Joint Monitoring Programme for Ambient Noise North Sea
2018 – 2020

JOMOPANS
Measurement Guidelines

JOMOPANS Work Package 5
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1. Introduction

These measurement guidelines were developed as part of the Interreg project JOMOPANS and specify the measurement plan which was used for the field measurements within the project.

The document was prepared collaboratively with input of all partners of the measurement work package:

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1.1. Objective

Objective is the development of a framework to establish long-term joint ambient-noise monitoring using standards and specifications produced within the project. The generated raw data will be processed in a standardized way to make it comparable across the region.
In the JOMOPANS project, measurements of continuous underwater sound are carried out by all project partners. These measurements are conducted in the respective national waters with different measuring instruments, setups and measuring procedures.
The aim of this report is to obtain a coordinated measurement guideline/plan to make comparable measurements of continuous underwater sound. This provides a basis in the project, as a defined and agreed measuring procedure is a prerequisite for all further project work.

This report comprises the descriptions of the implementation of the measurement phases and covers the following points:

I. Measurement concept
II. Measurement locations
   - Overview and description of measurement locations
III. Requirements for technical parameters
   - Description of technical parameters and used equipment/devices
IV. Measurement setup
   - Description of different setups for the measurements
V. Overview and description of calibration and processing of the measured data
   - Data handling and quality control
VI. Data hosting and sharing
   - Development of a harmonized data format

2. Measurement Concept

In order to follow the project objectives, underwater sound measurements were carried out at a total of 18 measuring positions in the North Sea for one full calendar year (2019). The measurements took place in a defined project area and were conducted by the project partners in their respective EEZ (Exclusive Economic Zone). This involves the use of different measuring equipment and settings (devices, setups and measuring features) by each partner. The data processing is also done individually and then processed data is stored centrally. The following chapters describe how to ensure that the data (from data acquisition to data processing and sharing) is compiled and shared in a comparable form to be made available to the project in a reliable way.

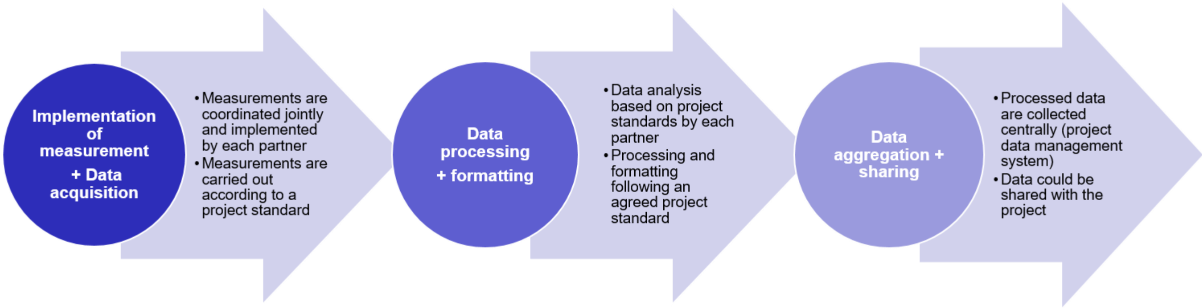


Fig 1: Overview of the workflow for the underwater sound measurements in the JOMOPANS project. The diagram shows the main structure for the coordinated measurements, processing and data provision within the project.

Figure 2 shows the specific measurement locations in the corresponding project area. Table 1 summarizes the index numbering, geographic location and naming of the measurement locations. In the following, the measuring locations are described using this numbering and naming convention.

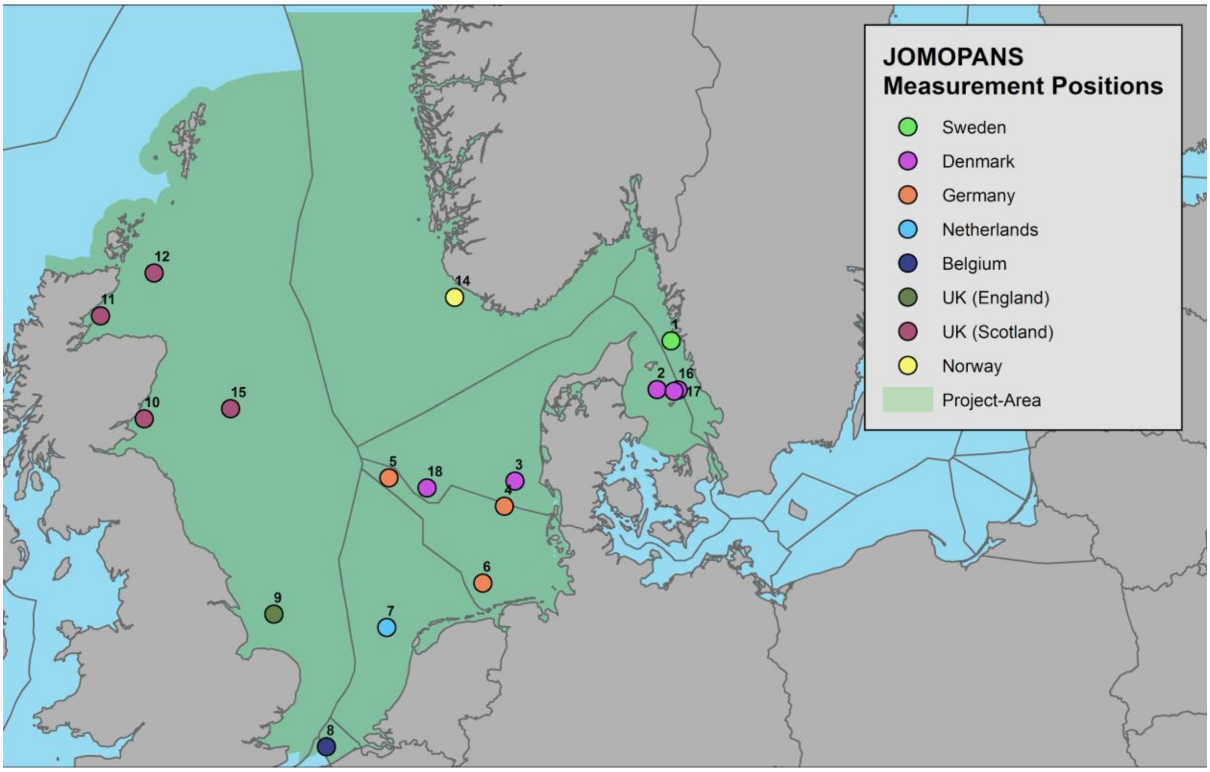


Fig 2: Underwater sound monitoring locations of the JOMOPANS-project. Monitoring locations are depicted with consecutively numbered circular markers (colours represent the different partners/countries). The green-coloured area indicates the project area. *It should be noted that one monitoring station (13-NO-LOV) is not shown on the map. This station serves as a reference station (very low shipping) and is located in the northern area of Norway and outside of the specific project region.*

Station#	Partner_Name	Measuring Institution	Water depth [m]	Position (WGS 84) LAT | LON	
01-SE-VIN	Sweden_Vinga	FOI	45.0	57.623150	11.571850
02-DK-ANH	Denmark_Anholt	AU	12.0	56.926670	11.200000
03-DK-HRF	Denmark_HornsReef	AU	14.9	55.575000	7.438330
04-DE-FN3	Germany_FINO3	BSH	21.8	55.195000	7.158330
05-DE-ES1	Germany_ES01	BSH	32.0	55.625710	4.098520
06-DE-FN1	Germany_FINO1	BSH	33.9	54.014860	6.587640
07-NL-TEX	Netherlands_Texel	RWS	30.0	53.315700	4.042900
08-BE-WST	Belgium_Westhinder	RBINS	21.0	51.383000	2.445330
09-UK-DOW	England_Dowsing	CEFAS	21.0	53.528600	1.053090
10-SC-ARB	Scotland_Arbroath10	MS	48.0	56.499800	-2.379900
11-SC-HEL	Scotland_Helmsdale5	MS	50.0	57.975900	-3.536000
12-SC-MOR	Scotland_Moray Firth	MS	80.0	58.574870	-2.119470
13-NO-LOV	Norway_LoVe	FFI	258.0	68.910000	14.380000
14-NO-NTR	Norway_NorwegianTrench	IMR	340.0	58.236750	5.839420
15-SC-CNS	Scotland_CentralNorthSea	MS	81.0	56.647100	-0.093900
16-DK-TN1	Denmark_TangoN1	AU	38.0	56.918983	11.758200
17-DK-TN4	Denmark_TangoN4	AU	17.2	56.901650	11.648183
18-DK-EDA	Denmark_ENDA	AU	45.0	55.473851	5.110474

Tab 1: Summarized information of locations and specifications of measurement sites (stations 16 - 18 are additional stations not originally planned at the beginning of the project)

2.1. Importance and use of measurement data

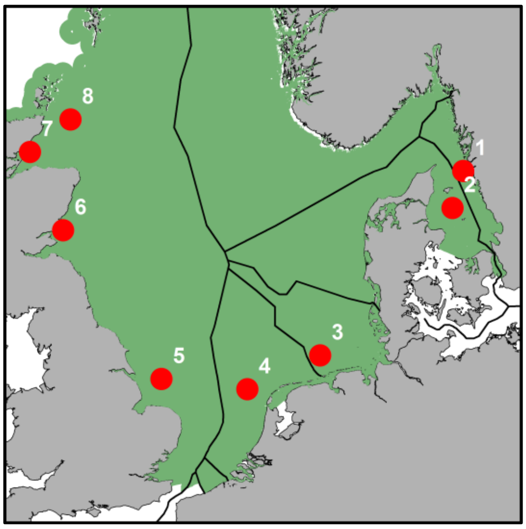
In JOMOPANS the measurement data was mainly used to support, test and validate the numerical model results. The main purpose was to create confidence maps to show the variations/differences between modelling and measurement. Although measurements were an important step to verify the model results, having a large pool of sound data leads to other big advantages and further analysis that could be done with the data:

- Get a full/extended picture of the acoustic soundscape (model only considers limited continuous sources at this stage of development (wind and ships) but other source types (e.g., impulsive sound, seismic surveys, operational wind farms) contribute to the soundscape)
- Long-term measurement will improve the scientific knowledge of the soundscape
- Background information (e.g., for wind farm constructions as baseline/T0 level)
- Baseline for time series (e.g., to answer special scientific questions like possible continuous modification due to effect of COVID19 on shipping intensity)
- Continuous measurement gives the possibility to get more information on the best/better measurement procedures at the selected stations. The improved continuity of data can also improve data analysis (the measuring position and possible influences are better understood and could be used in improving the analysis). This will improve the quality of data when it comes to assessment or future model comparison.
- National MSFD requirements include the conduction of measurements

2.2. Pre-measurement phase

In order to support the initial model verification (WP4) with measurement data, to provide first test data for the combination of model and measured data (WP6) and to gain experience for the main measurement phase (WP5) a pre-measurement phase was conducted during 2018. Furthermore, the pre-measurement phase gave a first input for the implementation of the data analysis procedures (WP3) and provided a helpful test dataset for the development of an appropriate data storage and management system (WP5) for the whole project.

It was agreed that the initial measurement phase comprises underwater sound measurements at 9 stations. Results and experiences, combined with recommendations and feedback from the other work packages, were used as direct input for possible adjustments and finalization for the concept of the main measurement phase. In particular, the acquired data was used for a first verification of the numerical model of WP4. Each station of the pre measurement phase collected at least two weeks of data.
After the initial measurement phase a main measurement phase was conducted for a full calendar year at 18 stations across the North Sea in 2019.

no.	Partner	Name	Map
1-pre	SWE	Vinga	
2-pre	DK	Anholt	
3-pre	GER	FINO1	
4-pre	NL	Texel	
5-pre	UK(ENG)	Dowsing	
6-pre	UK(SCO)	Abroath10	
7-pre	UK(SCO)	Helmsdale5	
8-pre	UK(SCO)	Moray Firth	
9-pre	NOR	Love	

Tab 2: Summarized information of locations and specifications of pre measurement sites.

Station	2018											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sweden - Vinga			■	■								
Denmark - Anholt						■	■	■		■	■	■
Germany - FINO1											■	
England - Dowsing							■					
Scotland - Arbroath 10												
Scotland - Helmsdale 5				■	■	■						
Scotland - Moray Firt				■	■	■						
Norway - LoVe				■								

Tab 3: Available hydrophone data from pre measurement phase in 2018

3. Monitoring methods

This chapter describes the underwater sound measurement equipment, setup, configurations and locations used in the project. We also describe the motivation, specifications and requirements that were set in the project to obtain data that is as homogeneous/consistent as possible.

