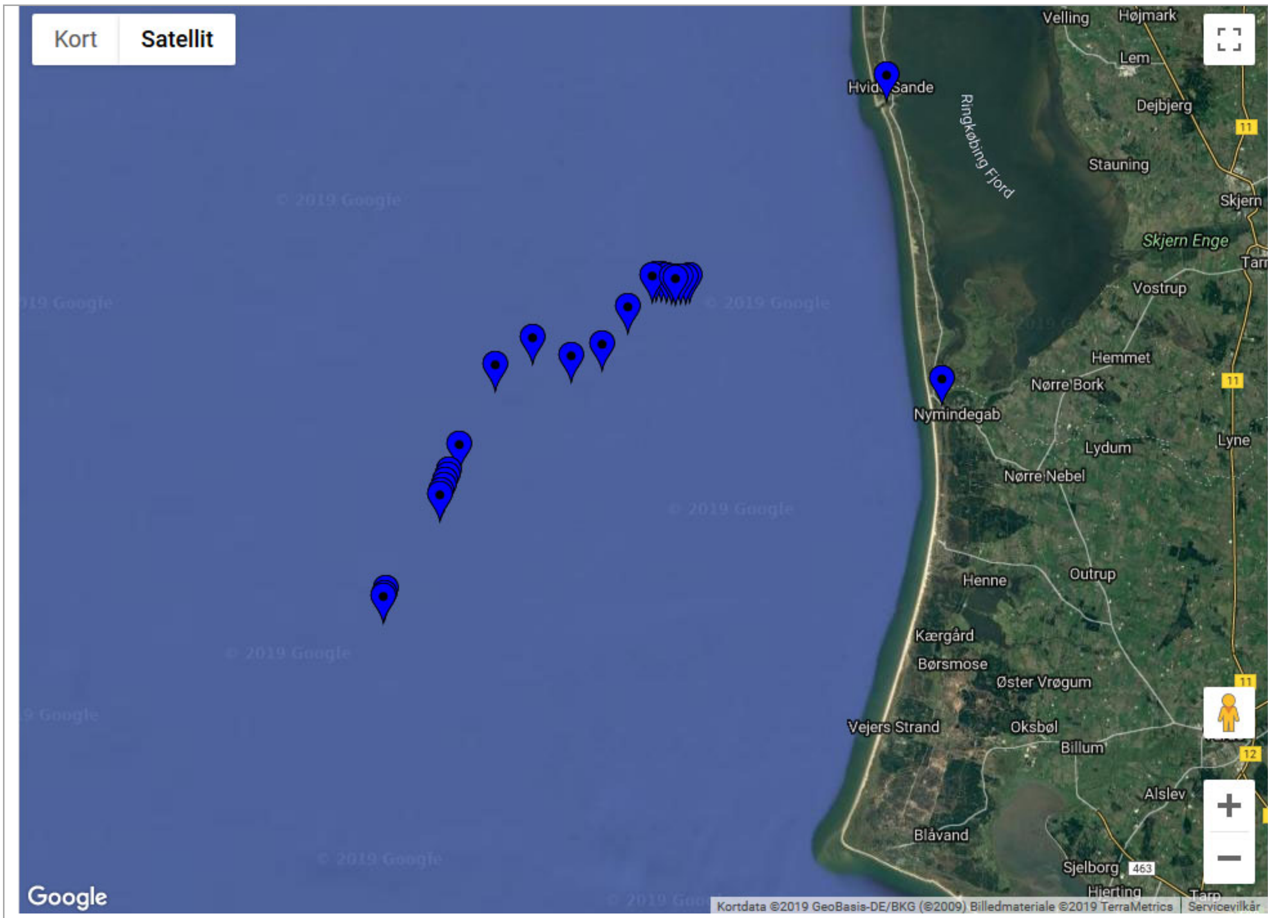
Description of survey failure: Premature surfacing

Problem: ST500 sound recorder (ID: AU08, 671670302, hydrophone ST-1038) deployed at *Horns Rev* (DK) detached prematurely from the anchor on September 11th 2019. The recorder was deployed with a Xeos Kilo GPS/Iridium beacon, which reported the position of the logger when it surfaced. The entire system was recovered on the following day by JT and the SAR boat from Ringkøbing. Despite heavy swell and about 10 m/s wind from west, the logger was quickly localised and recovered.
Inspection of the system showed that the acoustic release was not activated but no rope was attached to the plastic nut. The cause of the premature release is thus almost certainly wear and ultimately failure of the rope. There was no sign of impact on the rig.

