BIAS

Baltic Sea Information on the Acoustic Soundscape

Life

BIAS Implementation Plan

Monitoring and assessment guidance for continuous low frequency sound in the Baltic Sea

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Front cover: Mosaic of photos from the collective BIAS photo folder

BIAS - Baltic Sea Information on the Acoustic Soundscape

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BIAS Implementation Plan – Monitoring and assessment guidance for continuous low frequency sound in the Baltic Sea

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Contents

Summary

The BIAS Implementation Plan describes a regional programme for monitoring underwater ambient noise in the Baltic Sea. The programme combined measurements and modelling and was successfully implemented in 2012-2016 within the EU LIFE+ project *Baltic Sea Information on the Acoustic Soundscape* (BIAS) by Sweden, Denmark, Germany, Poland, Estonia and Finland.

In 2014, one year of sound measurements was performed at 36 locations with the purpose of establishing the baseline state of ambient noise levels in the Baltic Sea. The measurements, as well as the post-survey processing of the data, were subject to standardized field procedures, quality control and signal processing routines were all developed within BIAS.

BIAS dealt exclusively with monitoring continuous low frequency sound as referred to by the Marine Strategy Framework Directive indicator 11.2.1. Therefore, the study focused on the 1/3 octave frequency bands of 63 and 125 Hz, as specified by the indicator, and a third frequency band (2 kHz) which was added to strengthen the ecological relevance of the BIAS results.

The measured sound data were used to model the soundscape for the entire project area, providing the first results for the Baltic Sea on a monthly basis. Soundscape maps were produced for the three targeted frequency bands, and three depth intervals: the surface layer (0 to 15m deep), the deep layer (30m to the bottom), and the full water column of the Baltic Sea.

A large number of soundscape maps were produced constituting the base for future management of noise in the Baltic Sea. To facilitate an efficient handling of these, and future, results a GIS-based soundscape planning tool was created for visualizing the measured data and the modelled maps in a management friendly concept. BIAS identified two useful statistical measures for characterizing the soundscape which were incorporated into the soundscape planning tool. The year-by-year change of these measures directly relate to the current definition of the indicator.

Based on the experiences made in the project, the BIAS implementation plan also outlines a plausible strategy for the future monitoring and the elements needed for maintaining a joint implementation for underwater ambient noise in the Baltic Sea region.

1. Background

Sound is always present in the underwater environment, irrespectively of the status of the sea. Underwater sound is extremely diverse and can be categorized in many different ways and a commonly accepted division is in *natural* and *anthropogenic* sounds. The first term refers to all kinds of sound generated by either marine life, such as marine mammals, fish and crustaceans, or geophysical processes, such as rain, waves, ice, thunder, seismic activity and thermal noise. The second term encompasses sound produced by mankind, for example ships, piling, sonars, seismic airguns, underwater explosions and operational infrastructure noise [1][13].

1.1. The MSFD Descriptor 11 and TSG Noise recommendations

Within the context of the EU Marine Strategy Framework Directive (MSFD)[10], the emission of underwater noise falls under the introduction of energy into the sea [12]. Aiming towards achieving Good Environmental Status (GES) of EU marine waters by 2020, the MSFD descriptor 11 states that GES is achieved when the introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.

Anthropogenic sounds affect organisms in different ways depending on if the sound is of short duration (*impulsive*; such as from seismic surveys, explosions, or piling), or long lasting (*continuous*; such as dredging, shipping and energy installations). Hence, two criteria concerning underwater noise were given for descriptor 11: *11.1 Distribution in time and place of loud, low and mid frequency impulsive sounds*, and *11.2 Continuous low frequency sound*.

The initial interpretation and practical implementation of descriptor 11, was developed by the Technical Sub-Group on Underwater Noise and other forms of energy (TSG Noise), formed in 2010 by the Marine Directors. TSG Noise focused on clarifying the purpose, use, limitations, and methodology of the two noise indicators [31][35]. Thereafter the work of the subgroup was continued with the task of recommending how Member States might best make the indicators operational. This resulted in a set of recommendations [13], and monitoring guidance specifications [14], for each of the two indicators.

The work of TSG Noise (now the EU MSFD Technical group on underwater noise, TG-Noise), raised the overall awareness of underwater noise and of the MSFD descriptor among European environmental managing bodies. However, several practical aspects of its implementation remained, and still remains, to be solved both on national and on regional level within the EU.

1.2. The BIAS project

The EU LIFE+ project *Baltic Sea Information on the Acoustic Soundscape* (BIAS) started in September 2012 for supporting a regional implementation of underwater noise in the Baltic Sea. The project was shaped in line with the EU MSFD roadmap and the general recognition that a regional collaboration on descriptor 11 is advantageous or even necessary for regions such as the Baltic Sea.

Shipping activities dominate the soundscape of the Baltic Sea offshore environment. Ships generate sound in a broad frequency range, which overlaps with the hearing range of many marine species. Several groups of marine animals are known to use sound in their foraging, mating and orientation behaviours. The increase in ambient noise level and spectral composition due to the introduction of anthropogenic noise therefore exerts a significant pressure on the marine environment with plausible negative effects.

BIAS was directed exclusively towards monitoring of continuous low frequency sound (ambient noise). The project aimed at establishing a regional implementation plan for this sound category with regional standards, methodologies, and tools allowing for cross-border handling of acoustic data and the associated results. The regional approach of BIAS was important for several reasons. First, the MSFD specifies a series of actions, such as monitoring and modelling of the average noise level, to be carried out within the spatial division of marine regions or subregions, with the Baltic Sea constituting one of these (MSFD Article 6). The reasoning for such regions is that conditions, problems and needs vary between them and therefore require region-specific solutions. Second, the transboundary nature of the marine environment calls for cooperation both at EU and regional levels. Underwater noise itself has a transboundary nature, especially low frequency noise that can propagate across entire ocean basins. Furthermore, there are great economic benefits by regional monitoring and assessment of underwater noise compared to multiple national approaches.

The objectives of BIAS were formulated to create the foundation for an efficient joint management of underwater sound in the Baltic Sea by elucidating, and solving, the major challenges in the monitoring of ambient noise. During its lifetime, BIAS cooperated closely with TSG Noise. Thereby, the work conducted within the project was based on the TSG Noise recommendations and specifications, which were adjusted and further developed based on practical experience gained through their application in the Baltic Sea marine region. Although the project focused on the Baltic Sea marine region, its outcomes are relevant also for other marine regions of the EU.

Baltic Sea Information on the Acoustic Soundscape (BIAS)

In summary, BIAS was initiated to help the EU Member States establish a collaborative approach for implementing the Marine Strategy Framework Directive descriptor 11, and specifically continuous low frequency sound (ambient sound). The main aim with a coherent implementation was to increase the efficiency and reduce the national costs, to the benefit of the environmental status of the Baltic Sea. The project objectives were to:

- Perform the first implementation suite for continuous low-frequency sound in accordance with the MSFD in the marine region of the Baltic Sea, in order to raise awareness for underwater noise among authorities, managers, stakeholders and other relevant bodies on local, national and EU levels.
- Demonstrate national and regional advantages of a transnational approach for management of underwater noise in accordance with the MSFD.
- Establish the foundation for Baltic Sea standards and tools for recording, handling and processing data on continuous underwater noise.
- Undertake an initial assessment of underwater noise in the Baltic Sea in accordance with the MSFD.
- Bridge the gap between the technical and management spheres by introducing a user-friendly soundscape planning tool designed to aid the management of underwater noise.

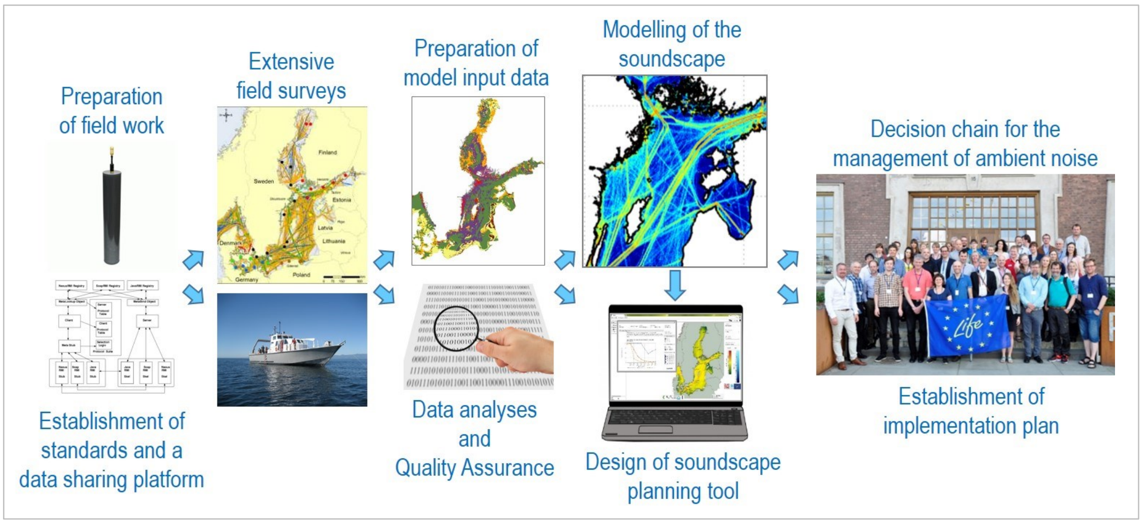


Figure 1. The project actions of the Baltic Sea Information on the Acoustic Soundscape (BIAS), 2012-2016.