3.1. Measurement locations

Measurement sites were chosen based on modelling and operational conditions to concentrate on specific acoustic source types. To obtain a comprehensive picture of the acoustic conditions through the measurements, the positions were selected for the following motivation: Not very close to coastal areas or intertidal regions (e.g., Wadden Sea) were chosen for possible measurement stations as this would have exceeded the project's technical and modelling limitations (sound propagation is not modelled for water depths <10 m).

Issues, that need be considered when deciding on measurement positions:

- relevant continuous acoustic sources in the area
- relevant impulsive acoustic sources in the area
- quiet and noisy regions to verify modelling results
    - quiet areas, where environmental sound dominates
    - noisy areas with high input of anthropogenic sound
- the different bathymetry of the North Sea
    - from deep water to shallow water
- the availability of metadata
    - environmental data and metadata
- the different types of sea bottom sediment
    - sound propagation is highly influenced by seabed properties
- areas of ecological interests
    - MPAs or regions inhabited by key-species
- available logistical and infrastructural options
    - available vessels/ship time and financial feasibility
- use of already existing measuring sites
- national requirements
- experience from other underwater sound measurements
- model requirements
- pragmatic positioning of station in order to enhance safety of the instrument in regard to other activities like trawling

The Information gained in the initial measurement phase was also used for adjustments during the main measurements phase. Therefore, the positions of individual measuring stations were adjusted to cover areas that were acoustically interesting or not sufficiently covered. For example, the station 05-DE-ES1 was initially planned as a coastal station but was later moved to the central North Sea. As the project progressed further, individual measurements (No. 16-18) were added, which were then also taken into account when validating the modelling work.

Information of the JOMOPANS stations is summarized in Figure 2 (map of the locations) and Table 1 (detailed information for each location).

A more structured overview of JOMOPANS stations and underwater noise sources in the vicinity is shown in Annex 4. The individual sites are considered and various predominant expected noise sources are identified. The sources are divided into categories (continuous, impulsive and other sources).

3.2. Measurement equipment

Technical requirements:

The project minimum requirements for technical parameters considered specifications from the TSG-OSPAR guidelines [1], NPL guidelines [2] and the BIAS measurement standards report [3]. In this report an overview of the typical requirements is shown. The detailed overall project standards and description can be found in the WP3 report of standard procedure for equipment, performance, calibration and deployment [9].

Underwater acoustic sensors convert a sound signal in water into an electrical signal. There are a variety of different systems on the market which can be used to measure and record underwater signals. Depending on the field of application every system has differences in performance, specifications and accuracy. To measure ambient underwater sound suitable for monitoring MSFD Indicator 11.2.1 all partners agreed on a common approach for minimum requirements in order to obtain consistent data that are comparable (see Table 4).

	Minimum requirements	Comments
Frequency range	10 Hz – 20 kHz	focus is on low frequencies (centre frequencies 63 and 125 Hz) in addition to broadband (10 Hz - 20 kHz) and low (20 Hz - 160 Hz), middle (200 Hz - 1.6 kHz) and high (2 kHz - 16 kHz) 1/3 -octave bands
Dynamic range	at least 16 bits (dyn. range 96 dB) preferably 24 bits (dyn. range 144 dB)	lowest and highest expected sound pressure should be recorded
Sensitivity	-165 to -185 dB re. 1 V/µPa	-
Directionality	Omni Directionality	sensitivity should be invariant with direction
Sampling rate	at least 44.8 kHz (22.4 kHz freq. range)	sampling frequency should be at least twice the highest acoustic frequency, that should be recorded
Filtering	Filter characteristics should be known	low and high pass filtering/clipping-filter
System self-noise	6 dB below the lowest expected sound level	-

Tab 4: Overview of agreed minimum requirements for measurement equipment.

Measurement equipment used in the project:

In contrast to other projects (where identical measurement systems were used), a variety of different measurement systems were used in the JOMOPANS project. The project partners could choose which devices they preferred or already had available for the measurements and thereby reduce costs. This way, the participants were able to contribute with their own experience in order to simplify the measurement processes and procedures, as the equipment they were working with was already known. Furthermore, it was also possible to test whether different systems are suitable for a joint measurement programme.

The measurement equipment of the project partners had to meet the specifications in Table 4, where possible. New equipment was purchased or existing equipment (from already established national underwater sound monitoring programmes) was used. Some of the hydrophone/recorder systems do not fully cover all requirements (e.g., sensitivity) as they were already existing systems with a slightly different configuration, but in general the used equipment met the requested criteria.

Partner	Manufacturer/ Type/ Hydrophone	Sensitivity [dB re. 1 V/µPa]	Frequency range
Sweden	HTI DSG010	-180	10 Hz - 20 kHz
	Ocean Instruments SoundTrap ST300HF	-174	10 Hz - 20 kHz
Denmark	Wildlife Ac. Subm. SM2M Standard	-201	10 Hz - 20 kHz
	Ocean Instruments SoundTrap ST500	-201	10 Hz - 20 kHz
Germany	Brüel & Kjaer Hydroph. (preamplifier) B&K 8106	-173	10 Hz - 20 kHz
	Ocean Instruments SoundTrap ST500	-173	10 Hz - 40 kHz
Netherlands	Ocean Instruments SoundTrap ST300HF	-177	10 Hz - 20 kHz
Belgium	Multi-Electronique, Aural-M2 HTI 96-MIN	-164	10 Hz - 20 kHz
	RTSys instrument with B&K 8104 and RTSys preamplifier	-163	10 Hz - 20 kHz
England	Ocean Instruments SoundTrap ST300	-186	25 Hz - 20 kHz

Scotland	Wildlife Ac. Subm. SM2M Ultrasonic	-165	10 Hz - 40 kHz
Norway	Ocean Sonic Hydroph. (preamplifier) SB35 ETH	-171	10 Hz - 16 kHz
	Loggerhead LS1 High Tech Inc. HTI-96-MIN	-170	10 Hz - 16 kHz

Tab 5: Measurement equipment used by the JOMOPANS partners. For cabled stations only the chosen hydrophone is described; see Table 6 for detailed description of used measurement setups.

3.3. Measurement setups

There are different measurement setup options for measuring sound at sea. But, in general, the different setups can be divided in a bottom mounted (at sea floor) and in a surface deployed (at sea surface) solution. Within the project only the bottom mounted option was chosen therefore only this type will be considered.

A detailed description of different setup and deployment options can be found also in the WP3 report of standards [9]. The main focus of this report is to describe the different deployment options used during the project, to consider and avoid possible impacts from specific setup solutions to the measurement and to understand the limitations and conditions regarding the use of the setups.

Bottom mounted systems:
The overall design of the bottom mounted stations followed one of two different construction setups:

1. The first one consists of a metal frame, platform or an anchor, on which the hydrophone system is mounted (Figure 3 - right). These setups are usually relatively small and medium weight (ca. 100-300 kg) and can be heaved by using a small crane from a boat. They are designed to stand on the sea floor steadily and to remain stable under heavy current and wave conditions. Occasionally this setup was connected with a cable to the shore or to existing offshore structures, ensuring real-time data transfer and continuous power supply, but they also could be used as autonomous stand-alone devices.

    - main advantages include:
        - Opportunity to connect the system with a (shore- or platform-) cable to ensure real-time data transfer of a complete or partial dataset. Communication link is the bottleneck since underwater sound is generating large data files. For instance VHF data link permits only partial info in real time.
        - Online operation: system could be checked immediately, data storage and energy supply are ensured
        - More protected by the proximity to a platform (if cabled)
        - Suitable for long-term measurement (> 6 months)
        - Suitable for areas with high tidal currents and waves
        - longer maintenance intervals for cabled stations required

    - main shortcomings include:
        - Deployment with larger vessels and equipment (crane, divers, ROV) required
        - Surveying offshore locations is strongly weather dependant
        - Cables are fragile and may suffer damage
        - Biofouling of sensors is a problem
        - Unwanted noise caused by nearby surface platform/shore (if cabled)
        - More deployment gear which can create noise
        - Deployment/Recovery is more complex

2. The second type of bottom mounted designs consists of a self-floating autonomous hydrophone-system which is connected to an anchor weight to keep the system in position (Figure 3 - left). All parts (data storage, data acquisition unit, A/D converter, energy supply) - with the exception of the hydrophone - of the system are positioned watertight in a pressure-resistant housing. These systems are typically small, lightweight and easy-to-deploy stand-alone devices.

    - main advantages include:
        - Relatively simple mobile use (also at remote locations)
        - Can be deployed with smaller vessels
        - Minimized unwanted noise caused by nearby surface platform
        - Also suitable for long-term measurement (3-6 months)

    - main shortcomings include:
        - Offline operation: No possibility to check whether the measurement is working
        - Susceptible to fishing activities (trawling) and other activities at sea
        - Not suitable for areas affected by strong tidal currents and waves

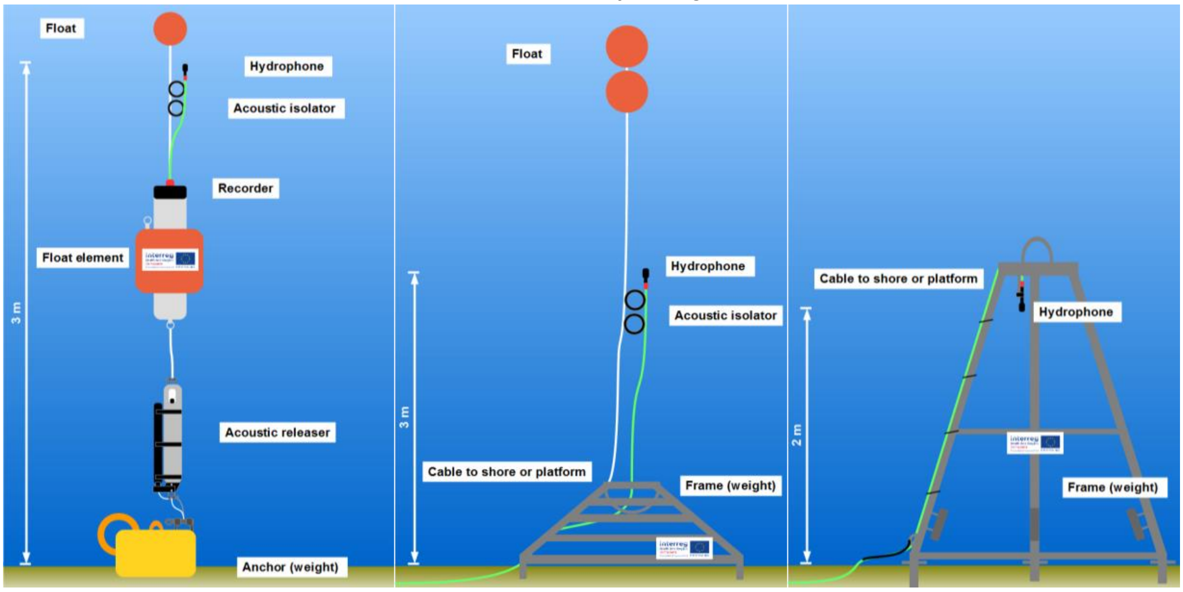


Fig 3: Typical continuous underwater sound measuring system setups for deployment: Figure left - using a floating system with releaser. Figure middle - with a frame/platform (metal) which also could be equipped with acoustic release systems for recovery. Figure right - connected with a cable to a platform/shore to use it in real time operation.

Requirements for measurement setups:

There are many different methods for setting up an underwater sound measurement station (but in general a similar structure is used as described in 3.3) . In order to minimise unwanted noise (from the station itself and from the environment), there are recommendations that have been considered in the project. Some of the changes in the setup are minimal but will have a significant positive effect on the measurement results.

- Some systems operate with a directly attached hydrophone to the logger-unit but it is recommended that the hydrophone is used decoupled (with cable extension) from the recording housing to avoid any interference (body reflections, vibrations or any sounds from the recorder) from the logger itself. The hydrophone should be mounted at least 0.5 m above the logger on a separate rope. To avoid rope vibrations the hydrophone should be installed with acoustic isolators (o-rings) to the rope (see Figure 3).

- It was agreed that the hydrophones should be placed 2 to 3 m above the sea floor to avoid/minimize any interactions (reflection) with the bottom.