Affected data: As the datalogger had stopped prior to surfacing (see error report 2019-9 Horns Reef battery failure), this error did not affect any data directly.

Solution:
It is important to secure the rope in the plastic nut to prevent, as far as possible, any movement and thus wear on the rope. Could be done with strips or tape, or preferably with biodegradable string (sisal).

Plastic nut on acoustic release.



GPS positions received from the Kilo unit through the Iridium link from surfacing until recovery.

Rig floating in the surface with the white Kilo unit pointing into the air.

Equipment failure report 2019-4

Date:	*December 2019*	Point of contact:	*Line Hermannsen*

Description of equipment failure: Lost connection to hydrophone
Problem: 82 recording days, but no sounds in the files, so the connection to the hydrophone was lost. The logger was tested prior to this deployment and worked fine, although therewas no red diode in the hydrophone. It was started manually just prior to deployment, the hydrophone cable was coiled the opposite way and tape to the motherboard connector, before the lid was closed – perhaps the hydrophone cable was stuck in the lid or the cable was pulled out of the motherboard, which cut the hydrophone connection. **Affected data**: All data collection lost. **Solution**: Run thorough test on this logger before considering redeployment, previous deployment with this logger (Feb-May and May-Sep) also had problems with the hydrophone connection, causing periods with no recordings.

Equipment failure report 2019-5

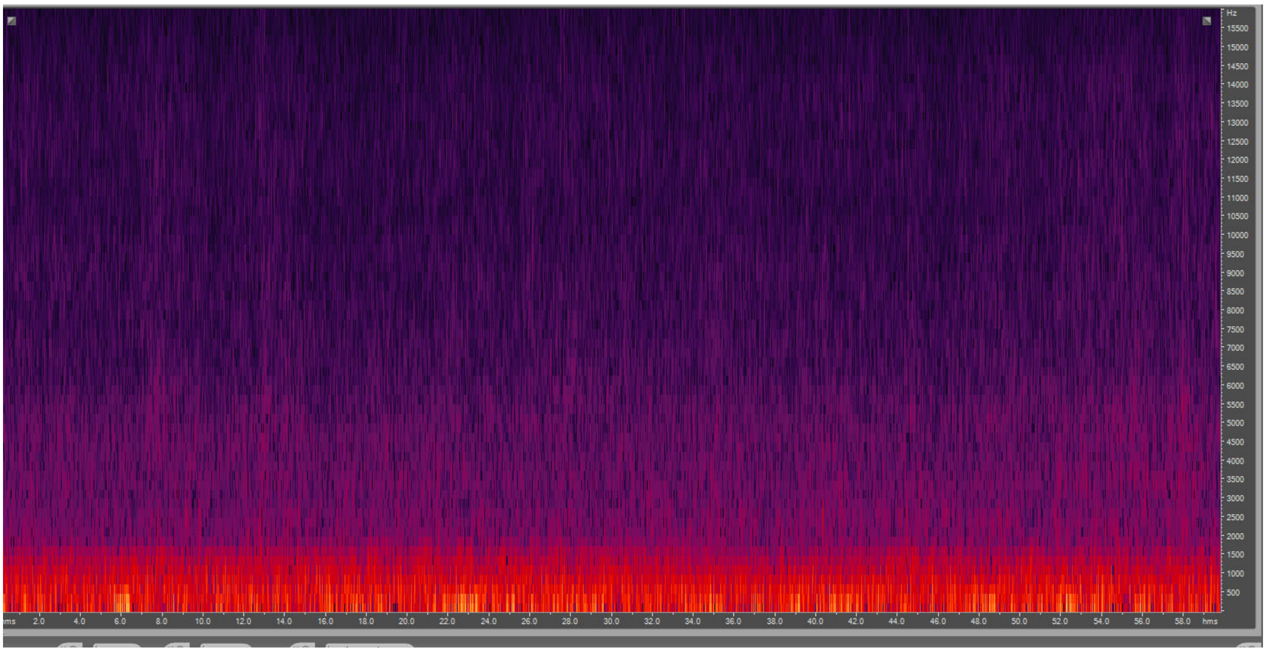
Date:	*December 2019*	**Point of contact:**	*Line Hermannsen*