The BIAS project was the first one in Europe to conduct a joint large-scale monitoring programme of underwater noise across national borders (Figure 1). With the purpose of establishing a baseline of the current state of ambient noise levels in the Baltic Sea, one year of sound measurements were performed by six nations in 2014. These measurements, as well as the post-survey processing of the acoustic data, were subject to standardized field procedures, quality control and signal processing routines, all developed within BIAS. The sound measurements were used to determine the noise levels at the monitored locations and also to ground truth the soundscape model developed in BIAS.

The modelling data were compiled to monthly and annual soundscape maps for the BIAS project area. These maps correspond to the initial assessment of the environmental status of underwater ambient noise and human activities in accordance with the latest methodological recommendations of the TSG Noise. In parallel, a GIS-based online tool was designed for handling, visualizing and interpreting both the measured and the modelled soundscape data. The collected set of outputs from BIAS provided unprecedented views of the Baltic Sea soundscape and its monthly variation as well as several practical means to aid the implementation of MSFD descriptor 11.

BIAS was formulated to pro-actively work for transferring the project results and experiences to the end-users in the Baltic Sea states. This dissemination came to be shaped by the overall development within the EU for the topic of underwater noise. BIAS started at the time when underwater noise seldom was part of national and regional agendas for the implementation of the MSFD and when TSG Noise had just released their first monitoring recommendations for descriptor 11 [35]. With BIAS succeeding, and activity around underwater noise increasing, the project communication and dissemination veered from taking place on national level to being channelled mainly through the forums of the Helsinki Commission (HELCOM). HELCOM is the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention). The increased involvement of HELCOM was a welcomed support and needed development in line with the purpose of BIAS; to propose an effective implementation plan for ambient noise in the Baltic Sea based on joint efforts.

A cooperation developed between BIAS and HELCOM, in particular with the working groups on Pressure and State & Conservation, as well as within the BalticBOOST project. Together with the Member States, the European Commission and other Regional Conventions, HELCOM is now regarded as the target audience for the outputs of the BIAS project.

1.3. The scope of the BIAS Implementation plan

The purpose of the BIAS Implementation Plan is to summarize the knowledge established and the experiences made in the BIAS project during all its stages, and to propose the means for a regional implementation of continuous low frequent underwater sound in accordance with the MSFD. Following the objectives of BIAS, the plan strives towards a joint monitoring programme for the Baltic Sea, a prerequisite for a regionally coherent and cost-efficient management with common goals and common responsibilities.

For understanding the future implementation of this indicator one needs to understand how BIAS performed the underwater sound measurements and the subsequent soundscape modelling, as well as how the results can be interpreted and utilized for current and future assessments. The aim is to provide answers to questions like the following:

- How can underwater sound measurements be performed in the Baltic Sea?
- How can modelling of the underwater soundscape be performed for the Baltic Sea?
- Which steps are needed in the data processing and quality assessment in order to ensure reliable and comparable measured and modelled data?
- How are data stored and shared?
- How do we utilize the data to assess the environmental status of underwater ambient noise?

This report is written on a non-expert level and intended to be comprehensive yet brief. Sections 2, 3 and 4 describe the BIAS undertakings while sections 5 and 6 summarize the proposed ways forward based on the experiences gained within the project. Detailed information and technical specifications of the BIAS proceedings are found in the project reports and deliverables: *BIAS Standards for Noise Measurements* [1], *BIAS Standards for Signal Processing* [2], the BIAS quality assurance report [3], and *BIAS modelling of soundscape* [4]. All these documents are available from the BIAS project webpage (www.bias-project.eu).

2. Monitoring the Baltic Sea ambient noise

Monitoring underwater sound, in general, can be a complex undertaking that requires detailed knowledge of natural as well as anthropogenic sound sources, the environmental factors influencing the sound propagation and, ultimately, the receiver being exposed to sound. For the context of the MSFD, a basic introduction of underwater sound characteristics and the perception of sound in aquatic life can be found in the BIAS Standards for Noise Measurements report [1].

Underwater sound may be directly observed through on-site measurements of noise levels by a hydrophone (sensor). These measurements yield data of the sound level and contain the noise generated by anthropogenic as well as natural sound sources such as ships, marine infrastructure, marine life, wave breaking, rainfall, or ice cracking. Depending on the frequency of the sound, as well as on the surrounding environment, the measurements by one hydrophone are representative for a varying range around the measurement point.

Sound may also be monitored with help of soundscape models, which can be used to predict the sound levels in a three-dimensional environment. The models are based on data for anthropogenic and natural sound inducing sources (e.g. ship traffic and/or winds/waves) and on data describing environmental features which influence the propagation of sound in the modelled region, such as bathymetry and sea bed sediments, water stratification and speed of sound.

In order to properly understand the origin of the sound as well as the spatial and temporal variations of the soundscape, both these monitoring approaches need to be combined. The targeted sound parameters and frequencies in the BIAS monitoring are described in Section 2.1. A brief description of the BIAS underwater sound measurements is given in section 2.2 while the modelling is summarized in section 2.3.

2.1. Targeted frequency ranges

The BIAS project dealt specifically with monitoring continuous low frequency sound as covered by the MSFD indicator 11.2.1 [12]:

> "*Trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re 1µPa RMS; average noise level in these octave bands over a year) measured by observation stations and/or with the use of models if appropriate.*"

The 1/3 octave frequency bands of 63 and 125 Hz were recommended by TSG Noise as proxies for noise generated by ships [31]. Therefore these frequency bands were the main focus of the data processing and modelling within BIAS, although the sound measurements themselves covered a wider frequency range (10 Hz – 10,000 Hz).

In the Baltic Sea, ambient noise generally peaks at higher frequency levels than the two specified frequencies of indicator 11.2.1. In order to strengthen the ecological relevance of the BIAS results, a third frequency band was added to those specified by the indicator; the 1/3 octave band for centre frequency of 2 kHz (2,000 Hz). This centre frequency was decided based on the constraints and needs to:

- complement the low frequency bands specified by indicator 11.2.1,
- contain frequency components of ship noise,
- be audible to a wide range of marine organisms,
- be measureable with the sampling settings already applied (e.g. sampling frequency).

Even though most of the energy in ship noise is between 10 and 1000 Hz (Figure 2), high-frequency components have been measured at 1/3 octave bands up to a centre frequency of 31.5 kHz, causing significant behavioural reactions of harbour porpoises (*Phocoena Phocoena*) [15]. The centre frequency of 2 kHz is at the lower end of the harbour porpoise hearing range [23]. Further, 2 kHz is well within the hearing range of the grey (*Halichoerus grypus*), harbour (*Phoca vitulina*) and ringed seals (*Pusa hispida*) [24][26][29], and in the upper hearing range of Atlantic herring (*Clupea harengus*)[16]. Thereby, continuous underwater noise containing energy in this frequency band is audible to all resident marine mammals in the Baltic Sea, as well as one fish species important both commercially and as an element of the marine food web. However, the appropriateness of monitoring the 2 kHz band, as well as the two indicator frequency bands, for the Baltic Sea is subject for further evaluation in the years to come.

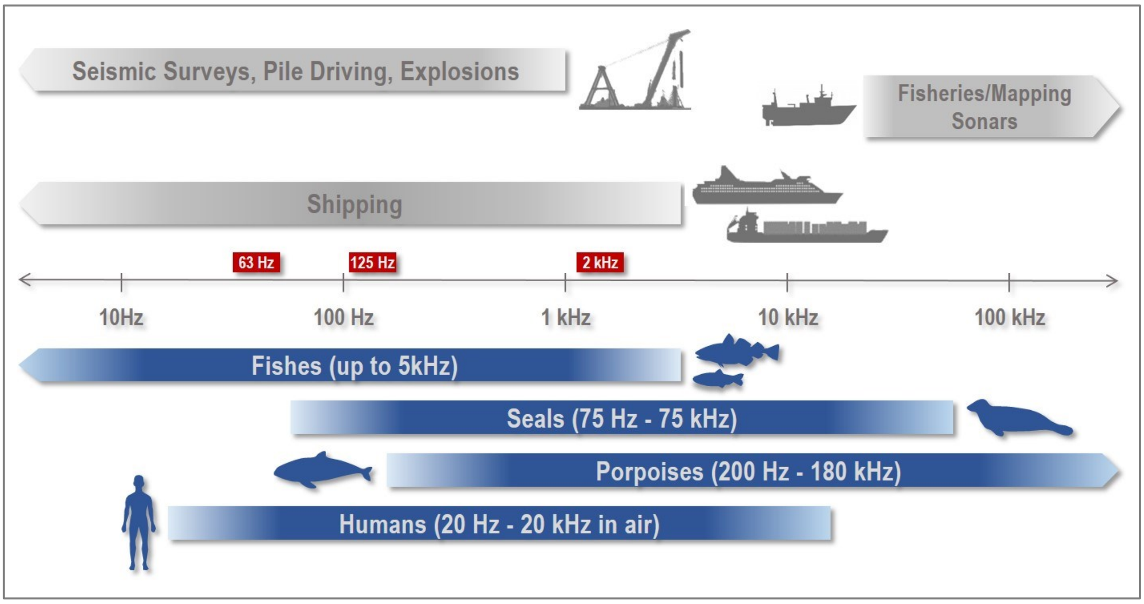


Figure 2. The auditory range of marine species present in the Baltic Sea, and noise frequencies produced by man-made underwater sound sources. Human hearing range is provided as a reference. After Scholik-Schlomer (2015), adjusted to Baltic Sea conditions. The red fields indicate the monitored frequency bands within BIAS.