- Rigid floating equipment should have a sufficient positive buoyancy to keep the measuring unit upright in the water column. If an acoustic release system is used the required extra buoyancy needs to be considered to bring the equipment to the surface (for recovery) as quickly as possible. Particularly in the case of long-term measurements, it must also be considered that the unit can become significantly heavier due to biofouling and sedimentation. Floating equipment should have a striking appearance (bright colours, size etc.) so they are easy to find when recovering instruments during high sea states or bad visibility.

- To avoid any reflections or signal shading the used flotation equipment should not be mounted in the close range of the hydrophone.

- In areas of high fishing activity, it is advisable to consider possible system protection measures, as trawling close to the seabed can cause the hydrophone to be lost. Surface buoys for marking may protect the measuring point, but should themselves produce as minimal noise (from the mooring gear) as possible.

- In principle, attention should be paid that during the measurement the entire station and all parts produce as minimal noise as possible. Anything that could clatter (e.g., shackles, chains), vibrate (e.g., rope, floats) or create noise (e.g., turbulence due to the design of the station, deployment gear) in some way should be avoided or locked in place. If possible, it is advised to use soft shackles instead of hard materials.

Figure 4 gives an overview into the JOMOPANS measurement setups (photos from the sites) and Table 6 summarises all information on the used setup of all positions.

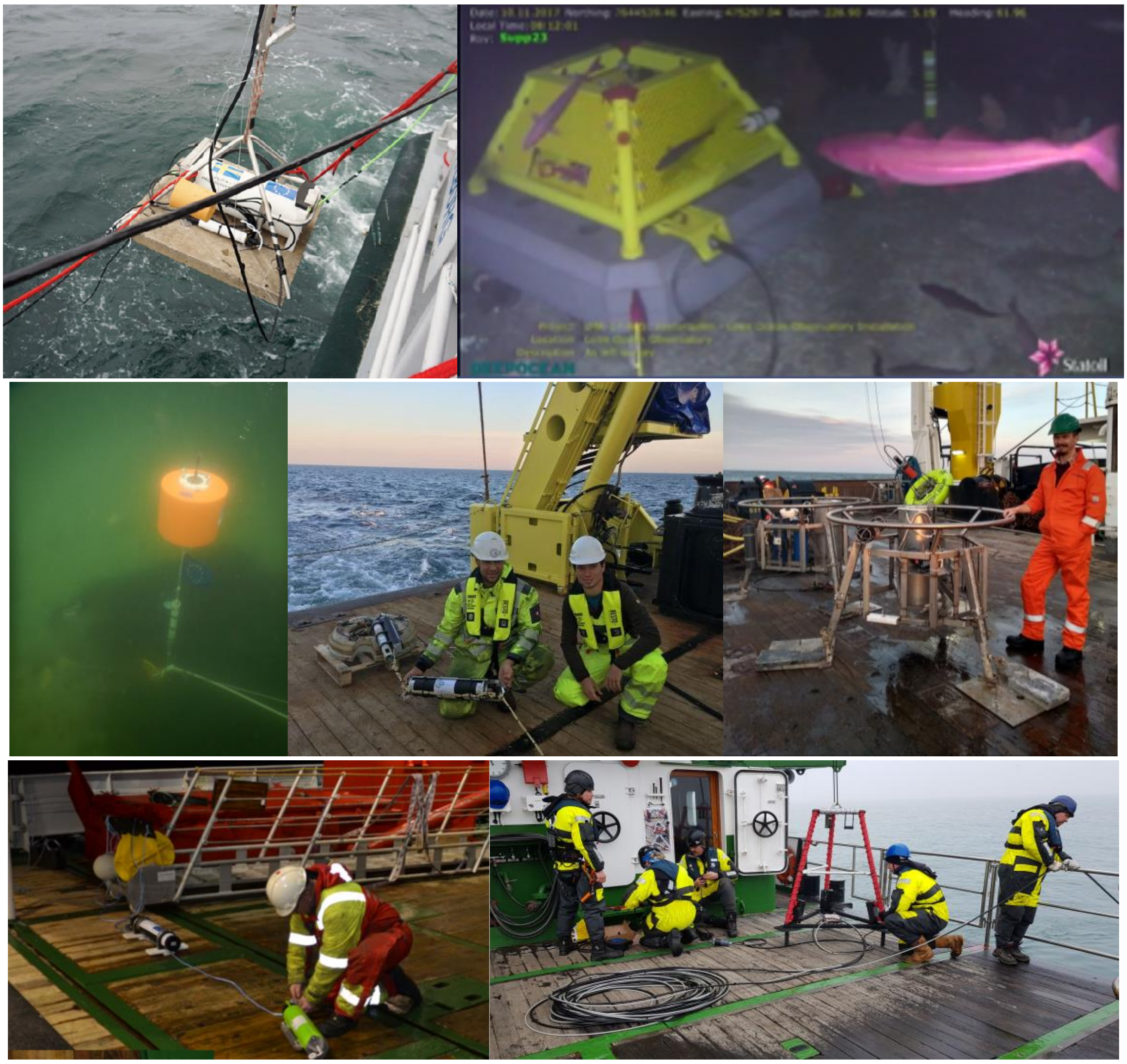


Fig 4: Different hydrophone setups used in JOMOPANS; top: cabled Sweden Vinga station, Norwegian LoVe station; middle: moored Soundtrap with releaser and buoy of German ES01 station, deployment at Netherlands Texel station, British CEFAS bottom frame Dowsing station; bottom: Norwegian Trench station, deployment of cabled FINO1 station.

Station No.	Construction design	Sensor height above seafloor	Mode of Operation	Duty cycle [ON/OFF minutes]
01-SE-VIN	Mooring with floating buoy / Bottom frame mounted	3.0m	autonomous / online	continuous
02-DK-ANH	Bottom frame mounted	3.0m	autonomous	30/30
03-DK-HRF	Bottom frame mounted	3.0m	autonomous	continuous
04-DE-FN3	Bottom frame mounted	1.5m	online	continuous
05-DE-ES1	Mooring with floating buoy	3.0m	autonomous	continuous
06-DE-FN1	Bottom frame mounted	1.5m	online	continuous
07-NL-TEX	Mooring with floating buoy	3.2m	autonomous	5/55
08-BE-WST	Bottom frame mounted	1.0m	online	90/120
09-UK-DOW	Bottom frame mounted	1.5m	autonomous	15/15
10-SC-ARB	Mooring with floating buoy	4.0m	autonomous	10/20
11-SC-HEL	Mooring with floating buoy	4.0m	autonomous	10/20
12-SC-MOR	Mooring with floating buoy	4.0m	autonomous	10/20
13-NO-LOV	Bottom frame mounted	1.0m	online	continuous
14-NO-NTR	Bottom frame mounted	8.0m	online	3/17
15-SC-CNS	Mooring with floating buoy	4.0m	autonomous	10/20
16-DK-TN1	Bottom frame mounted	3.0m	autonomous	continuous
17-DK-TN4	Bottom frame mounted	3.0m	autonomous	continuous
18-DK-EDA	Bottom frame mounted	3.0m	autonomous	continuous

Tab 6: Used JOMOPANS measurement setup during main measurement phase.

3.4. Measurement duty cycle

The duty cycle at the different JOMOPANS project locations was selected by the partners and based mainly on their experience and to get the best balance between energy consumption, data storage capacity and deployment time. For most of the partners, a measurement station was already established (through national monitoring programmes or former project initiatives) therefore a data basis - for the duty cycle setting - was available.
Duty cycle settings used during the project can be found in Table 6.

Recommendations for duty cycle settings:
The duty cycle of the recordings shall be sufficiently high to ensure that each recording is a representative and reliable statistical sample of the ambient soundscape at each station. If the deployment position is known or experience from other measurements or model results allow an estimation of an appropriate/suitable setting of the duty cycle this can be used. Otherwise, it is useful to make an assessment of the natural and anthropogenic sound level of the deployment location with continuous setting in the first recording period to set the duty cycle for this new location.
Of course, the storage capacity and the energy supply of the system, as well as the accessibility (for deployment/recovery of the system) of the location are limiting factors and must therefore be considered when setting up the duty cycle for the recording.

3.5. Measurements challenges and best practices

The measurement of underwater sound in rough maritime conditions has many challenges and problems that need to be faced. This section of the report explains in more detail problems that could arise when measuring sound at sea.

Biofouling:
Offshore measurement stations are often affected by several environmental and human impacts. Depending on location, depth, season and other factors biofouling could have a big impact on sound measurements. Over time the hydrophone itself will be impaired by layers of soft or even solid biomass, which could dampen distinct frequency bands. To avoid a possible deterioration of the sound signal every station should be serviced in reasonable intervals. As autonomous stations need service intervals anyway this applies specially to cabled stations (see Figure 5 for the 06-DE-FN1 cabled online station after 12 months deployment time). Preferably these service intervals should not exceed 3-6 months, depending on biofouling severity on location.

Fig 5: Biofouling on hydrophones in bottom frame after one year operation

Flow noise:
Flow noise can have a significant impact on measurements especially on low frequency bands up to 50 Hz. Very high flow noise can even compromise higher frequency bands. On locations with high tidal flow speeds flow noise is hard to eliminate completely via device setup. As flow noise is relatively easy to detect in data sets in continuous measurements in areas subjected to tidal flow (flow noise interference will correspond to tidal flow) it is possible to filter data for times with low flow speeds, e.g., during slack tide (see 4.3.6 for an example).

Cable strum and other turbulent flow induced vibrations:

In the same way as with flow noise cable strum and bottom frame strum impact (cable/rope and/or bottom frame low frequency vibration around 10 Hz induced through turbulent flow) can be reduced through decoupling. Detached hydrophones (~0.5-1.5 m cable between hydrophone and recorder) as well as decoupled hydrophone fixation (use of rubber rings as a dampening device between hydrophone and rope) will help decrease flow-induced vibrations. A potential but not fully tested solution could be installing turbulent flow reducing surface alterations (see Figure 5 on the left, ropes around the metal frame tubes).

Mechanical noise:

Loose metal parts like shackles or ropes and cables cause mechanical noise which interferes with the measurement data. To reduce or mitigate mechanical noise it is advised to tightly fasten every loose part of the station and use wrapping tape around shackles that could otherwise cause clicking or rubbing induced noise effects and to decouple the hydrophone itself from the rig. If possible, it is advisable to use soft shackles.

Cabled stations:

Although cabled stations provide a lot of benefits for sound measurement like unlimited energy supply and data storage as well as near instant availability of the data they also come with their own problems. If the cable itself is not properly shielded it is possible that interference noise occurs during measurement. In addition, having the cable rub against parts of the station, the environment or to itself sound disturbances can occur. With the cable moving due to currents and tides it is also very likely that the cable will get damaged over time and is pulling water.

Adrift and lost stations:

Due to storms, fishing activities or material deterioration (constant stress on material or galvanic effects on badly chosen metal combinations) stations could get lost or adrift anytime during deployment. Especially on locations far from more protected areas around other offshore structures (e.g., research platform near cabled station) it is possible that the whole station gets dragged away, damaged or severed from the anchor point by trawl nets from fishing vehicles. Contrary to current measurement stations which can be designed more trawl net resistant with sloped surfaces and a flat profile, hydrophones have to protrude from their bottom frame or float several meters above the anchor point and are therefore more vulnerable to external influences. For this reason, it is especially important to attach sufficient contact data tags on the used equipment. During the project two of three lost stations were recovered with recorders and hydrophones still intact after they were lost for several months (Figure 6). Again, a service interval of 3-6 months is advised to realize in time if a station needs to be redeployed.

Fig 6: Recovered stations; top: Netherlands_Texel (stranded in Denmark); bottom: Germany_ESO1 (stranded at west coast of Sweden)

Best practices during deployment:
If sufficient ship time is available and weather conditions allow to conduct the following measures at least once for a new station or when a new setup configuration or hydrophone is used, for later QC tests (4.2):

- Short term data overlap between two recorder/hydrophone systems during deployment or recovery
    - All partners are encouraged to deploy a second hydrophone during maintenance of their station before recovery of the old system. A minimum overlap of the hydrophone measurements of 1h is helpful.
- Long-term data overlap between two recorders during deployment
    - For stationary long-term recorders all partners are encouraged to deploy another recorder for a temporary period to provide duplicate measurements at the same location. This is not a calibration but it is possible to do a simple comparison this way. The temporary recorder should be deployed at least 1 day to catch tidal variations, if possible.