Description of equipment failure: Recording stopped prematurely

Problem: Only four days of data. The reason could be disrupted recording due to a vessel, potentially a dredger, within close range of the logger for a long duration (hours), which is clearly audible on the last sound file (see picture below). The logger ends one 30 min recording period, but never starts again after the 30 min break, so perhaps something happened in the break. Another potential reason is there being an extra SM2M configure file on the SD card in slot B, which could cause errors within the recording scheme and result in a premature recording end.

Affected data: Most of data collection lost, and not sufficient data to fulfill the 7 days requirement for inclusion in the analysis.

Solution: Deploy in areas without dredging or improve anchor to avoid movements of the equipment. Ensure that there is only a configure file on the SD card in slot A and that SD cards in the other slots are empty.



Survey failure report 2019-6

Date:	*February 2020*	Point of contact:	*Emily T. Griffiths*

Description of survey failure: Premature surfacing/Damaged Hydrophone

Problem: ST500 sound recorder (ID: AU08, 671670302, hydrophone ST-1038) deployed at *Horns Rev* (DK) detached prematurely from the anchor on 10 February 2020. The recorder was deployed with a Xeos Kilo GPS/Iridium beacon, which reported the position of the logger when it surfaced (Fig1). The entire system beached itself in Sønder Nissum, Ringkobing and was recovered on the following day by JT and ETG (Fig2).

Inspection of the system showed that the acoustic release was not activated. Rope was still attached to the plastic nut, and it is clear that the ropes around the weighted gravel bags slipped off (Fig3).

While the datalogger appears unharmed, the hydrophone was damaged (Fig4).

Affected data: Data abruptly stopped at 06 January 2020 about 2/3rds through a file started at 11:15:22, about a month before the unit surfaces (Fig5). There is no indication why the data stopped recording. However, data between deployment (31 October 2019) and this data is GOOD. Unit likely ran out of power.

Solution:
Currently investigating better ways to either a) tie the mooring to the gravel bags or b) an alternative weight solution.

Figures:

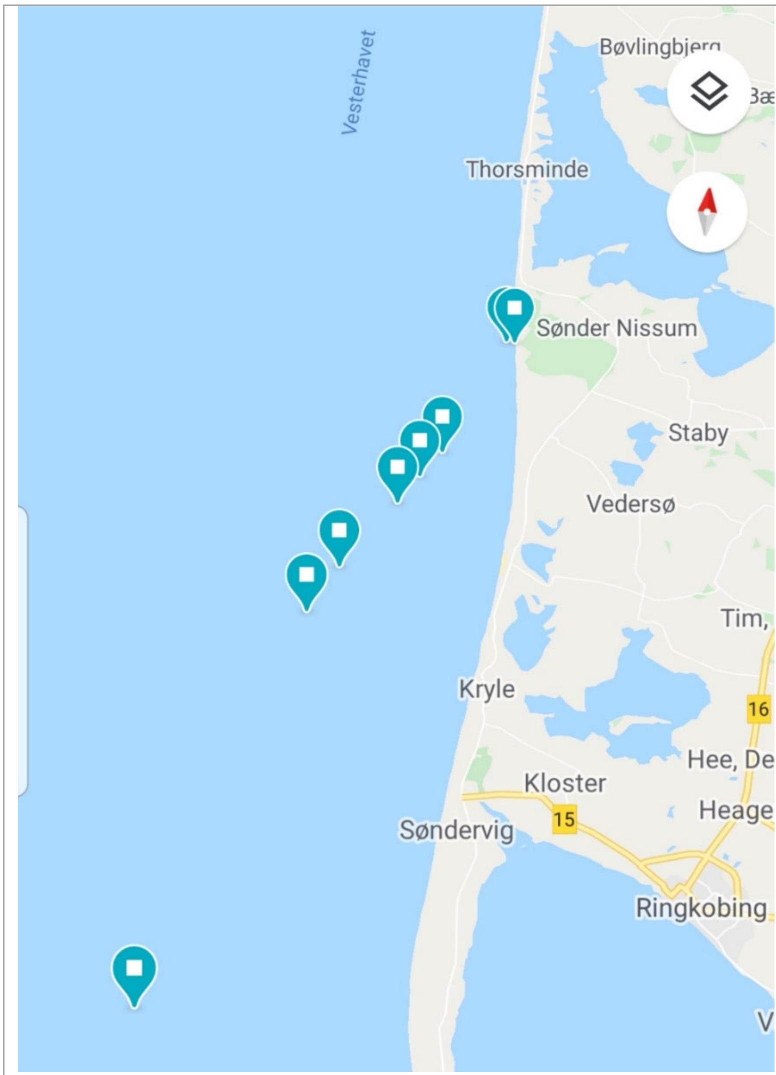


Figure 1. GPS positions received from the Kilo unit through the Iridium link from surfacing until recovery.

Figure 2. ETG retrieving the unit from the foamy surf. Photo by JT.

Figure 3. Rope still firmly tied to Sonardyne nut.

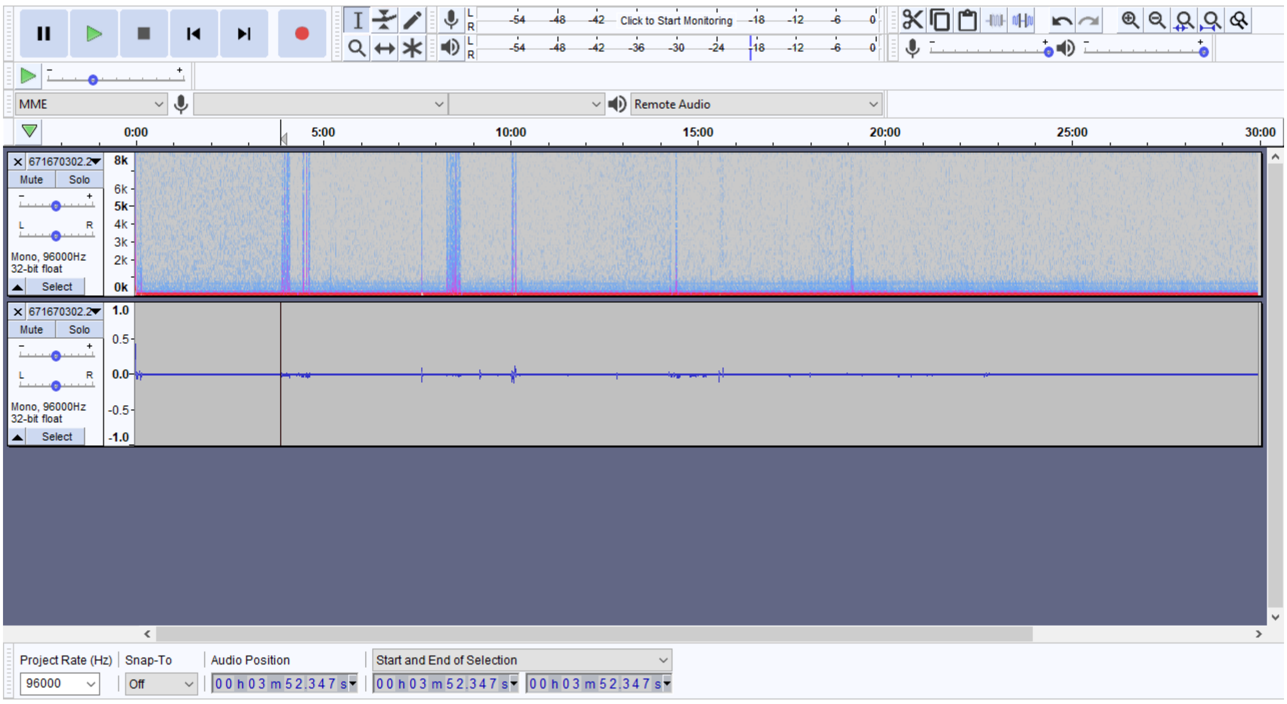


Figure 4. Waveform and Spectrogram of hydrophone test of ST-1018 on 25-02-2020. No usable sound was recorded. The ST500 (AU08) was also tested with a different hydrophone and is still functional.