2.2. Underwater sound measurements

There are a number of sound recording systems in use for measuring underwater sound. Stand-alone systems, also called loggers, are autonomous in the meaning that they are battery powered and record sound levels on a predefined schedule. These systems are easy to deploy and retrieve and can be deployed in remote locations. However, there is no way of knowing if data actually has been recorded until the unit is retrieved and opened. Land-based systems, on the other hand, have a long cable from the deployed hydrophone to a land-based station. In these systems the data can be analysed in real time and failures in the recording chain can be detected and dealt with immediately. This type of system has the advantage that the data can be stored on hard disks when storage capacity plays a role, but could be costly depending on the length of the cable.

In BIAS, only stand-alone systems were used since the aim was to have many monitoring stations and most of them were far from shore. In the following, by *sensors* we refer to autonomous underwater sound recorders to be deployed in shallow waters (continental shelf).

Guidelines for the BIAS measurement procedures, sensor requirements and handling of sensors as well as data, were compiled in the *BIAS Standards for Noise Measurements* [1]. In the same manner, standard procedures for the digital data (signal) processing were compiled in the *BIAS Standards for Signal Processing* [2]. Provided with these guidelines are also templates for checklists, manuals and protocols useful prior, during, and after the field work activities. The aim of these standards reports was to outline common definitions and procedures within BIAS, in order to guarantee compatible and quality assured data in the project. The standards were based on the experiences of the project beneficiaries but also on a number of publically available recommendations and instructions [25][27] [33][34][35]. After the initial use of the standards for the 2014 field surveys, they are now left as one of the main legacies of BIAS, suitable for underwater sound monitoring in the Baltic Sea independently of the size of the field survey effort.

2.2.1. Field survey setup

Selection of measurement locations

Focus for the BIAS monitoring network was to provide a baseline for indicator 11.2, and to provide sufficient data to thoroughly ground truth the soundscape model. With baseline a specified/known state of ambient noise is meant rather than the true reference state free from anthropogenic ambient noise. Hence, the monitoring stations were positioned to capture as large variation as possible in terms of environmental parameters and shipping density (Figure 3). Guidance was given on the deployment strategy by the TSG Noise. The BIAS project area was restricted to a minimum depth of 10 metres for accommodating the applied measuring and modelling approaches. Therefore, very shallow coastal areas were not monitored.

Each of the 36 monitoring locations were selected to fulfil one of two monitoring objectives: *Category A* monitoring aiming to establish information on the soundscape in an area and to ground truth the soundscape model, and *Category B* monitoring aiming to reduce the uncertainty on the ship source levels (ship signatures) to be used as input for the modelling.

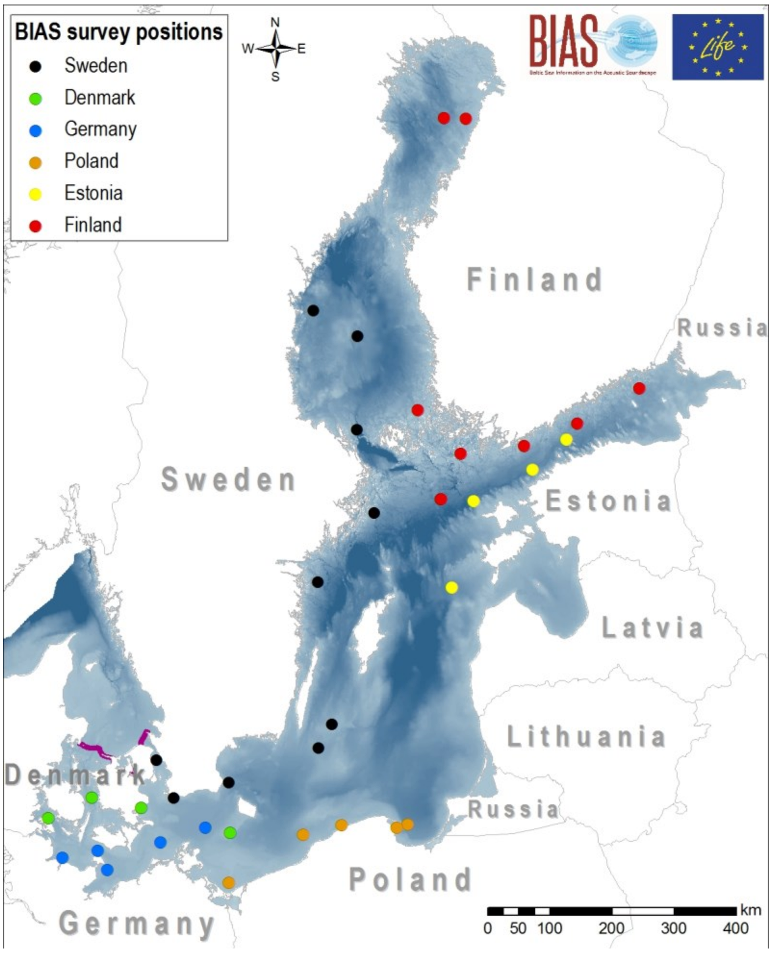


Figure 3. The monitoring strategy of the BIAS field survey in 2014 with a total of 36 measurement locations (one of the Finnish locations was occupied with two sensors at various depths, hence the 2014 dataset adds up to 37 data series on sound pressure level). The coloured dots show the nation-specific locations and the purple line between Denmark and Sweden indicates the boundary of the BIAS study area. Bathymetry provided by the Baltic Sea Hydrographic Commission [38].

This resulted in the stations being located at various distances from shipping lanes. Additional considerations for choosing a position were shipping density, leisure boat activity, water depth, and bottom substrate since these factors influence the sound recorded by the hydrophone system. The rig (anchoring system) locations were also adjusted to general military or shipping lane regulations and avoided areas subject to trawling activities, strong currents, or extreme ship traffic.

Rig design, Sensor specifications and Data handling

Two types of standard rigs were used within BIAS, for two different brands of autonomous loggers. In addition, a trawl safe version of the rig (anchoring system) was developed for use in areas with frequent trawling activities. A rig consists of a logger, a sub-surface buoy, an acoustic releaser and a ballast weight (Figure 4). The design of the BIAS rigs was developed and tested during a dedicated workshop to ensure consistency among all stations and nations in terms of secured data quality as wells as handling and recovery of sensors and rigs. The details concerning the required specifications of sensors and associated hardware are given in the *BIAS Standards for Noise Measurements* [1].

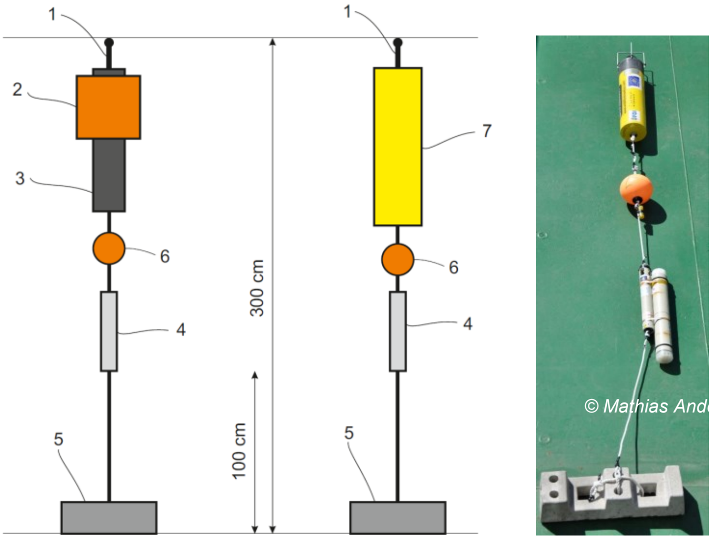


Figure 4. Left: Sketches of the BIAS standard rig for the two utilized loggers: 1. Hydrophone, 2. Extra buoyancy, 3. DSG Ocean logger, 4. Acoustic releaser, 5. Ballast weight (min 20 kg wet weight), 6. Buoy, 7. SM2M logger. Right: photo of a rig prepared for deployment. The design can be changed, in principle, but the hydrophone should always be placed at the top position.

The standards also give instructions for all phases of the field work, spanning from the preparatory work until the final retrieval of the systems: essential function tests and calibration of the instrument chain, sensor memory programming of sampling mission, routines for positioning and synchronization of time, safety instructions and procedures for the handling of rigs and measurement data. Templates of logbooks, deployment protocols and suggestions for ID marking for backward traceability are also included.

Sampling strategy

Due to memory capacity and battery power autonomous loggers have some constrains in terms of recording duration. For long-term noise monitoring the aim is to leave the loggers as long as possible at sea before data will be retrieved, to minimise the survey costs. The time a logger can monitor at sea is limited either by the storage capacity of inherit memory for the sound data or by the battery power being diminished after a certain period of time. For BIAS, a three months service period for the measuring rigs was envisaged, and a noise monitoring of sound between 10 Hz and 10 kHz. Due to the technical constrains of the loggers used, continuous noise monitoring was in most cases not possible. Therefore, a duty cycled sampling strategy was aimed for, meaning that repetitively only a certain percentage of a time period was monitored. Data analysis of recorded data from the central Baltic Sea showed that a minimum of 15 minutes of data per hour was required to obtain a stable average estimate. The recommendation of BIAS was therefore to record continuously if possible, or at a minimum 25% of the time (that is, 15 min each hour). To obtain the envisaged frequency range, the sampling frequency was set to 25 and 32 kHz, respectively, depending on logger model.

2.2.2. Signal processing

The main purposes of the signal processing in BIAS were to extract relevant estimates from the raw data measured in the field, to control the quality and compatibility of the results, and to ensure that uniform conventions were applied for file content and file format. Long-term sound recordings result in large data sets which need to be stored, processed and quality secured. The handling of these data sets can be time consuming and, therefore, automated processes and data reduction are necessary. But processing of data is not uniquely defined and there are a number of optional methods that can be employed influencing the statistical results. The most optimal method to use it determined by the quality required, which sound parameters are relevant, and which audience to target with the results.