3.6. Metadata and auxiliary data

The provision of auxiliary data sets is necessary to enhance the verification of the modelling outputs, to verify the results within the work of the combination of measurements and modelling and in general to get a basic understanding/interpretation of the measured acoustic results. It also serves as input to the modelling. Together with acoustic measurements this data will be provided to all relevant work packages. Auxiliary data can be obtained from different sources or measured locally together with the acoustic measurements. Throughout the main measurement phase environmental measurements were carried out at specific and agreed locations to support the project work.

Auxiliary environmental data includes:

- Sea State (height and direction)
- Current speed and direction (and associated measurement depth)
- Wind Speed and direction (and associated measurement height)
- CTD (Conductivity, Temperature and Depth) profile measurements (for calc. of SoundSpeedProfiles)
- Rate of rainfall (and other precipitations)
- Water depth and tidal variations
- Air and water temperature
- Seabed type

and other sound sources like,

- Information on nearby shipwrecks, military restricted areas, nature reservation zones, wind farms and other sources of anthropogenic sound sources (pipelines, dredging activities, etc.)
- Information on impulsive sound sources (construction work, explosions, seismic surveys, etc.) is an important interpretation basis to understand the measured data and should also be reported. This information is important when comparing model and measurement, as the modelling only considers continuous sources
- Information of any other noise sources (e.g. engines from platforms, nearby oil-rigs, etc.) in the area of measurements

AIS + VMS data:
AIS data was provided for the pre and main measurement period from a sub-contracting company (for AIS structure see Annex 3). Both terrestrial- and satellite-based AIS data were considered. The AIS data is (with limitations) free available (see Figure 7) but can only be used for the project purpose after complex data processing and correcting. For this reason, the project decided to obtain the processed data sets from an external provider. The detailed specification of AIS data and processing steps can be found in the monthly AIS data analysis provided by Quiet Oceans. In addition, a more in-depth report on quality and usability of the AIS data can be found in the report from WP4 [5]. AIS datasets do not include VMS data (identification system on smaller vessels which are not equipped with an AIS transmitter (e.g. fishing vessel)) and this information had to be provided directly from the partners to support and complete the AIS data. In some countries the VMS data is subject to strict data protection rules and difficult to obtain. Therefore, not all partners were able to provide VMS data for the project.

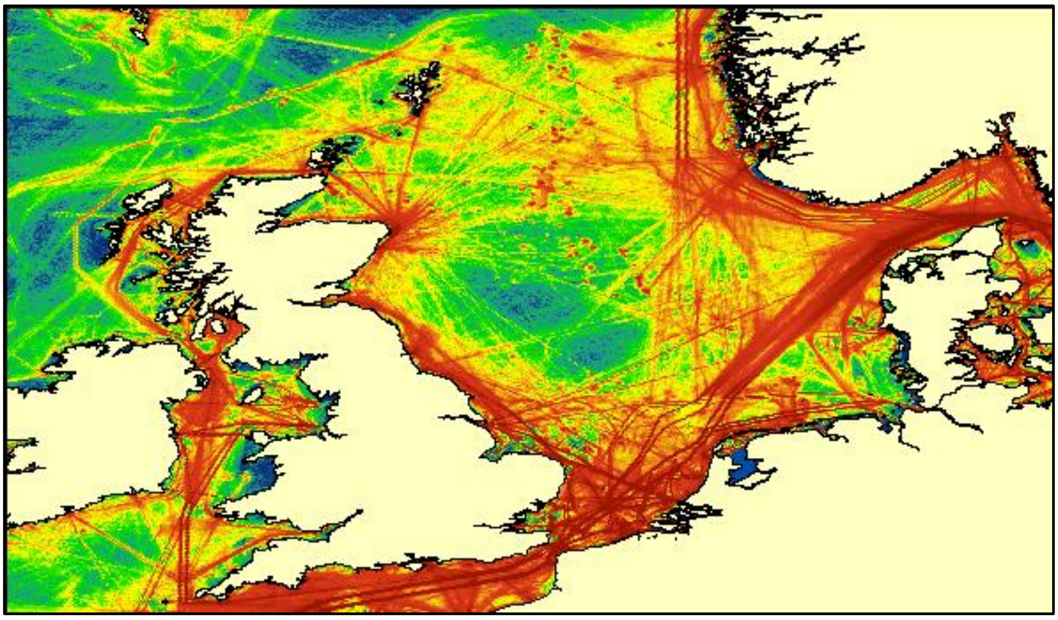


Fig 7: Example of AIS-dataset with ship density for the year 2019 (source: https://www.emodnet-humanactivities.eu)

4. Data availability

4.1. Data availability summary

To be able to compare and assess the model results with measured data, JOMOPANS carried out a one-year sound monitoring program. During 2019 every partner in the project installed a sound measurement station with a calibrated hydrophone and recorder at a pre-selected position in their national waters. The hardware used had to meet the agreed technical standards and all systems were calibrated in a standardized and coordinated way (see WP3 report).

The locations of the stations were chosen to cover a wide range of different regions, from areas with high traffic to more remote locations. Also, logistical aspects were taken into account in the selection of locations, as cabled hydrophones in the vicinity of existing measurement stations can be maintained more easily than those located far away in the centre of the North Sea.

JOMOPANS deployed hydrophones at 18 different offshore locations (distributed among the 8 partners in the project). After several processing and quality control tests (5.2 and 5.3), the project partners were able to gather a reliable data set for the model comparison from these 18 stations. The reasons for the data gaps, which are shown in Table 7, are diverse: Selected monitoring stations were initially planned as temporary measurements (e.g. 05-DE-ES1 in the centre of the North Sea), there were of course difficulties and risks in installing monitoring stations at sea (rough offshore conditions can always lead to system failures), some stations were lost due to storms or fishing activities (although some were found again) or it was temporarily impossible to recover them due to weather or ship time restrictions.

But in total, a unique set of reliable and essential data has been successfully measured collectively, which is not only essential for further project work, but will also be made available to the broader community after the project ends.

Station	2019											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sweden - Vinga	■	■	■	■	■	■	■	■	■	■	■	■
Denmark - Anholt		■	■	■	■	■						■
Denmark - Horns Reef			■	■	■	■	■				■	■
Germany - FINO3						■	■	■	■	■	■	■
Germany - ES01									■	■	■	■
Germany - FINO1			■	■	■	■	■	■	■	■	■	■
Netherlands - West of Texel				■	■	■	■	■	■	■		
Belgium - Westhinder					■	■	■	■	■	■		
England - Dowsing	■	■	■	■	■	■	■	■	■	■	■	■
Scotland - Arbroath 10	■	■										
Scotland - Helmsdale 5	■	■	■									
Scotland - Moray Firth				■	■	■	■					
Norway - LoVe		■	■	■								
Norway - Norwegian Trench	■	■	■	■	■	■	■	■	■	■	■	■
Scotland - Central North Sea										■	■	■
Denmark - Tango Nord 1									■	■	■	■
Denmark - Tango Nord 4									■	■	■	■
Denmark - EDNA									■	■		

Tab 7: Available hydrophone data from 2019

5. Data calibration and QC

One of the main tasks of WP5 was the management of all measurement data collected during JOMOPANS. This comprised the data from the pre-measurement phase as well as from the main measurement phase in 2019. In addition to all processed acoustic data, also all available auxiliary data needed to be collected and made available to the relevant work packages (WP4 & WP6). Furthermore, WP5 was responsible for gathering and hosting all available AIS/VMS-data, which was processed and provided by Quiet Oceans and needed for modelling purposes by WP4. In the following, the way from data acquisition to archived HDF5 files will be illustrated with special focus on problems and approaches to solve them.

5.1. Calibration

For an ambitious and extensive project like JOMOPANS, it was essential to ensure that the acoustic data is comparable in quality. The collected data from different stations needed to have the same levels of accuracy in order to provide WP6 with comparable data, which was required to validate JOMOPANS' model results (WP4). During the project a survey was conducted by WP5 to ensure that all partners are performing suitable calibrations of their instruments before deploying them.

The calibrations needed to be performed according to the report on standards for data processing from WP3 [4]. Calibration information of each deployment is included in the metadata of each HDF5 file. According to the JOMOPANS HDF5 format specifications (see 5.2) the used calibration procedure has to be mentioned as well as the frequencies and the corresponding levels at which the hydrophones were calibrated. All JOMOPANS partners calibrated their acoustic measurement chain 'from hydrophone to data file' (hydrophone, amplifiers, filters, A/D conversion) before deployment and after recovery in order to detect any signs of drifts in the instruments (this is in line with the Good Practice Guide for Underwater Noise Measurement by NPL [2]). However, most partners used hydrophone-calibrators (pistonphones), which provide the hydrophone with a well-defined tonal signal at a certain frequency (e.g., 125 Hz or 250 Hz) and amplitude to calibrate their instruments. By doing so it can be controlled if the hydrophone's sensitivity at this certain frequency still does comply with the manufacturer specifications or with previous calibrations. The sensitivity for the rest of the spectrum is either assumed to be flat or following a defined sensitivity curve that is generally not altered but shifted parallel.
Only a few partners had the facilities and capabilities to calibrate their instruments at a multitude of frequencies. If possible, it is recommended to perform a full laboratory calibration before and after every major deployment or sea-trial [9]. The recommended frequency range for calibrations should cover the frequencies of interest – thus in case of JOMOPANS ranging from 10 Hz to 20 kHz. All calibrations have to be traceable to internationally-recognised standards [9].
A detailed description of the JOMOPANS standards on how to perform the calibration (either with a pistonphone, full scale or free field) can be found in the document on Standard procedure for equipment, performance, calibration and deployment [9] provided by WP3.

5.1.1. Ring Test/Benchmark Calibration

Although all partners were performing some sort of suitable calibration, the inter comparability of the different methods needed to be proven to rule out different calibration procedures as major error sources. While some partners were only able to test their instruments (autonomous recorders or hydrophones) at certain frequencies using pistonphones, others had the facilities to calibrate their devices over the whole frequency range. A point calibration with a pistonphone can only verify that an instrument is still performing according to the manufacturer's calibration and only gives one calibration factor. It thus needs to be assumed that frequency response curves are either known or flat. After the first iteration of model verification [10] the need to compare calibration procedures emerged to rule out different calibration standards or procedures as possible error sources.

In JOMOPANS it was not possible to calibrate all used systems over the whole frequency range (see [8]). This is partly because a variety of different systems (some of which are cable bound) were used and also because the need for such a test emerged in the middle of the project. During that time not all partners could spare their instruments. Some instruments were still measuring at sea. Therefore, WP3 and WP5 decided to benchmark the calibration procedure rather than the used recorders.

NPL offered to calibrate one instrument per partner in the low frequency range from 10 Hz to 300 Hz. Therefore, partners were asked to calibrate their systems and send them to NPL. NPL performed the calibration and sent the instrument back. Ideally the calibrations made by NPL and the individual partner should not differ, respectively the deviations should be within acceptable error margins. Not all partners could participate in this benchmarking analysis. During the time of the test FFI/IMR (NO) had no spare instrument. The results for the Netherlands and MarineScotland's own reference calibrations are not yet included in the below comparison.

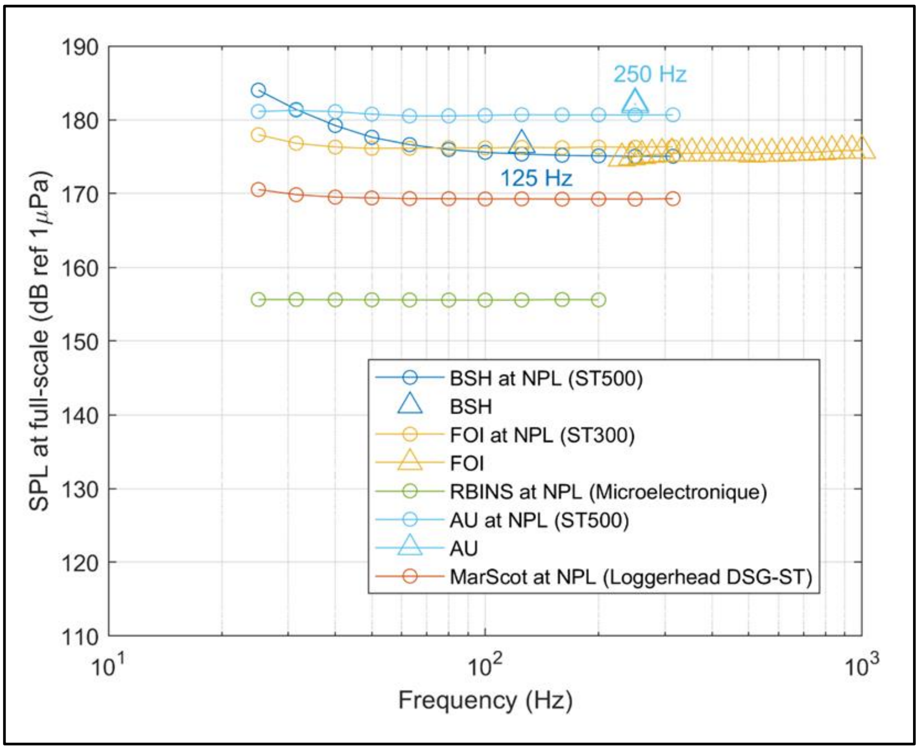


Fig 8: Intercalibration results

However, for all remaining partners it could be ensured, that the deviations between both calibrations were all within 1.35 dB re 1 µPa of the pistonphone transfer standard. The calibration comparison workshop revealed some interesting challenges and behaviour for the instruments:

- Couplers not interchangeable for hydrophones of different size
- Some lack of repeatability at frequencies below 63 Hz
- Sensitivity drifting after the boot-up of instrument
- Deviation from the manufacturers' specification
- Instruments of the same type having different sensitivity

The benchmark calibration workshop is considered in detail in [9].