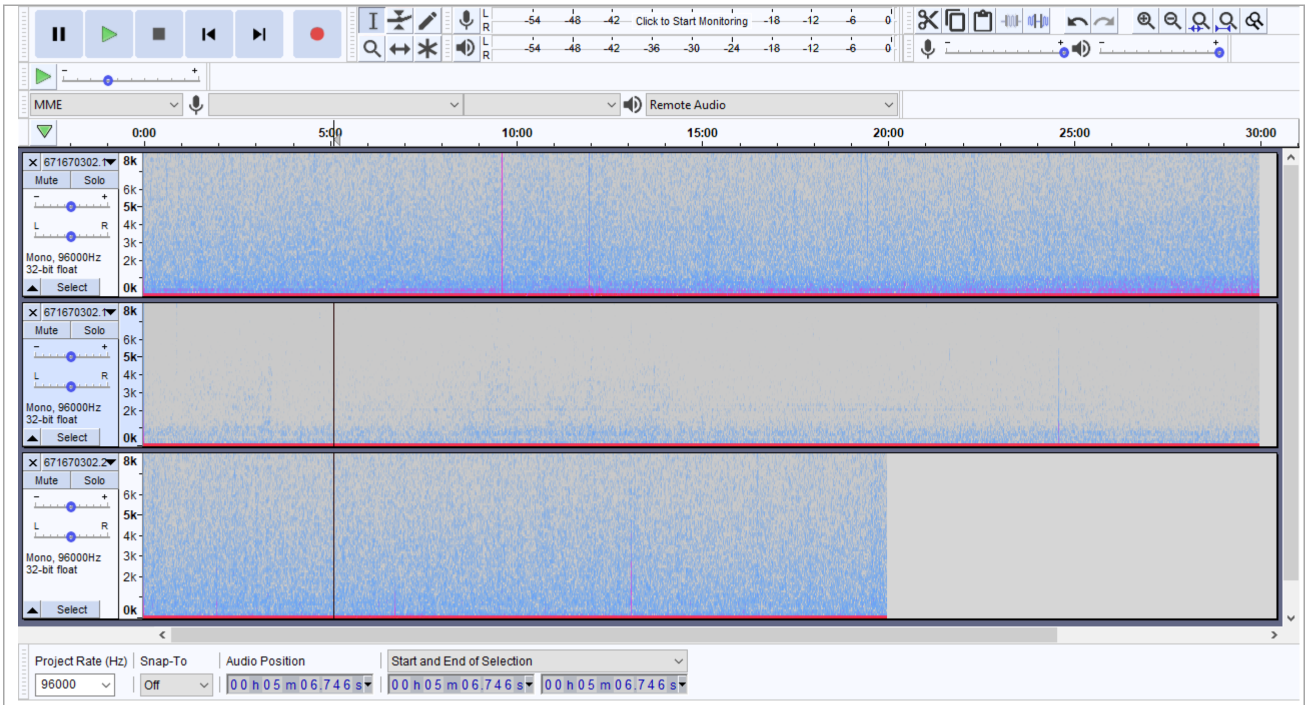


Figure 5. Spot check of three files from the beginning (top) middle (middle) and end (bottom) of this Horns Rev deployment. The last file cuts out before completion.

CONTINUOUS UNDERWATER NOISE IN DANISH WATERS 2019-20

Marine strategy framework directive criterion D11C2
HELCOM pre-core indicator low-frequency continuous noise

The Danish Environmental Protection Agency (Miljøstyrelsen) has a monitoring program for continuous underwater noise in the Danish marine waters. This monitoring program fulfils requirements regarding low-frequency underwater noise of the Marine Strategy (Havstrategien) and the HELCOM monitoring program. Underwater noise was measured on five monitoring stations in the North Sea, Kattegat and Danish Straits in 2019 and 2020, in continuation of previous years' monitoring. Recordings show systematic differences in noise levels between recording stations, consistent with different levels of ship traffic, the main anthropogenic source of low-frequency noise. The time line of monitoring does not extend long enough to allow detection of possible trends in levels.

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