In the case of the MSFD indicator 11.2.1 the targeted quantities are the annual averages of sound pressure level (SPL; in dB re 1µPa) of the 1/3-octave bands 63 (56-71 Hz) and 125 Hz (112-141 Hz), respectively (section 2.1). In BIAS, the adopted signal processing procedures, additionally included the calculation of monthly statistics (Betke et al., 2015, cf. section 2.3.1), as well as all the corresponding statistics also for the third frequency band 2 kHz (1,780-2,240 Hz; section 2.1). Since the BIAS measurements covered a much larger frequency range, broadband averages for the 10-10,000 Hz interval were also established, but not used in the subsequent modelling (section 2.3).

Quality assessment for minimizing random and systematic uncertainties was implemented throughout the processing steps by testing the signal processing software, controlling the computer systems and performing inter-organization comparisons (ring tests) of the signal processing methodologies (section 2.4). The processed data were subsequently delivered to the data sharing platform (see section 3.1). These data are hereafter referred to as measured data.

2.3. Modelling of the underwater soundscape

Acoustic modelling systems allow to numerically reconstruct the underwater soundscape with consideration of the given environmental circumstances and human activities [17][18]. With these techniques the sound is estimated as a function of time, depth, latitude and longitude according to the prevailing conditions. Hence, modelling enhances local measurements to a full basin-scale description and aids our understanding of the geographical variation of underwater sound. Extending the view to full basin-scale also has the advantage that monitored features and changes of the soundscape may be proven representative for a larger region than possible to recognise from individual measurement locations [19].

The production of a noise map relies on a number of input data sets, as well as several steps for processing and analysing these input data, developing the model calibration algorithms, and performing the physical modelling of noise propagation. The modelling approach applied in BIAS focused on the soundscape induced by shipping activities. Hence, the measured noise data were combined with environmental data and ship traffic data in order to generate soundscape maps for the full Baltic Sea area. The soundscapes produced combine two major components of the underwater noise chorus: the anthropogenic component introduced in the marine environment by shipping, and the natural component due to wave activity on the ocean surface according to local meteorological conditions.

The different constituents and actions involved in the modelling approach are shown in Figure 5 and summarized in the below sections. A detailed description of the modelling methodology is given in the BIAS modelling report [4].

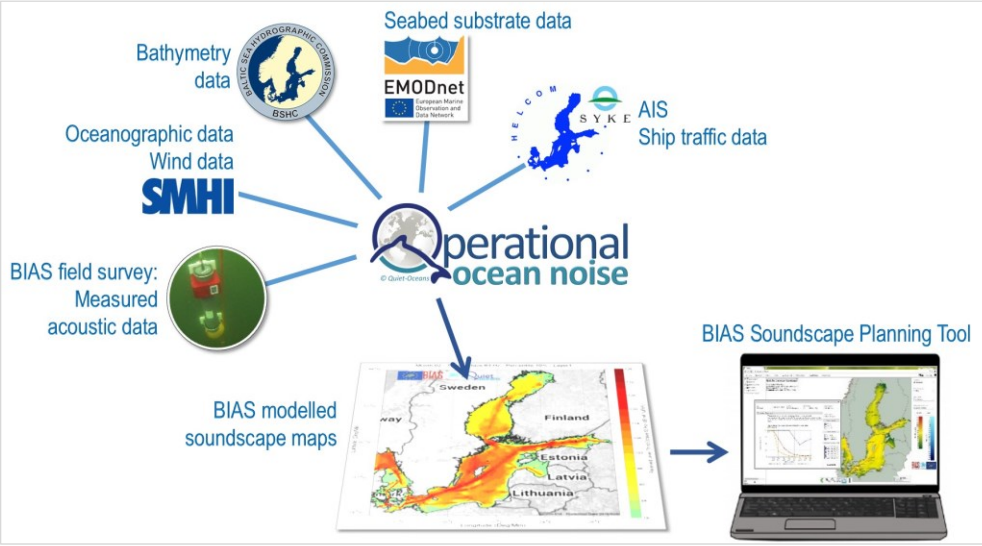


Figure 5. Schematic view of the data constituents and activities involved in the BIAS modelling approach.

2.3.1. Methodology

Data from the 36 measurement locations in the BIAS field survey, were utilized in the soundscape modelling in several ways. The data were brought into the ocean noise prediction system Quonops© [18], to ground-truth the noise maps according to an innovative protocol [19]. The measured data were also utilized in the model calibration procedure, which is based on the statistical content of both the measured data and the three-dimensional modelled data, inspired by techniques used in weather forecasting systems. Moreover, in order to describe the natural component of the soundscape the measured data also served to feed a regional model for estimating the noise caused by wind-generated surface waves. These results were incorporated into the making of the final noise maps [4].

In order to describe the anthropogenic component of the soundscape, the modelling protocol makes use of spatiotemporal data of the shipping activities provided by the Automated Identification System (AIS) and the Vessel Movement System (VMS) as well as oceanographic and geological parameters which significantly influence the propagation of underwater sound. The AIS ship traffic data were provided for the entire Baltic Sea by HELCOM through the Finnish BIAS beneficiary at SYKE. Ship data from VMS were obtained nationally through all BIAS beneficiaries and collaborators [37].

The data describing the environmental conditions in the soundscape model were taken from gridded products in order to maintain a uniform spatial and temporal coverage in the modelled region. The bottom topography was obtained from the Baltic Sea Bathymetry Database (BSBD), as released in autumn 2013 by the Baltic Sea Hydrographic Commission [38]. Acoustic bottom properties were compiled with the help of the seabed surface sediments as provided by the substrate map from the EMODnet-Geology project [39]. Hydrographic data (temperature and salinity) were obtained from the HIROMB BS01 model and significant wave height data from the SWAN model, both operated by the Swedish Meteorological and Hydrological Institute (SMHI) [40][41]. Wind data were obtained from the meteorological model MESAN operated by SMHI [42]. Several of these input data sets were also used to plan the measurement locations and prepare the field survey equipment, and furthermore serve as ”background layers” in the BIAS soundscape planning tool (cf. section 3.2).

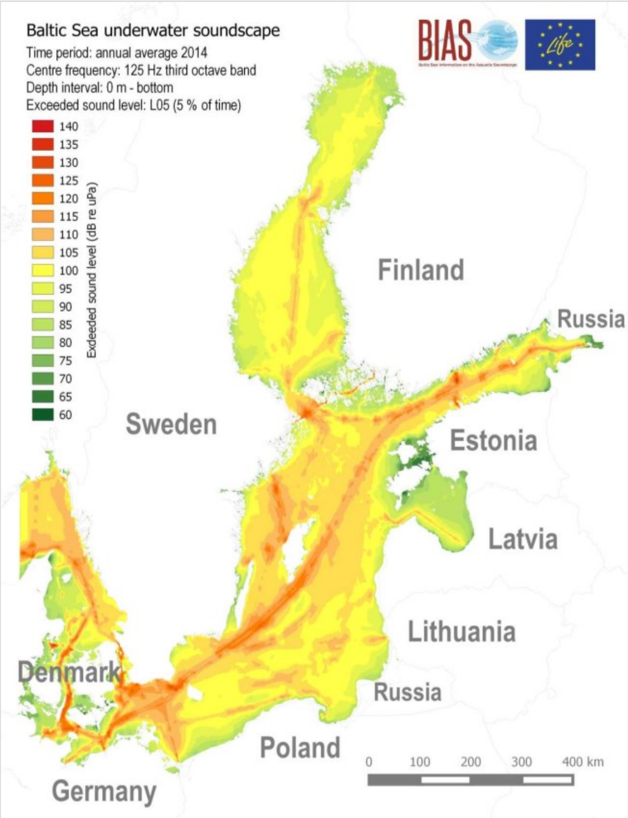
2.3.2. The soundscape model output

In the BIAS modelling approach soundscape maps were produced at a monthly time scale throughout 2014 for the 63 Hz, 125 Hz and 2 kHz third octave bands. The maps present the modelled sound pressure level (SPL) in terms of percentage exceedance levels. The *n*-percent exceeded level (*Ln*) is defined as the sound pressure level exceeded *n* percent of the time interval considered. Therefore, the soundscape maps describe not only the noise levels as such but also the proportion of time subjected to the noise levels. This is a key aspect when it comes to interpreting and using the modelled soundscape data for the regional management of underwater noise: in addition to the noise level, also the duration of the noise is important to consider. The BIAS soundscape maps are given for the 5, 10, 25, 50, 75, 90, and 95 % exceedance levels, see examples Figure 6. The 5-10 % exceedance levels, show the “occasional soundscape” usually reflected by the loudest (maximum) noise levels. Accordingly, the 90-95 % exceedance levels reflect the “regular soundscape” (the most observed soundscape), normally associated with the lowest (minimum) noise levels. *L50* is the median “half-of-the-time” soundscape.

The propagation of sound is affected by the hydrographic properties of the water and the use of the water column can be different for different species and their activities. Therefore, the modelling was performed for three different depth layers to facilitate investigations of various species and habitats:

- Surface layer: from the surface to 15 metres depth, a part of the water column utilized by many marine mammals as well as some pelagic fish species.
- Bottom layer: from 30 m depth to the bottom.
- Full water column (surface to bottom).

A total of 819 soundscape maps were produced for the twelve months of 2014 and one annual average, serving as the baseline for future assessments of the Baltic Sea underwater ambient noise. All maps are delivered to the BIAS data sharing platform and to the soundscape planning tool (see section 3).