5.2. In-situ QA checks

It is advised to follow some good practices to ensure good quality data when measuring out in the field [9]. One method to verify results is by comparing signals of hydrophones that were deployed very close together. The signals should not be identical, but closely positioned hydrophones with signal levels differing by many decibels may be indicative of a possible error.

If ship times allow it is a possibility to temporarily deploy a second hydrophone close to the actual deployment. The corresponding comparison of the signals may be indicative of possible errors. By correlating the recorded signal, a time shift between the recordings should be taken into account before finally comparing the results.

Additionally, it can sometimes be useful to deploy a local source (e.g., ping of a release unit) of known frequency and amplitude when deploying and again when recovering. This check-up can easily be combined with deploying a temporary hydrophone. Pinging for calibration checks of the hydrophone and instrumentation is reasonably accurate if the source is calibrated and the source-receiver distance is known within reasonable accuracy.

This is a good capability to introduce to a cabled system which is difficult and expensive to retrieve for repeated recalibration. In such cases, it is better for the source to be controlled from the shore base such that it can be switched on and off when required and does not generate interfering acoustic signals to the recordings [9].

5.3. Quality Control

The quality control (QC) of each dataset has to be considered as a primary step of the data processing. It is inevitable to assure basic quality standards before processing and sharing data. This holds especially true for acoustic data, because it is not possible to share raw-data, but rather processed statistical values. This is due to unmanageable data sizes and often also military restrictions. It is much harder to identify deficiencies of any kind in processed acoustic data than it is in raw data and therefore it needed to be ensured that the QCs were performed by all partners.

5.3.1. Pre-processing

Pre-processing is a step in signal processing to prepare data for estimation and analysis, being the order of the procedure recommended as follows:

- Downloading and preparation of data
- Raw data files should be placed in a measurement specific folder.
- Preparing a back-up copy of the raw data
- Data recorded before deployment and after retrieval of the system is to be removed.
- Data recorded while the deployment is ongoing and when the deployment ship is still near to the deployed sensor is to be saved but not to be used.
- Verify that all data files have been downloaded by verifying that the number of files and the size of the files matches between the logger data and the downloaded data.
- Analysis of file size and clipping
- Testing of file size and file length of the recorded files should be performed,
- Testing of non-numerical values NaN (not-a-number) and Inf (too high value for a numerical representation) in the recorded data files: these values are to be omitted prior to processing,
- Testing of clipping, e.g., if the data values are saturated by the recording system: the percentage of clipped samples (e.g., samples whose value equals the minimum or the maximum level) should be calculated for each 20s interval of the data file. The recommendation is to flag the 20s interval as clipped when at least 0.1 % of the samples are clipped. Information on the flagged data should be noted in the processing protocol for further consideration and tracking.

The results of a questionnaire regarding the performance of the QC's were analysed and are presented below. WP5 had received feedback on this from five partners (CEFAS, BSH. RBINS, FOI and WaterProof B.V.). The requirements on the QC's standards are lined out in detail in [4]. In the following procedures and examples are provided on how to cope with the necessary quality checks.

5.3.2. Check for missing data and data consistency

Following the guidance from WP3 there were different approaches in JOMOPANS to address quality checks either automatically, manually or as a combination of both. FOI used a proven Matlab script developed in the BIAS project that checks the length of each file and the interval between each file. This is a script for BIAS/LIFE pre-processing data analysis that returns gaps between files, gaps in samples, file times and file sizes. It can be found on the BIAS homepage [11].
BSH developed a python script, which does not only cope with this first quality check, but also with the three following aspects. The number of data files gets compared to the number of expected data files. Furthermore, it checks if the length and the sample rate of the recorded files is as expected. If an DC-offset is detected the data also gets flagged.
The Dutch company WaterProof B.V. also checked collected data for coverage and consistency using automated software routines. All files were checked and indexed in a database, using their timestamp and length of the recording. The routines of WaterProof B.V., being a private company, shall not be made public.
While the routines mentioned above were already used successfully during JOMOPANS (and partly also during BIAS) other partners were examining their datasets by plotting spectrograms and searching for inconsistencies manually. This simple procedure is highly recommended to follow no matter what automatic routines might be available.

WP5 recommends to use automated scripts to cope with the expanse of acoustic recordings but complement these with manual investigations of spectrograms and spectrums and listening to raw data, which might give hints to errors or events that happened during the recording.

5.3.3. Removal of contaminated data

The script *BIAS_gaps.m* (FOI) was used for this simple task as well. This matlab script is made to find gaps in recordings and discard them correspondingly. The python script, developed by BSH, is used to remove data before deployment and after recovery. All data earlier than one hour after deployment and later than one hour before recovery is removed automatically.
Again, WaterProof B.V. has an automated routine for this problem, but cannot share it publicly.
Manual investigation, cropping and especially listening for other contaminants can be mentioned as alternatives to the automated approaches.

5.3.4. Checks for clipping and distortion

In most cases clipping is avoided by high dynamic ranges (e.g. 24-bit depth or even 32-bit depth for the FINO stations). The dynamic ranges of the SoundTrap recordings are well below clipping. Anyhow, some automated routines were put in place to scan through the measured files and detect clipping.
The already mentioned BSH-developed python script is capable of checking for clipping. It measures the percentage of clipped samples per file and removes files if the percentage exceeds 0.1 %.
FOI used their Matlab to tag and remove clipped data.
WaterProof B.V. does not only check for the clipping to be well below 0.1 % per file, but also per evaluated second.
Only few partners (NPL) were capable of determining their measurement's system noise (e.g. in anechoic basins). These partners could ensure that their system's noise floor is sufficiently low to always be exceeded. However, most partners do not have access to anechoic basins and so could not determine noise floors of their instruments.
Partners who were not checking their recordings automatically reviewed their files anecdotally with software packages like Audacity.
WP5 is under the impression that due to high dynamic ranges clipping does not seem to be much of a problem when monitoring underwater noise with current state of the art sound recording instruments.

5.3.5. Additional data analysis

The automatic detection of signals not already considered in the model (low frequency periodicities, periodic impulsive sounds, etc.) still pose a problem. To get a quick overview of whole months of recordings, monthly spectrograms are the method of choice. Proper investigation of these spectrograms enables localization of these signals, which eventually can be checked audibly.
During the project several methods have been discussed on how to deal with a detected signal. It was agreed on not deleting any data, but rather indicating 'known issues' per station. These 'known issues' should be reported to WP5 and were forwarded to WP6, either by the earlier mentioned questionnaire or in the 'comment'- dataset in the submitted HDF5 files. Known issues could include continuous unreliably high SPLs in certain TOBs, periodic noise by e.g. dredging, piling or close-passing fishing vessels or flow noise. The following chapter will present some results for such data.
The proposal of flagging the data was dismissed, by acknowledging that this might be too ambitious for this project. Anyhow this could be a goal for future research approaches e.g. with deep learning algorithms. By not deleting any data it is also assured that the data can as well be used for future research work focusing on different aspects of the underwater soundscape (occurring between 10 Hz and 40 kHz).

5.3.6. Audio and visual inspections of the data

When visually investigating the spectrograms various kinds of anomalies can be found in the data. Most of the time it is difficult or even impossible to identify the sources visually and auditory checks become necessary. Below some of the observed anomalies are presented as well as some considerations on what might have caused them.

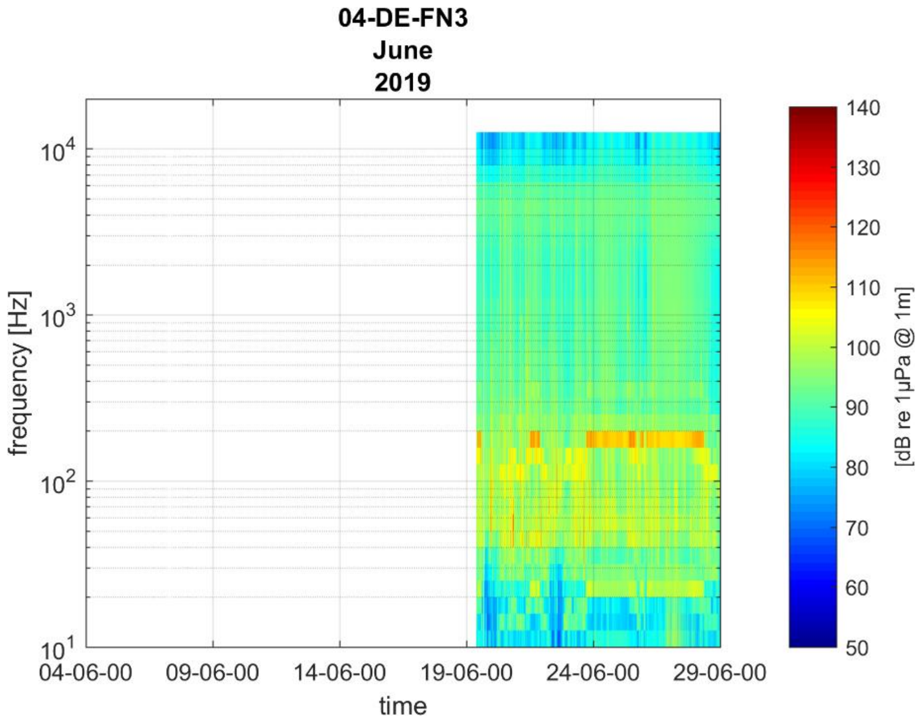


Fig 9: Example spectrogram from June 2019 at 04-DE-FN3 station, showing signals in the 200 Hz TOB

In Figure 9 an example spectrogram from June 2019, recorded at the German 04-DE-FN3 station is shown. A clear continuous signal at 200 Hz can be seen. This might be the harmonic of the diesel generator on the FINO platform generating electricity at a 50 Hz rate, but it might as well be induced by other effects or other sources that are not obvious at the moment and require further investigation. Continuously high SPLs in certain TOBs are always suspicious and most often a result of imperfect measurement setup or other anthropogenic sources in the hydrophone's vicinity, constantly emitting sound.

A different source for disruptive signals is flow noise, which in the North Sea occurs mostly due to tidal currents. In Figure 10 an example of the British JOMOPANS site 09-UK-DOW is shown. The repetitive pattern in low TOBs (10 to 40 Hz) is quite obvious and indicates the tidal cycle. As discussed before, it was decided to not delete any such data, but to report these issues to WP6, who eventually consider observed artefacts when comparing measurement with modelled data. For future projects it might be worth considering different setups like described in [7].

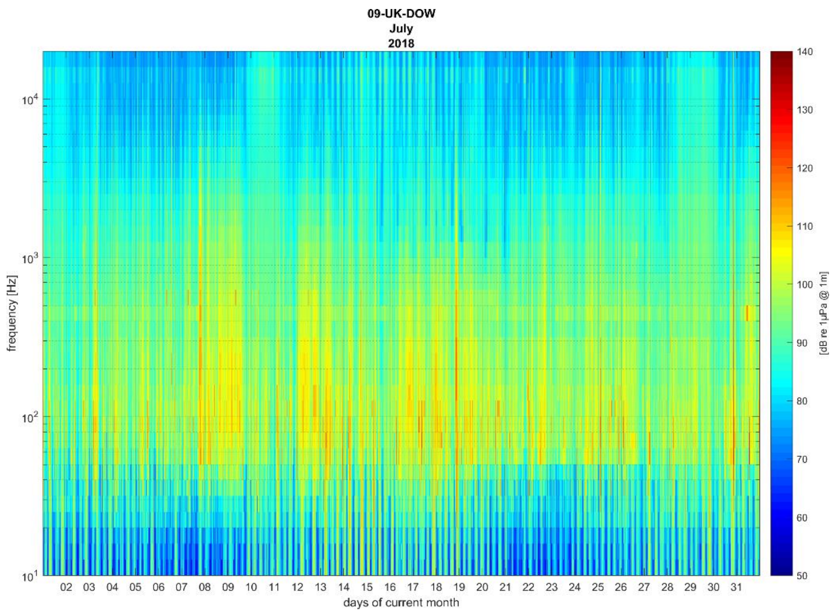


Fig 10: Example spectrogram from July 2018 at 09-UK-DOW site with strong tidal flow noise which is obvious on the lowest TOBs.

With this regard it was convenient to investigate the data, recorded at the German 03-DE-FN1 station. There, not only acoustic but also other parameters like currents, winds etc. are measured continuously. Condensing and comparing acoustic and current data from July to December 2019 led to the results, presented in Figure 11.

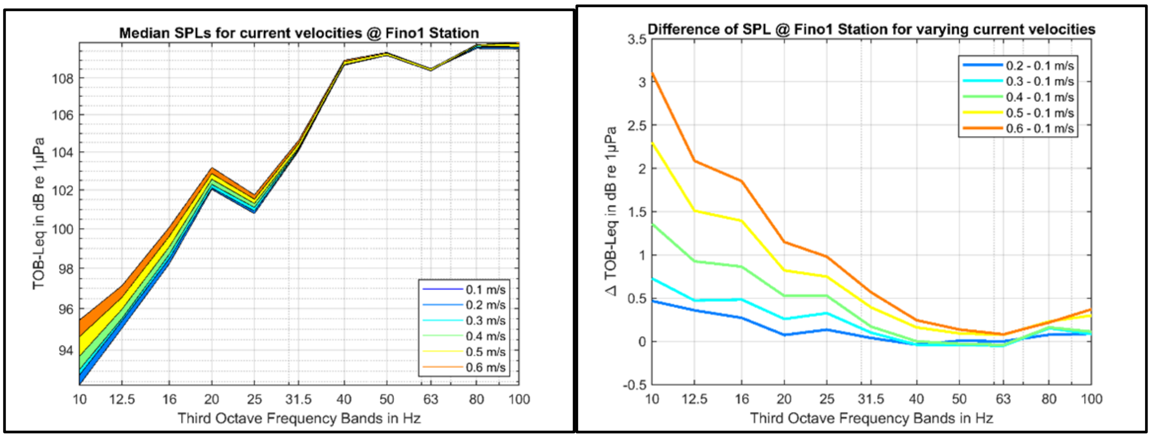


Fig 11: Effect of current speed on SPL for low TOBs at Station 06-DE-FN1. Left - median SPL for bin of current velocities. Right - difference of SPL compared to lowest current velocity bin (0-0.1m/s)

The SPLs increase with rising current speeds. This is especially true for low TOB and for the 10 Hz TOB, this can amount up to 3 dB. For TOBs higher than 40 Hz the differences in SPL, induced by flow noise, are reduced to less than 0.5 dB, thus only the lower TOBs are affected significantly by flow noise. This is consistent with the observations at the Dowsing site (see Figure 10).

The most important information for the modellers of WP4 was to confirm the effect of flow noise on the percentiles as they focus on more percentiles than the median. They expected the contribution of flow noise to increase towards higher percentiles, which could be confirmed by the data of FINO 1 (see Figure 12).

Obviously, this is just an investigation for one site and is impacted by local conditions (close vicinity of wind farms, the FINO platform itself and many CTVs). Future work will aim for a general approach, investigating all JOMOPANS stations. Also, the influence of other environmental data (wind, rain and of course also marine traffic) shall be investigated.

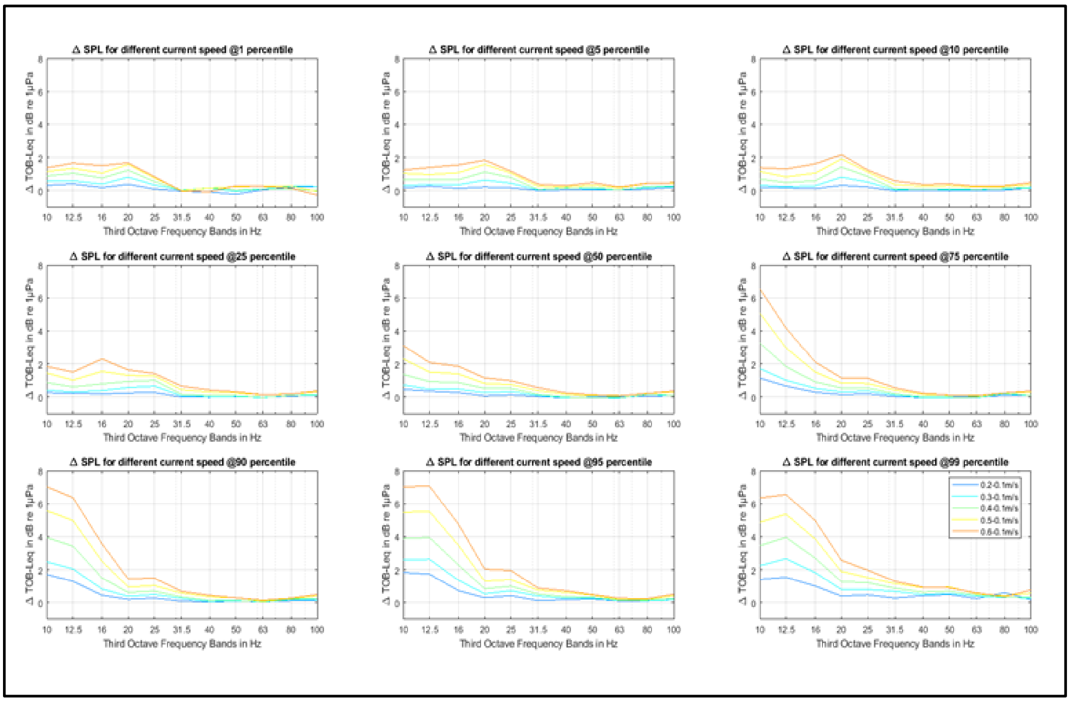


Fig 12: Differences of SPL compared to lowest current velocity bin (0-0.1m/s) for all relevant percentiles at Station 06-DE-FN1.

As a third and last aspect of a special signal, we like to mention events like the one represented in Figure 13. In this example the TOBs from 200 – 500 Hz are subject to an unknown source of sound. This might coincide with dredging activities in the area over this period, but in other examples, events like this were also likely to be induced by close-passing fishing vessels. It needs to be noted that data like this was not deleted but rather reported to WP6 to be considered when analysing.

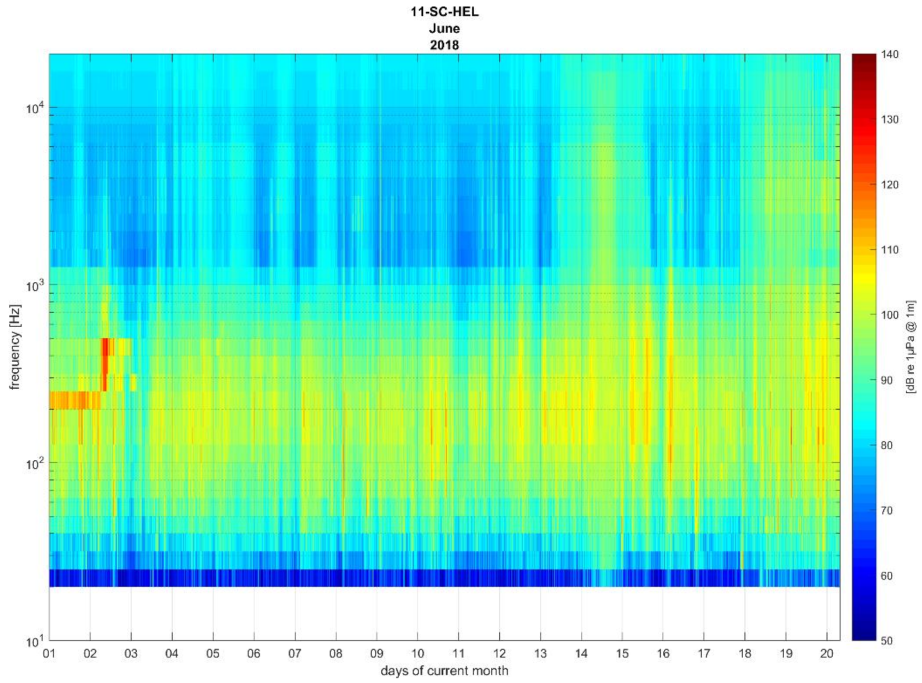


Fig 13: Spectrogram of June 2018 at the Scottish site 11-SC-HEL showing some sound pattern within the first two days.

5.4. Software control

As described above, not many different software was used among the partners in the JOMOPANS project, so software control was not entirely necessary for all partners. CEFAS uses GitHub for internal version control of their Matlab codes. Some partners used PAMGuide [6] for calculating the SPL, which is also hosted on GitHub and is thus subject of quality control and is further very well documented [6].
It is noteworthy and exceptional that in JOMOPANS it was not advised which software or tool should be used to convert raw audio data to statistical (1 sec or 20 sec) mean-SPLs. By conducting a benchmarking test during the early stages of the project it was assured that the deviations of the individual methods of evaluation are neglectable (below 1dB difference). Therefore, the same recordings were evaluated by each partner and the results matched sufficiently well (see 4.5.2).

5.5. Data Processing

In the report on standards for data processing from WP3 [4] all relevant steps that need to be done to get from the raw measurement data to processed third-octave band sound pressure levels are described in detail. Here only the main outline of those steps is presented.

5.5.1. Benchmarking of processing and calibration

Considering the overall goal of JOMOPANS – to create a tool for decision makers based on validated sound maps – it is evident that it is crucial that the measured sound data is standardized and quality comparable. The models (WP4) are being validated with the measurements of 2018, assuming that the measurement data resembles the ground truth of the soundscape of the North Sea at the given measurement positions.
To ensure comparability of the quality of the measurement data two tests were performed, that are presented in the following. The first test was conducted during the first phase of the JOMOPANS project and investigated the different (not completely standardized) methods to calculate third octave band power levels (see below). The

second test was conducted after the measurement phase and focused on the various forms of calibrations carried out throughout the project (4.1.1).

5.5.2. Ring Test/Benchmark Data processing

As part of WP3 a benchmarking exercise was performed for project partners to compute third octave band power levels from a common synthetic data set. It should be checked how solid the guidance from WP3 was and if the results were the same within acceptable margins. Both the guidance and the results from the test are described in detail in the report from WP3 [4].
Each partner was asked to analyse two synthetic datasets (white noise and pink noise) and the derived power spectra were compared by WP3. It was noted that there were no correct answers in the results, only different presentations of the same data. However, eventually it could be shown, that the guidance from [4] could be followed and that the processing could be performed largely in a consistent way.

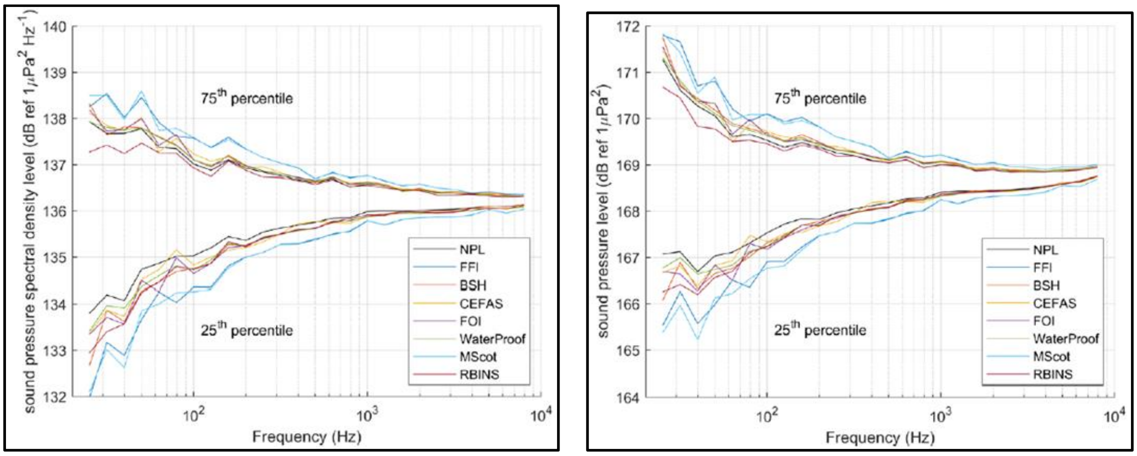


Fig 14: Sound pressure spectral density levels of white noise (left) and pink noise (right) in TOB as reported by partners for the 25th and 75th percentile.