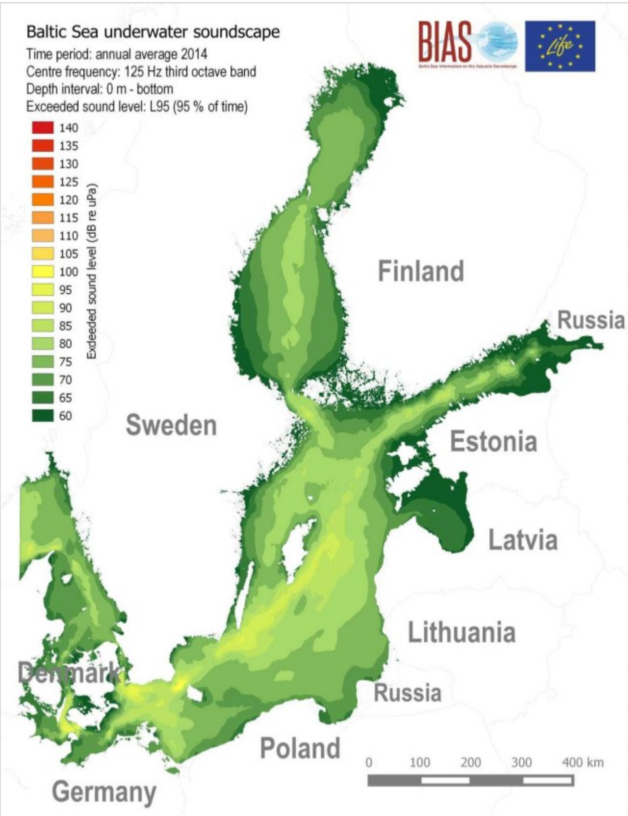


Figure 6. The modelled annual average soundscape for 2014, for the 125 Hz third octave band and over the full depth. (Top figure) Noise levels occurring occasionally (5 % of the year; L05), and (bottom figure) noise levels occurring regularly (95 % of the year; L95).

2.4. Quality assurance

In general, quality assurance refers to the systematic activities applied in a quality system to fulfil the requirements on quality and transparency in all actions and outputs. In BIAS, such activities implied establishing standards for systematic measurements and data analyses, feedback loops for error prevention, and inspection routines to control and harmonize project procedures among different performers (Figure 7). The internal audit reports for the quality assurance actions, and a description of the inter-organization comparisons of the data processing methods (ring-tests) are given in the BIAS quality assurance report [3].

A crucial aspect of maintaining quality is that established standards and protocols are indeed used, in all stages of the monitoring process. If these products are inadequate or too complicated there is an imminent risk that the quality assessment work will fail. With BIAS involving many complex activities, and many of these being pioneering work, the number of instructions (standards and guidelines) were rather high. To assure quality and follow up the procedures therefore took considerable time and effort, a point which needs to be noted for future efforts. In spite of some minor problems and associated adjustments, the end results were satisfying and the quality assurance work in the project was also acknowledged by end-users and parallel projects. The issues faced in the project were described in “failure reports” which can be of great help for the future management of underwater noise. These reports were collected in the data sharing platform (section 3.1) as one of the project legacies.

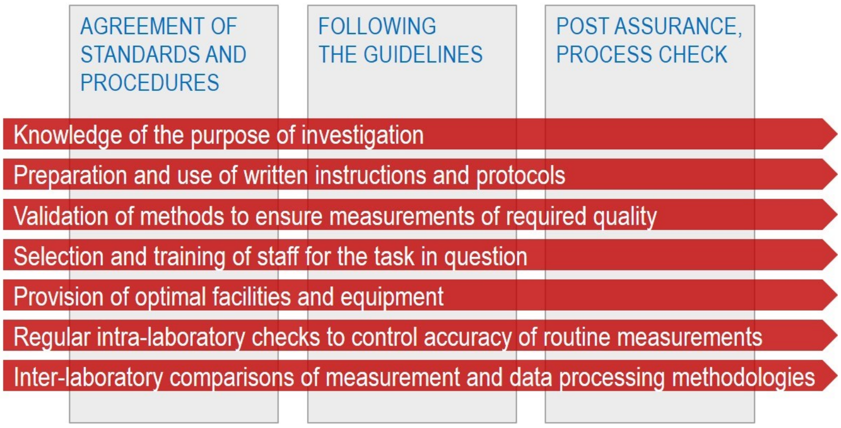


Figure 7. The principles for the BIAS Quality Assurance applied on hydrophone requirements, anchorage arrangement, measuring locations, data logging/analyses/storage, as well as on the soundscape modelling in the three consecutive phases of the quality work (agreement of standards and procedures, guidelines, and follow-up of the processes).

3. Regional handling of the monitoring results

For being able to assess underwater noise in accordance with the MSFD long-term and accessible solutions for the storage of monitoring data and associated results are needed. It is also crucial to establish common routines for sharing and evaluating these data and, not the least, for continuously updating the data storages with future monitoring results.

In terms of data storage, BIAS laid the foundation of a data sharing platform, holding data from the field survey as well as the input and output data for the soundscape modelling (section 3.1). Moreover, a GIS-based soundscape planning tool was designed to handle and visualize both measured and modelled soundscape data, and for providing quantitative results aiding the management of ambient noise (section 3.2). The member states now need to decide who can take the lead for hosting the database, and who can secure the operation and development of the soundscape planning tool. These future aspects are further discussed in section 5.3.

3.1. Data storage and data sharing

Underwater sound measurements generate large amounts of data. A sensor that is continuously recording with a sample rate of 20 kHz will generate about 4 TB of raw data per year. A monitoring network with several sensors will generate a substantial amount of data to be stored (the measurement programme in BIAS produced about 80 TB of raw data), putting special requirements on the data storage capacity. On the modelling side, soundscape maps produced at a monthly time scale for a series of frequencies, exceedance levels, and depth ranges also add up to a considerable amount of data.

In most countries of the Baltic Sea region, raw acoustic data as well as processed data (up to 20-second averages) are classified by national defence and cannot be shared publicly. In BIAS, the data were therefore converted into 20-second averages for being able to make them publically available. For this reason two technical solutions were utilized in the project; one national data storage device and one international data sharing platform common for all project partners [5]. The national data storage device was intended for internal use by the data-owner to store raw data. The data sharing platform served as the internet-based node for sharing and exchanging data, particularly within the signal processing and soundscape modelling activities. The data sharing platform should contain everything needed for a repeated analysis of the BIAS 2014 results.

3.2. The BIAS soundscape planning tool

One of the main legacies of BIAS is a GIS-based soundscape planning tool for continuous underwater noise in the Baltic Sea [6]. The tool was developed for managers with the main focus to facilitate their evaluation of underwater ambient noise. Specific needs and requirements of the end-users were incorporated into the tool design through surveys among the targeted national authorities within MSFD management and HELCOM. The tool was also tested before finalization in early 2016 by the Swedish Agency for Marine and Water Management (SwAM).

The soundscape planning tool is aimed to:

- Simplify the management of continuous underwater sound in the Baltic Sea Region.
- Serve as a tool for planning, testing and evaluation - a tool for making decisions.
- Collect and present information from monitoring efforts (BIAS and future ones), including both measured and modelled data.
- Extract the acoustic data in user-defined areas of specific interest.
- Filter between a large number of soundscape maps by selecting particular time periods, frequencies, depths, exceedance levels, etc.
- Produce maps, graphs, and tables based on the applied filters.

The tool provides some different ways of evaluating the soundscape. For a user-specified time period, centre frequency, and depth interval, the following results on sound pressure level *(SPL)* may be obtained:

Temporal variation of measured noise level: the SPL exceeded a certain amount of time at a measurement location.

Spatial coverage of mapped noise levels: The proportion of an interest area in which the modelled SPL values are exceeded a certain amount of time (Section 4.1.1).

Temporal variation of the mapped coverage above a noise threshold: The proportion of the interest area for which the modelled SPL values surpass a user-defined noise threshold (Section 4.1.2).

The soundscape tool brings together the measured and modelled soundscape data and provides a number of functionalities to evaluate the spatial and temporal sound characteristics within a user-defined geographical region. The results for sound can also be explored in relation to supplementary GIS data of species distributions or abundance, information on protected areas or other environmental layers. Currently, the tool holds soundscape data for the BIAS field programme year 2014, but is prepared for importing measurement data and modelled soundscape maps from future monitoring efforts.

The main panel of the tool (the map view) is an interface visualising different types of spatial data (Figure 8). Here, one can explore the modelled soundscape maps and overlay supplementary GIS data such as maps of species distributions or species densities, polygons for protected areas or detailed environmental layers. Next to the measured and modelled soundscape data from BIAS the tool contains information on seabed substrate, bathymetry (water depth), and ship traffic density. It is possible to upload additional GIS layers (polygon files), which may be used for visual comparisons or for further analysis displayed in the Graph Panel.

In the second part of the tool (the graph panel), three diagrams can be used to visualize some temporal and spatial characteristics of the measured or modelled data (cf. Figure 9). The results can be restricted to one or several user-specified areas of interest and filtered to the specific time periods, centre frequencies, depth layers and sound exceedance levels applied in BIAS; see section 2.3.2.

The graphs provide quantitative values related to the management of underwater noise, as a means to express the underwater sound levels in terms associated to environmental status (section 4.1). In practice, the tool is able to deliver *ad hoc* plots accustomed by the end-user for their own particular needs. For example, answers may be provided in terms of sound levels at a specific measurement position, the most frequent sound levels distributed within a Natura 2000 site in a particular month, or how large extent of an essential spawning area for cod that is subject to sound levels comparable to cod communication levels.

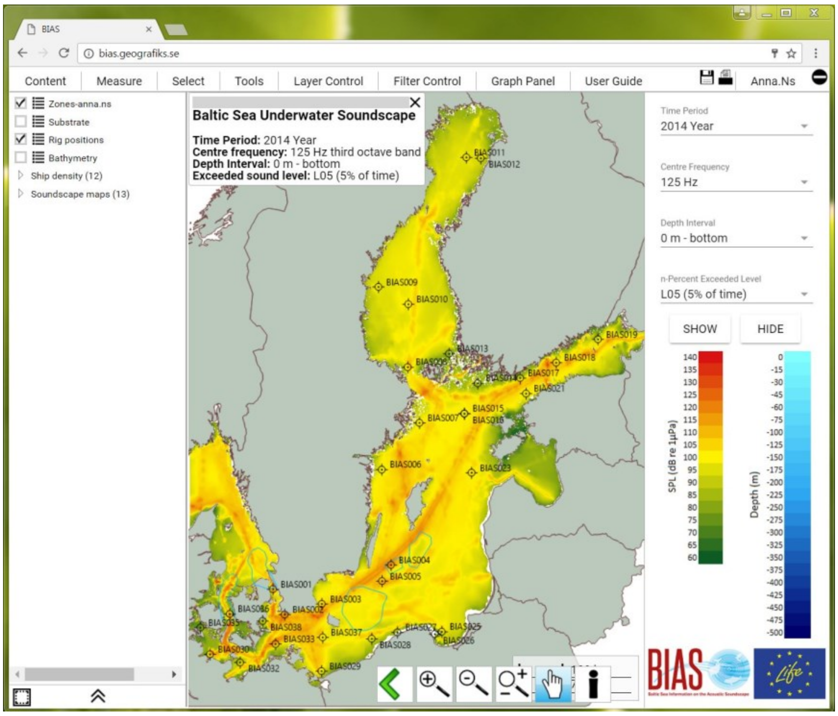


Figure 8. The map view of the BIAS soundscape tool. This example shows the annual average (2014) of the 5% exceeded sound level for 125 Hz centre frequency in the full water column. Black circles indicate the BIAS survey positions and polygons (blue solid line) outline some arbitrary areas for which further results may be extracted in the Graph Panel. The polygon around the BIAS004 survey location at Norra Midsjöbanken outlines a Natura 2000 site used for the examples in Figure 10 and Figure 11.

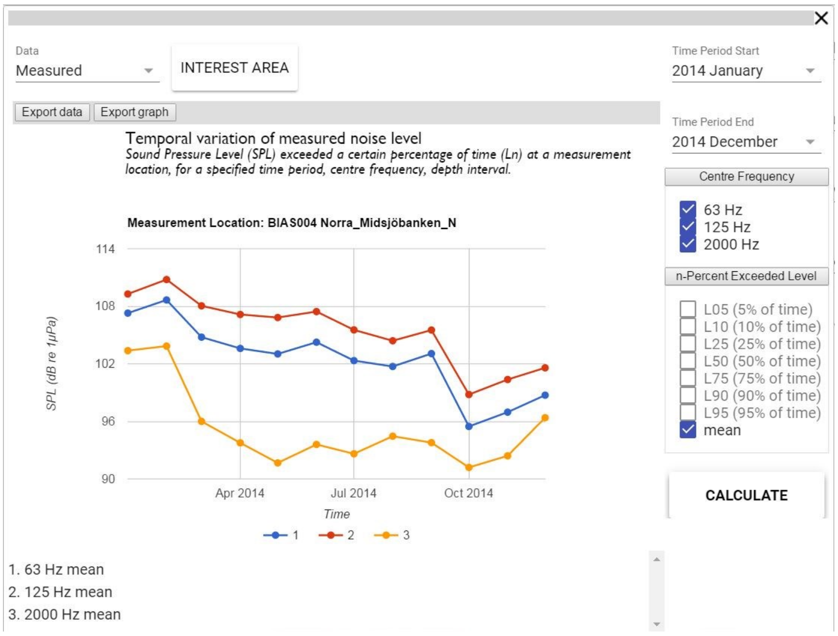


Figure 9. One of the diagram types in the graph view showing time series of measured Sound Pressure Level (SPL) for a user-specified time period, centre frequencies and noise levels. This example shows the average noise levels from January to December 2014 at the BIAS004 survey location at Norra Midsjöbanken.

4. Assessing the Baltic Sea underwater soundscape

The MSFD sets the overall framework for the required assessments of the environmental status of our seas. However, the indicators of Descriptor 11 are neither related to impact based definitions of GES, nor may be sufficient for ecologically relevant GES assessments. Indicator 11.2.1, and thereby GES for underwater ambient noise, is currently expressed in terms of the *trend* of acoustic sound pressure level within the third octave bands centred at 63 and 125 Hz, respectively (section 2.1). Hence, the status for ambient noise is currently monitored and assessed as a *change* in noise level (a change in the pressure exerted on the environment), without a clear relation to the actual impact on marine life.

Until sufficient knowledge on the impact by noise is retrieved, a harmonized approach is needed to analyse the pressure-based monitoring results which relates to GES in the Baltic Sea region. BIAS identified two useful statistical measures for characterizing the soundscape (section 4.1). These were incorporated into the soundscape planning tool and are possible to extract for any user-defined area within the BIAS project region (section 3.2). The year-by-year change of these measures directly relate to the current definition of indicator 11.2.1 (section 2.1).

4.1. Statistical characterisation of the soundscape

In large areas of the Baltic Sea the distribution of species is not well known. The possibility to assess and, in extension, to possibly regulate the noise based on guidelines for a specific species is therefore very limited. Nevertheless, ecologically valuable areas could be assessed based on the precautionary principle for polluted areas, regardless of the occurrence of specific sound sensitive species [10]. Then, the spatial and temporal soundscape characteristics within such areas can help formulate guidance levels of how much noise, when, and for how long, can be tolerated without putting anything at risk.

4.1.1. Spatially Exceeded Area

The Spatially Exceeded Area (SEA) describes the spatial distribution of specific sound levels (exceedance levels) within an arbitrary area of interest. SEA analyses the proportion (%) of an interest area for which a certain sound pressure level is exceeded a certain amount of time, for a specific frequency, depth interval, and time period. This aspect may be used to evaluate the environmental pressure in areas where there is a general need to regulate the noise levels, such as Nature 2000 sites. It may also be sufficient to use in areas where no sound sensitive species are known to be present (cf. 4.1.2).

4.1.2. Temporally Exceeded Areas

As a means to assess areas hosting particularly sound sensitive species a second statistical characterisation of the soundscape was identified; the Temporally Exceeded Area (TEA). This gives the temporal distribution of specific sound levels (exceedance levels) within an interest area with respect to a user defined noise threshold (SPL threshold) for a certain time period, frequency and depth interval. This statistical measure can be used when there is a known noise level which reflects when a species is affected by the noise, e.g. by masking of biologically important signals. Sound pressure levels louder than the threshold would then potentially decrease the communication range and affect the fitness of the species.

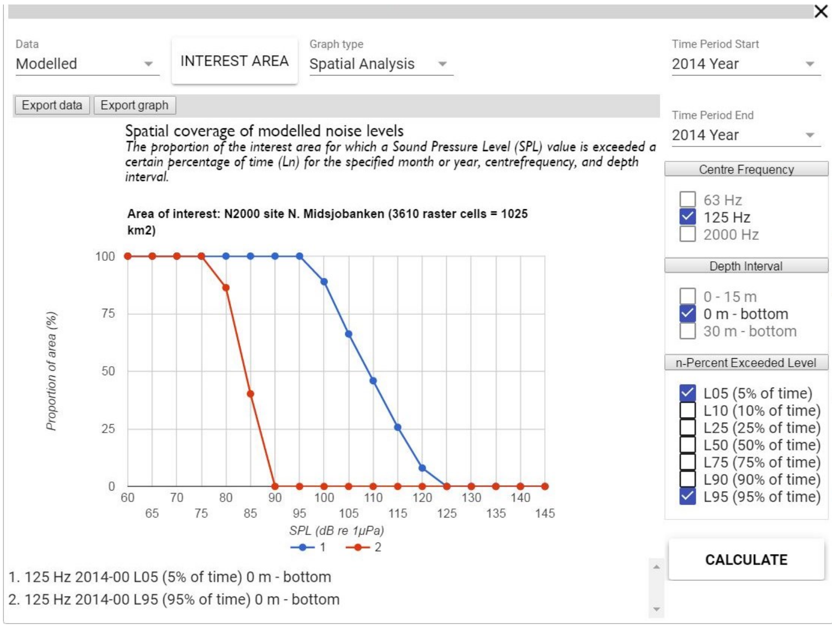


Figure 10. An example on SEA from the planning tool for annual average values (2014) in the Natura 2000 site close to the BIAS004 survey location (see Figure 8). The proportion of area is shown for the 5% (blue) and 95% (red) exceeded levels. L05 is strongly influenced by nearby ships while the L95 shows the ambient sound composed of natural ambient noise and noise from distant shipping. The graphs shows that nearby ships, when present, considerably raise the sound levels in the area.