As an example of the consensus of data processing Figure 14 is showing the spectral density levels per TOB, calculated by each partner for the two test datasets. The obvious deviations are within acceptable error margins and mainly occur for low frequencies. They arise as a result of the exact implementations of the individual partners.

6. Data management

It was agreed in the initial stage of project planning that only processed data should be shared during the project. All collected raw underwater sound data sets remain in the respective countries that they were recorded in.

This approach has several advantages:

- The acquired underwater sound raw data sets are immensely large (multiple gigabytes to terabytes). Thus, a systematic transfer of data is enormously difficult and costly.
- Since a coordinated and comparable standardised data processing procedure is available, the exchange of raw data is no longer necessary, as all the required information is provided in the processed data sets.
    - The max. size of the processed JOMOPANS data sets is about 350 MB/month/station
- In some countries, raw underwater sound data is subject to special rules and obligations. Especially if you want to share this data with other countries for joint work (even if the work has a scientific focus). Thus, only an exchange of processed data is possible.
    - Individual requirements of the respective countries must be considered (e.g. specified averaging intervals during processing process)

The following section describes how data management is organised in the project. The development of a standardised JOMOPANS data format and the structure of how the data is aggregated are the main focus here.

6.1. Data hosting and sharing

The acquired data in JOMOPANS needed to be gathered and also made available for consequent work steps. Therefore, WP5 hosted a secure FTP-server environment. Every partner had their own available data directory only accessible by themselves and WP5 (for coordination):

Fig 15: Structure of ftp-server with partner specific folders for sharing processed data during project

Every partner was enabled to upload their data (in a defined format, see 6.2) to these folders, which also comprises auxiliary data (explained in more detail in 3.6) and results from modelling (e.g., soundscape maps). Access authorization to all directories was also granted to WP5 - for maintaining the structure and providing partners with information – and to WP6 in order to enable their comparison of measured data with model results (see WP6 report). This FTP server was accessible by every partner via common FTP clients (e.g., WinSCP or FileZilla). Obvious obstacles like firewalls (especially when working in and with government organizations) could eventually be overcome in all cases.

To fill in the FTP-database as organised as possible a uniform data format had to be defined. This is a mandatory step to store the data in the database in a structured way and to be able to pass on the uniform data sets for further project work. The next section describes the development of this JOMOPANS data format.

6.2. Data Format

The data format used in JOMOPANS was adapted from the national noise registry of Germany that is hosted at the BSH. Acoustic data, mainly recorded during the construction of wind farms, gets archived in the so called MarinEARS information system. The format used in this information system is the binary HDF5 format (hierarchical data format). HDF is supported by many commercial and non-commercial software platforms and it has the advantage that it allows it to work with data that exceeds the PCs memory. Users can add/append/modify data quickly as HDF formats are faster to process than other binary formats. A lot of different information can be stored as a collection of appropriately sized HDF files, which makes it appropriate for extremely large and complex data collections.

In many parts of the ocean science community the NetCDF format has established itself as a standard data format. Anyway, NetCDF has some restrictions that led to a decision in favor of HDF5. The NetCDF format and the HDF5 format resemble each other closely and it is very straightforward to convert from one to the other but HDF5 gives larger files and unlimited array dimensions, which can be necessary for long-term recordings.
HDF is like a directory and file hierarchy in a file. The data model is based on ‘groups’ and ‘datasets’, where ‘groups’ can be thought of like directories and ‘datasets’ like files. For the JOMOPANS project, the existing HDF5 format, already used at BSH, was modified for the purposes of JOMOPANS and distributed via the FTP server (6.1). WP5 distributed a PDF manual, explaining the current version of the JOMOPANS HDF5 format, into the respective

partner's directories together with a Matlab script, that could be used to write data into this format. The used format was constantly improved and thus a matter of change.
Later during the project WP5 decided to not further improve/change the format in order to avoid confusion about the current file format. This was done to facilitate data submission and by this avoid slack in the project. However, the format was constantly further improved internally and provided the basis for the data formats used within the JONAS project (sister project of JOMOPANS; https://www.jonasproject.eu/) and for the ICES initiative on developing an international storage for underwater sound data.

Single JOMOPANS HDF5 files included data from one calendar month per station. Every submitted HDF5 file contained the recording of one hydrophone. Some stations (e.g., the FINO stations) were equipped with more hydrophones for redundancy. Perceptively there might also be deployments of recorders with a number of hydrophones attached for recordings in different bandwidths. The JONAS and ICES format both aim to integrate more than one hydrophone per file.
One month of continuous (1 sec mean-SPL) recordings of one hydrophone already amounts to file sizes of 700 to 800 MB. To keep files organized WP5 recommended to also adapt monthly files whereas at the moment there are no constraints to the file sizes for ICES submissions.

In the following (Table 8) the updated JOMOPANS data format will be presented, which is endorsed by WP5 to be the most comprehensive and elaborated format during the time of this report.
In this updated JOMOPANS format a number of groups are used, resulting in a more organized file structure. Further it is referring to CF conventions for standardizing and data submissions, which is highly beneficial for unambiguous datasets. A detailed description of the format can be found in Annex 1. The detailed description contains more information per dataset e.g., whether it is mandatory or not, the required data type, the required dimension and example values. In the description below, we constrain to only describe the datasets.

Updated JOMOPANS HDF5 data format file structure overview

- format version *specification of format version/facilitates reading algorithms*
- conventions *Specify the CF convention used as recommended*
- author *creator of the HDF5 file, responsible for evaluations*
- date_of_creation *ISO8601 formatted date of creation of this file*
- measuring_institution *institution, which acquired the data*
- point_of_contact *contact for all external queries in the future*
- rawdata_uuid *unique identification number, linking the data submission to the corresponding raw data*
- /dataset_ambient_noise *parent group/directory for all following datasets*
  - comments
  - dataset_version *indicates version of the submitted dataset (counting resubmissions)*
  - measurement_purpose *project or national monitoring*
  - name_measurement_position *name of measurement position*
  - /calibration
    - calibration_datetime *Seconds since 1970-01-01 00:00:00Z. Follow CF 1.7 section 4.4 conventions. Date and time when the system was calibrated*
    - calibration_factor *factor to convert raw WAV data from volts to dB re 1 µPa*
    - calibration_procedure *Describe method used to check the measuring chain, e.g. point calibration with pistonphone, functionality test with microphone and loudspeaker (frequency dependent) or other. Ideally it should reference a calibration procedure.*
    - reference_frequencies *frequencies in Hz*
    - reference_levels *Reference sound pressure levels in dB re 1 µPa*
  - /hydrophone
    - hydrophone_manufacturer
    - hydrophone_sensitivity *in dB re. 1 V/µPa*
    - hydrophone_serial_number
    - hydrophone_type
  - /measurement_data
    - frequency_count *number of frequencies*
    - frequency *center of frequency band [Hz]*
    - frequency_band_definition *Describe the frequency band. Along the last dimension, first value is the nominal center frequency, second is the lower frequency of the band and third value is the higher frequency of the band.*

- leq_averaging_time *avg. time in seconds*
- leq_count *number of leq values*
- leq_datetime *Seconds since 1970-01-01 00:00:00Z. Follow CF 1.7 section 4.4 conventions.*
- leq_spectro_temporal_values *leq measurements over time for all covered frequency bands [dB re 1 µPa]*
- percentile_count *number of percentiles*
- percentile *list of percentiles*
- leq_spectral_stats *[dB re 1µPa]/dimensions etc.*
- /duty_cycle
  - duration_on *Duration in seconds, the device is recording*
  - duration_off *Duration in seconds, the device is not recording*
  - start_datetime *Seconds since 1970-01-01 00:00:00Z. Follow CF 1.7 section 4.4 conventions. Date of the start of the duty cycle. This is useful when the processed data does not start at the same time as the duty cycle.*

➢ /measurement_setup
- measurement_setup *description of deployment; indicate here if your station is 'autonomous' or 'cable mounted', if you are using a bottom frame or a floating buoy, if your hydrophone is acoustically decoupled from the recording unit etc.*

➢ /measurement_location
- location_count
- location_time *Seconds since 1970-01-01 00:00:00Z. Follow CF 1.7 section 4.4 conventions.*
- longitude *Follow CF 1.7 section 4.2 and section 5 conventions*
- latitude *Follow CF 1.7 section 4.1 and section 5 conventions*
- height *in meters, height above ground. Follow CF 1.7 section 4.3 conventions*

➢ /recorder
- recorder_manufacturer
- recorder_serial_number
- recorder_type

Tab 8: HDF5 data format structure

Further differences between existing HDF5 formats (JONAS/ICES/JOMOPANS):

When comparing the different formats (Updated JOMOPANS/JONAS to ICES) the striking difference is the notation of the ICES format. While JOMOPANS and JONAS used underscore notations, ICES is relying on the UpperCamelCase notation. Both notations are commonly accepted among coding conventions and WP5 does not want to recommend one over the other. Rather we want to emphasize the need for a comprehensive set of aliases for names of datasets and groups. These aliases can allow for common naming deviations or deviations, induced by new format versions.

Also, ICES emphasized the use of standardized vocabulary for certain datasets like measuring institutions, CountryCode, StationCode, HydrophoneType etc. (see Annex 2). WP5 endorses this endeavour to harmonise submissions and recommends using these vocabularies. Another difference between the formats is the choice of datetime indices. JOMOPANS first approach to develop a new time index (yyyymmddHHMMSS) did not prevail. Instead, standardized datetime formats like posix (updated JOMOPANS/JONAS) or ISO 8601 were found to be more useful.

6.3. Long-term solution for data sharing and hosting

To acquire underwater acoustic data is not only expensive, but also often quite challenging to do (especially for remote sites). It is therefore indispensable to organize proper data storage and archives. Obviously, the WP5 FTP server was only posing a temporary solution for the life cycle of the JOMOPANS project. Still the acquired data are highly useful for the scientific community and so are other underwater acoustic datasets from other projects (e.g. BIAS or JONAS).
For further work and understanding of underwater soundscapes it is advantageous that collected data can be re-used in the future and can be shared among partners, scientific projects and the interested public.
Currently the HELCOM Expert Network on Underwater Noise (EN-Noise) in collaboration with the International Council for the Exploration of the Seas (ICES) are developing a database system for ambient noise. An action request by the Netherlands was brought on its way to invite OSPAR to join this initiative and allocate the ICES database as the common storage for ambient noise measurements.

OSPAR's contracting parties Germany (BSH), Denmark (Aarhus University) and Sweden (FOI) support the initiative of HELCOM EN-Noise. These parties also participated in the JOMOPANS project and contributed the JOMOPANS work for a general data format - HDF5 (see 5.2), that is currently being tested at ICES.
ICES also hosts the impulsive noise registry that is used by both OSPAR and HELCOM contracting parties for the registration of impulsive noise generating activities. Aggregating available impulsive and continuous noise seems reasonable to facilitate holistic and elaborated approaches to investigate the reported soundscapes and their anthropogenic influences.