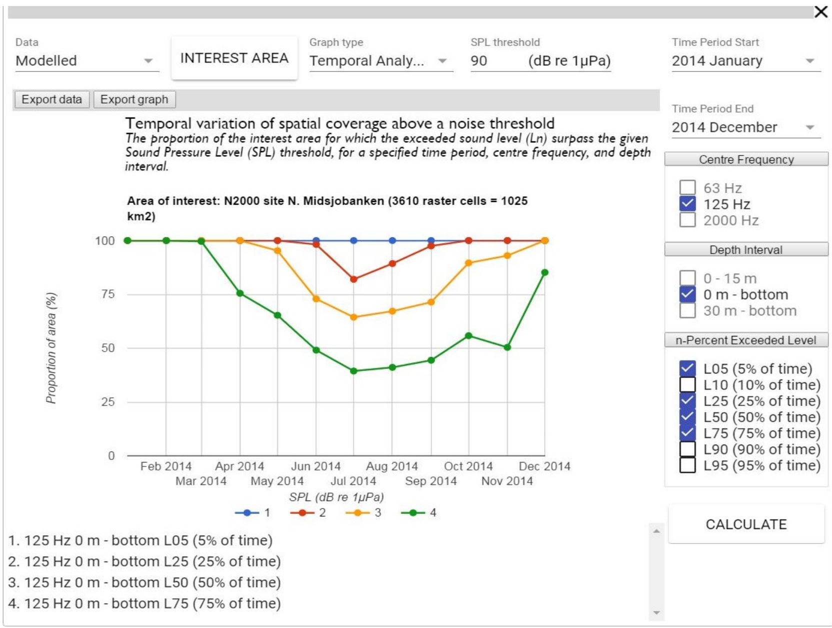


Figure 11. An example from the planning tool on TEA, for all months of 2014 in the Natura 2000 site close to the BIAS004 survey location (see Figure 8). A clear decrease of the occupied proportion of this interest area is seen for the 25-75% exceeded noise levels (L25-L75) during the summer period. This decrease in coverage is due to both less natural ambient noise and a downward refracting velocity profile during summer. Note that there is, in general, still quite a knowledge gap with regard to species specific noise thresholds. The threshold used in an analysis by TEA, can therefore be chosen after best available knowledge or by applying precautionary principles (guidance levels).

5. Monitoring strategy for ambient noise in the Baltic Sea

One objective of the BIAS project was to outline a future joint monitoring programme for continuous low frequency sound, through regionally collaborative efforts, with spatially well distributed measurements and a cost effective monitoring. It is essential for the handling of Good Environmental Status that a monitoring programme remains in operation.

Based on the outcomes of BIAS, and with input from parallel processes within the EU, the monitoring activities for ambient noise in the Baltic Sea are suggested to follow a strategy alternating minor and major monitoring efforts throughout the reporting cycles of the MSFD, see Figure 12. Efficient monitoring makes use of a combination of measurements and modelling. Therefore, continuous (annual) sound measurements at a few locations in the Baltic Sea and recurrent modelling at full Baltic Sea scale (section 5.1) makes the fundament of the data record needed to evaluate indicator 11.2.1. Periodic, extensive monitoring efforts, of the order of magnitude as that conducted in BIAS, could be repeated when a need for extended measurements is inferred by the annual observations, the modelling results, or specific needs associated with the MSFD reporting cycle (section 5.2). This is the BIAS viewpoint brought forward in various HELCOM forums in 2015 and 2016.

5.1. Annual monitoring effort

As in BIAS, sensors should be deployed so that the observational records are maintained for all Baltic Sea sub-basins. Based on the results of the BIAS project, each participating nation selected at least one location for continuing the hydrophone measurements in the years to come, see Figure 13. Finland, Estonia, Poland and Sweden continued their measurement activities at these locations already in 2015, while the remaining nations resumed their monitoring in 2016. The number of locations is considerably lower than during the BIAS field survey but cover the main sub-basins of the Baltic Sea and, hence, regions of various soundscape character.

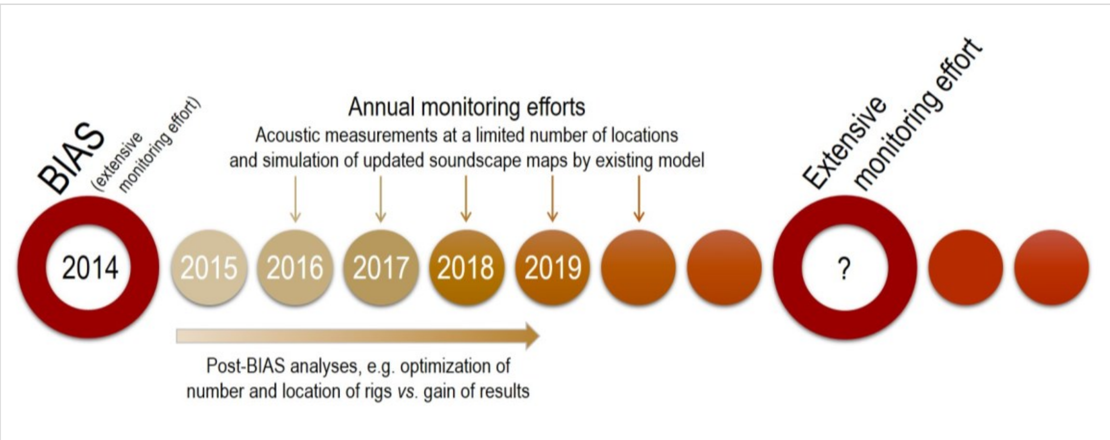


Figure 12. A plausible post-BIAS monitoring strategy with annual efforts shown as small circles and periodic BIAS-size efforts as large circles. The shaded arrow illustrates the further investigations needed in order to adjust the monitoring efforts for optimal balance between aims and costs. The timing and setup of the periodic, extensive efforts should be determined based on the results from the annual monitoring or on specific needs dictated by e.g. the MSFD reporting cycle.

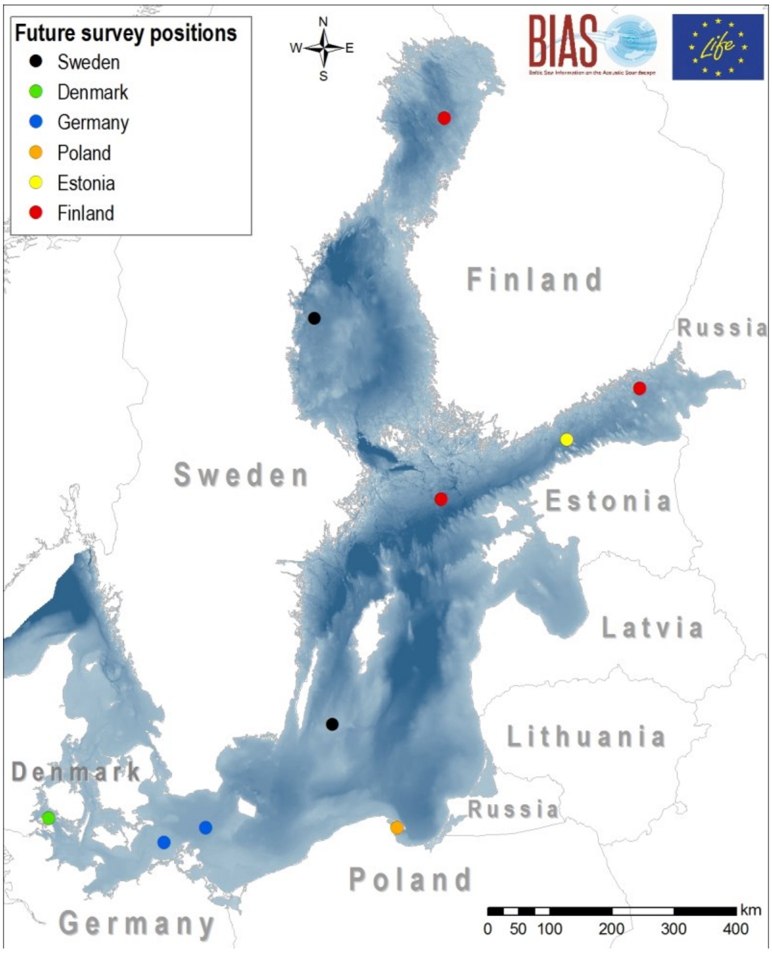


Figure 13. Suggested measurement locations (coloured by country) for the annual monitoring efforts. For a more complete coverage of the Baltic Sea proper, one or two locations along the coast of Latvia/Lithuania/Russia would be needed. All shown locations are monitored since 2016. Bathymetry provided by the Baltic Sea Hydrographic Commission [38].

In order to extend the measured data to full Baltic Sea scale, the latest version of the soundscape model can be used with updated information on ship traffic (AIS and VMS data) and environmental conditions for the current year (see section 2.3). The compatibility of the soundscape model should be controlled with help of the measured data. The data and results from the annual monitoring efforts should be regularly uploaded to the common data sharing platform and to the soundscape planning tool, see section 3 and the further discussion in section 5.3.

Through time, the general technical advancement or changes in the Baltic Sea environment will be reason for recalibrations of the soundscape model and this would require that an extended monitoring effort is repeated (section 5.2). The foreseen reasons on the technical side for such recalibrations are the development in vessel construction and changes in the fleet characteristics (ship traffic composition), which would require an update of the ship acoustic signatures used in the model. On the environmental parameter side substantial changes in climate would be a reason to update the model, but also upgraded model input data layers describing the environmental conditions or the climate.

5.2. Periodic extensive monitoring efforts

In the cases when extended monitoring is required the sensor network needs to be expanded to include more measurement locations than in the annual efforts. The locations need to reflect the noise conditions both close to major shipping lanes where individual signatures from ships are obtained, and at distance from shipping where individual ships cannot be resolved (section 2.2.1). The extensive efforts would aim to collect the necessary amount of data in order to carefully recalibrate the Baltic Sea soundscape model towards the prevailing acoustic characteristics. A similar set-up of the monitoring network as in BIAS could be applied (Figure 3).

5.3. Organization and workflow for a successful regional implementation

BIAS performed several of the core activities of the implementation of indicator 11.2.1 in the Baltic Sea. These activities involved the joint monitoring approach by most of the Baltic Sea nations and the common resources holding the monitoring data and results. With the end of BIAS, a number of decisions need to be made to maintain the regional monitoring and establish an effective assessment routine. The elements, and a plausible workflow, for such a routine in the Baltic Sea region is described schematically in Figure 11.