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Annexes

Annex 1: Detailed updated JOMOPANS (also JONAS) HDF5 data format

Object name	Type of field	Mandatory	Data type	Dimension	Description	Example
/						
format_version	attribute	Y	string		Format specification version	e.g. "1.0"
Conventions	attribute	Y	string		Specify the CF convention used as recommended.	e.g. "CF-1.7"
author	attribute	Y	string		creator of the NetCDF file, responsible for evaluations	e.g. ' Author name; firstname.lastname@exampl.de'
date_of_creation	attribute	Y	integer		ISO8601 formated date of creation of this file	e.g '20190131' for the 31st of January 2019
measuring_institution	attribute	Y	string		institution, which acquired the data	e.g. 'BSH; measuring.institution@acoustics.de'
point_of_contact	attribute	Y	string		contact for all external queries in the future	{'BSH; department M23..., general.contact@bsh.de'}
rawdata_uuid	attribute	N	string		unique identification number, linking the data submission to the corresponding raw data	example: 'e9b82f55-38f2-48a5-bc76-2cb651dd285f'
/dataset_ambient_noise	group	Y			parent group/directory for all following datasets	
comments	attribute	N	string			
dataset_version	attribute	Y	string		indicates version of the submitted dataset (counting resubmissions)	example: '1.0'
measurement_purpose	attribute	N	string		project or national monitoring	e.g. 'MSFD Monitoring'
name_measurement_position	attribute	N	string		name of measurement position	e.g. German Position A
hydrophone_count	attribute	Y	string		number of hydrophones described in the file	
/calibration	group	Y				
calibration_datetime	variable	Y	integer	hydrophone_count	Seconds since 1970-01-01 00:00:00Z. Follow CF 1.7 section 4.4 conventions. Date and time when the system was calibrated.	
calibration_factor	variable	Y	float	hydrophone_count	factor to convert raw .wav data from Volts to dB re 1µPa	e.g. 1000
calibration_procedure	variable	Y	string	hydrophone_count	Describe method used to check the measuring chain. e.g. point calibration with pistonphone, functionality test with microphone and loudspeaker (frequency dependent), or other. Ideally it should reference a calibration procedure.	Description of your effort to calibrate your measuring chain.
reference_frequencies	variable	Y	float	hydrohphone_count x no. of frequencies	frequencies in Hz	frequency(ies)
reference_levels	variable	Y	float	hydrohphone_count x no. of frequencies	Reference sound pressure levels in dB re 1 µPa	level(s)
/hydrophone	group	Y				
hydrophone_manufacturer	variable	Y	string	hydrophone_count		e.g. 'B&K'
hydrophone_sensitivity	variable	Y	float	hydrophone_count	in dB re 1 µPa	e.g. '-160.1'
hydrophone_serial_number	variable	Y	string	hydrophone_count		e.g. 'SN45736'
hydrophone_type	variable	Y	string	hydrophone_count		e.g. '8106'
/measurement_data	group	Y				
frequency_count	dimension	Y			number of frequencies	
frequency	variable	Y	float	frequency_count	Band center frequency [Hz]	
frequency_band_definition	variable	Y	float	frequency_count x 3	Describe the frequency band. Along the last dimension, first value is the nominal center frequency, second if the lower frequency of the band and third value is the higher frequency of the band.	
leq_averaging_time	attribute	Y	float		avg. time in seconds	{'1.0'} or {'20.0'} etc.
leq_count	dimension	Y			number of leq values	
leq_datetime	variable	Y	integer	leq_count	Seconds since 1970-01-01 00:00:00Z. Follow CF 1.7 section 4.4 conventions.	% Example MATLAB® code: unix_time = posixtime(datetime('now')) function dn = unixdatetime_to_datenum(unix_time) dn = unix_time/86400 + 719529; end >> datestr(unixdatetime_to_datenum(1562151104)) ans = '03-Jul-2019 10:51:44'
leq_spectro_temporal_values	variable	Y	float	frequency_count x leq_count	leq measurements over time for all covered frequency bands [dB re 1µPa]	
percentile_count	dimension	Y			number of percentiles	
percentile	variable	Y	integer	percentile_count	list of percentiles	e.g. "5,10,25,50,75,90,95"
leq_spectral_stats	group			frequency_count x percentile_count	[dB re 1µPa]	
/duty_cycle	group	Y				
duration_on	attribute	Y	integer		Duration in seconds, the device is recording	e.g. 1800 for 30 minutes
duration_off	attribute	Y	integer		Duration in seconds, the device is not recording	e.g. 1800 for 30 minutes
start_datetime	attribute	Y	double		Seconds since 1970-01-01 00:00:00Z. Follow CF 1.7 section 4.4 conventions. Date of the start of the duty cycle. This is usefull when the processed data does not start at the same time as the duty cycle.	
/measurement_setup	group	Y				
measurement_setup	attribute	Y	string		description of deployment; indicate here if your station is 'autonomous' or 'cable mounted', if you are using a bottom frame or a floating buoy, if your hydrophone is acoustically decoupled from the recording unit etc.	e.g. {'autonomous'} or {'cable mounted'}
/measurement_location	group	Y				
location_count	dimension	Y				
location_time	variable	Y	double	hydrophone_count x location_count	Seconds since 1970-01-01 00:00:00Z. Follow CF 1.7 section 4.4 conventions.	
longitude	variable	Y	double	hydrophone_count x location_count	Follow CF 1.7 section 4.2 and section 5 conventions	
latitude	variable	Y	double	hydrophone_count x location_count	Follow CF 1.7 section 4.1 and section 5 conventions	
height	variable	Y	float	hydrophone_count x location_count	in meters, height above ground. Follow CF 1.7 section 4.3 conventions	e.g. '3.4'
/recorder	group	Y				
recorder_manufacturer	attribute	Y	string			e.g. 'WILDLIFE'
recorder_serial_number	attribute	Y	string			e.g. 'SN45736'
recorder_type	attribute	Y	string			e.g. 'SM2M'

Annex 2: ICES HDF5 data format

The ICES- data format presented below is taken from the report 'Continuous underwater noise reporting format' by the HELCOM Expert Network on Underwater Noise. The format is divided in three groups: File information, Metadata and Data.

2.1. File information group

Field	Status	Data type	Field definition	Reference
Email	Mandatory	String(50)	Creator of the HDF5 file/ who holds responsibility for data QA and creation of the submited hdf5 file.	
CreationDate	Mandatory	DateTime(21)	Date of file creation. UTC DateTime in ISO 8601 format: YYYY-MM-DDThh:mm[:ss] or YYYY-MM-DD hh:mm[:ss]	
StartDate	Mandatory	DateTime(21)	Measurement collection start date. UTC DateTime in ISO 8601 format: YYYY-MM-DDThh:mm[:ss] or YYYY-MM-DD hh:mm[:ss]	
EndDate	Mandatory	DateTime(21)	Measurement collection end date. UTC DateTime in ISO 8601 format: YYYY-MM-DDThh:mm[:ss] or YYYY-MM-DD hh:mm[:ss]	
Institution	Mandatory	String(6)	Institution which acquired the data.	https://vocab.ices.dk/?ref=1398
Contact	Mandatory	String(255)	Contact of all future external queries/who submits/holds responsibility for submission	
CountryCode	Mandatory	String(4)		https://vocab.ices.dk/?ref=337
StationCode	Mandatory	String(10)	The station code and its associated coordinates can be found in the ICES station dictionary	https://vocab.ices.dk/?ref=1399

2.2. Metadata group

Field	Status	Data type	Field description	Reference
HydrophoneType	Mandatory	String(255)	This field describes the manufacturer and the used hydrophone type/model e.g. 'Brüel&Kjaer 8106'. This field needs to be an array if there are multiple channels (one per channel).	https://vocab.ices.dk/?ref=1584
HydrophoneSerialNumber	Mandatory	String(50)	e.g. "SN#1234"This field needs to be an array if there are multiple channels (one per channel).	
RecorderType	Mandatory	String(50)	Recorder/data logger type e.g. "Soundtrap"	https://vocab.ices.dk/?ref=1585
RecorderSerialNumber	Mandatory	String(50)	Recorder serial number e.g. "SN#2345"	
MeasurementHeight	Mandatory	Float(10)	Height above the seafloor, in meters	
MeasurementPurpose	Mandatory	String(10)	Description of why the continuous underwater noise measurements reported were monitored	https://vocab.ices.dk/?ref=1586
MeasurementSetup	Conditional Mandatory	String(10)	Description of deployment. Mandatory in case the purpose is "HELCOM monitoring"	https://vocab.ices.dk/?ref=1587
RigDesign	Conditional Mandatory	String(10)	Description of deployment construction. Mandatory in case the purpose is "HELCOM monitoring"	https://vocab.ices.dk/?ref=1588
FrequencyCount	Mandatory	Int(2)	Number of frequency bands	
FrequencyIndex	Mandatory	Float(10)	Third octave band nominal center frequencies	
FrequencyUnit	Mandatory	String(10)		https://vocab.ices.dk/?ref=1592
ChannelCount	Mandatory	Int(2)	Number of channels used	
MeasurementTotalNo	Mandatory	Int(5)	Number of measurements. This field needs to be an array if there are multiple channels (one per channel).	
MeasurementUnit	Mandatory	String(10)	Unit in which the values are in e.g. dB re 1µPa	https://vocab.ices.dk/?ref=1589
AveragingTime	Mandatory	Int(5)	Averaging time in seconds	
ProcessingAlgorithm	Optional	String	Algorithm used to process the data e.g. computation method for third octave band (fft, filter bank ...)-analysis	https://vocab.ices.dk/?ref=1590
DataUUID	Mandatory	String(255)	Unique identification number, linking the data submission to the corresponding raw data. It should be used for resubmissions of the same data; matlab function available: uuid = char(java.util.UUID.randomUUID);	
DatasetVersion	Mandatory	String(255)	Indicates version of the submitted dataset. It should be changed upon resubmission	
CalibrationProcedure	Conditional Mandatory	String(255)	Method used to check the measuring chain. e.g. point calibration with pistonphone, functionality test with microphone and loudspeaker (frequency dependent), or other method used to check the measuring chain. e.g. point calibration with pistonphone, functionality test with microphone and loudspeaker (frequency dependent), or other. Mandatory in case the purpose is "HELCOM monitoring"	https://vocab.ices.dk/?ref=1591
CalibrationDateTime	Contional Mandatory	DateTime(21)	Date of when the system was last calibrated. Mandatory in case "CalibrationProcedure" is specified UTC DateTime in ISO 8601 format: YYYY-MM-DDThh:mm[:ss] or YYYY-MM-DD hh:mm[:ss]	
Comments	Optional	String(255)		

2.3. Data group

Field	Status	Data type	Field definition
DateTime	Mandatory	DateTime(21)	UTC DateTime in ISO 8601 format: YYYY-MM-DDThh:mm[:ss] or YYYY-MM-DD hh:mm[:ss].
LeqMeasurementsOfChannel 1 LeqMeasurementsOfChannel ... LeqMeasurementsOfChannel N	Mandatory	Float(1)	Equivalent continuous sound pressure level measurements over time for all covered frequency bands. One frequency per column. In case there are multiple channels, there should be an array of values for each channel. If there are 3 channels, there would be three arrays called LeqOfChannel1, LeqOfChannel2, LeqOfChannel3. In case of channel failure, report NAN values.

Annex 3: Structure of AIS file

Column	Description/Comment
MMSI	MMSI number
source	AIS = terrestrial-AIS ASS = satellite-AIS
day	DD/MM/YYYY
hour	HH:MM:SS
longitude	longitude
latitude	latitude
speed	speed over ground
course over ground	course over ground
true heading	true heading
IMO number	IMO number
name	ship name
AIS ship type	AIS ship type
ship drought	drought
ship length	AIS A+B dimensions
ship width	AIS C+D dimensions
flagcode.isoCode2	ship flag

Annex 4: *Summarized overview of sound sources at the different JOMOPANS stations*

	continuous sound sources				impulsive sound sources				other sources			
Station#	shipping lane	'no AIS' ships	CTVs	operational noise	seismic surveys	construction work	sonar	explosions	flow noise	mooring noise	platform noise	biological sound
01-SE-VIN	x	x							x			
02-DK-ANH		x	x	x	x		x		x	x		x
03-DK-HRF	x	x	x	x	x	x	x	x	x	x	x	x
04-DE-FN3			x								x	
05-DE-ES1					x					x		
06-DE-FN1	x		x	x		x	x		x		x	
07-NL-TEX	x					x			x	x		
08-BE-WST	x	x	x			x		x	x			x
09-UK-DOW	x								x			
10-SC-ARB		x			x				x	x		x
11-SC-HEL		x			x	x		x		x		x
12-SC-MOR												
13-NO-LOV												
14-NO-NTR												
15-SC-CNS												
16-DK-TN1	x	x	x	x	x		x		x	x		x
17-DK-TN4	x	x	x	x	x		x		x	x		x
18-DK-EDA		x	x	x	x	x	x	x	x	x	x	x

Additional explanations to table categories: shipping lane: located near a shipping route; no AIS ships: recreational and fishing vessels with no AIS are present; CTVs: maintenance vessels (Crew Transfer Vessels) for e.g. offshore wind farms are present; operational noise: from offshore wind farms or oil-rigs are present; seismic surveys: explorations (e.g. air-gun) are conducted; construction work: piling and other construction activities at sea; sonar: echolocation from ships are present; explosions: detonations of explosive ordnance; other sources: noise from deployment on site and any biological sound.