A regional monitoring programme requires regional coordination of all involved activities; the field survey set-up, soundscape modelling, quality assurance, storage and handling of the data etc. Such a central coordination was automatically achieved within the BIAS project but the task now needs to be transferred to central Baltic Sea bodies, possibly HELCOM.

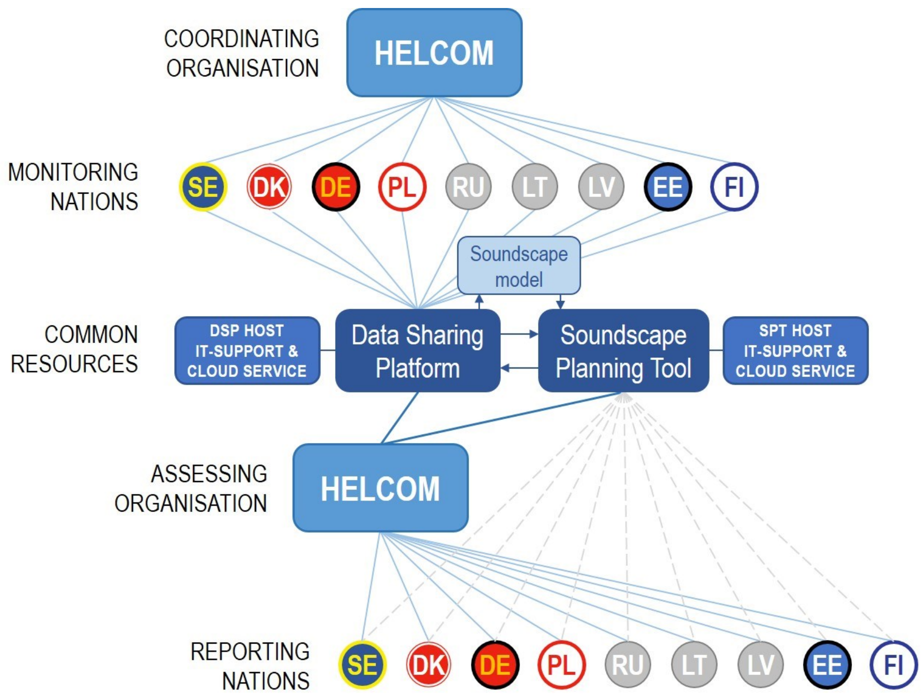


Figure 14. A potential workflow for the implementation of descriptor 11.2 for the Baltic Sea involving a number of elements and actors. The BIAS project implemented the elements in the middle of the diagram; the ones involving the monitoring nations and the common resources. Further decisions need to be made regarding the coordinating and assessing organisations (HELCOM given here only as an example), and the connections between these and the Baltic Sea nations. The maintained operation of the data sharing platform and the soundscape planning tool also needs to be decided.

The measured data need to be processed and quality checked by each monitoring nation, and reported regularly to a common database (the data sharing platform). It needs to be decided which data parameters that should be reported, and how often. Also the technical specifications for the common resources (operator, capacity, physical location etc.) and the terms of use for the data need to be determined. To develop automatized processes for the uploading and sharing procedures would be beneficial.

When new measured data are at hand, the modelled soundscapes should be updated in a joint regional effort. This is important both from an efficiency perspective as well as for ensuring a consistent view of the Baltic Sea soundscape.

The monitoring results need to be feasibly available from the data sharing platform and the soundscape planning tool for serving regional as well as national assessments. Hence, one or more coordinating parties need to be dedicated to follow up the reporting of the annual data by the monitoring nations, to host these common resources, and to administer the data flow between different actors.

The subsequent assessment of underwater noise may be most effectively carried out by one regional organisation such as a dedicated HELCOM group. The outputs from this overall assessment can thereafter be utilized by each respective member state, adapted to nation-specific perspectives and incorporated into the national reports to the EU.

6. Conclusions

The BIAS project exclusively dealt with continuous low frequency sound (ambient noise) with the aim to establish a regional implementation plan for the associated MSFD indicator. This implied developing regional standards, methodologies and tools to enable cross-border handling of acoustic data and associated results for the Baltic Sea. BIAS also put the implementation plan into practice, with many valuable experiences made along the different steps in the extensive monitoring effort. The measured and modelled soundscape data provided unprecedented views of the Baltic Sea soundscape and its monthly variation and the project outcomes have brought the Baltic Sea region one step forward in assessing the extent to which GES is being achieved in terms of underwater ambient noise.

6.1. The BIAS achievements

The technical development of ships as well as sensors and instrumentation, changes in the shipping routes and our increasing knowledge on the underwater soundscape, will alter the ways to handle continuous underwater noise in the Baltic Sea. Nevertheless, the BIAS way of pursuing this task has been proven to be successful and manageable and will function as a solid, yet adaptable, base to move ahead from.

Future monitoring strategy

A prerequisite for a successful implementation of indicator 11.2.1 is to maintain continuity in the monitoring data record. This does not mean that the same extensive effort as BIAS needs to be maintained, but that sufficient efforts are continued in order to increase our understanding of the Baltic Sea soundscape variability, and to ultimately estimate the trend for ambient noise. Hence, BIAS suggested a future monitoring strategy alternating minor and major monitoring efforts (section 5). Both types of effort combines observations with complementary modelling activities. BIAS established regional standards for rig design, sensor specifications, sensor handling, data handling and signal processing (section 2.2). Nevertheless, the format and means of future monitoring efforts will be subject to regular revision according to updated monitoring goals and new technical developments.

Measurements

The MSFD indicator 11.2.1 specifies the third octave frequency bands of 63 and 125 Hz as the target frequencies for the monitoring of ambient noise. A third frequency band (2 kHz) was also considered in BIAS. Subsequent analyses of the BIAS results are needed to clarify whether these frequency bands represent shipping noise or not in the Baltic Sea, and help to estimate the need of better alternatives for describing source levels (ship signatures). When we have a better knowledge on the frequencies best suited to monitor the impact of human-induced noise on the Baltic Sea marine fauna, it may be relevant to include additional frequency bands into the monitoring programme.

Measurement locations

The observational network should be adjusted to the monitoring effort. On an annual basis, while keeping the effort to a minimum, the network should cover the main sub-basins of the Baltic Sea and regions of various soundscape character (section 5.1). In extensive efforts, when the soundscape model is to be recalibrated, the network needs be expanded and cover two types of locations; close to shipping lanes, where individual signatures from ships are obtained, and locations where noise from distant shipping dominates (section 5.2). It may also be valuable to deploy sensors in areas of special interest or value, such as marine protected areas.

Soundscape modelling

In BIAS, modelled soundscape maps were used to extend the areal coverage of underwater noise measurements to full Baltic Sea scale. Over 800 soundscape maps were produced for the twelve months of 2014 and one annual average. These now form the base for future decisions by providing information on the geographical variation of noise and on various types and origins of noise. They also help to track, understand and interpret changes in the soundscape that may be caused by changes in e.g. maritime activities, shipping routes, or the implementation of maritime regulations. For building upon the BIAS setup, and remain consistent with the BIAS output, monthly and annual modelled soundscape data would need to be produced for the 63 Hz, 125 Hz and 2 kHz frequency bands, the 5, 10, 25, 50, 75, 90, and 95 % exceedance levels and three depth intervals; full water depth, top layer (0 - 15 m) and bottom layer (30 m to bottom), see section 2.3.

Quality Assurance procedures

Retaining quality in data and results is essential for their reliability. A methodical quality assessment should be applied during the entire regional monitoring process and in the assessment of GES; when handling, transferring, and analysing the data. BIAS established a quality assurance protocol (section 2.4), which the regional Member States may adhere to. National data should pass this quality check before distribution on regional level. Further, the lessons learned during BIAS can help prevent errors being repeated. Reports on such experiences were collected in the data sharing platform as one of the project legacies.

SEA and TEA

BIAS identified two useful statistical characterisations of the soundscape based on the modelled data (section 4.1). The Spatial Exceeded Area (SEA) is used for studying the sound levels within a specific area, while the Temporally Exceeded Area (TEA) is used to examine the sound levels in relation to a specific noise threshold, as a function of time. Both these characteristics of the soundscape can be used to study the changes of the sound levels over time, according to indicator 11.2.1. Further, SEA and TEA in connection with knowledge on e.g. species residence areas provides the means to manage the actual environmental pressure exerted by underwater noise. These are the central means for our initial assessment of the Baltic Sea underwater ambient noise, until additional measures can be identified along the road towards GES.

Soundscape planning tool

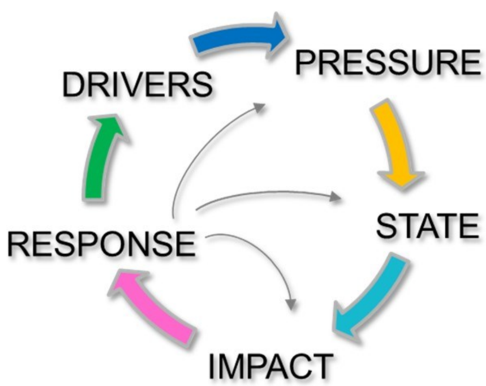
As an easily accessible, central node for the monitoring results BIAS designed an online GIS-based soundscape planning tool (section 3.2). The tool brings together the measured and modelled soundscape data for investigations of the spatial and temporal sound characteristics in the Baltic Sea. Monthly and annual data (currently for 2014), and results in terms of SEA and TEA can be extracted as maps, diagrams or tables for any user-defined geographic area. As long as the tool remains in operation it is prepared for incorporating monitoring results also from future monitoring efforts.

6.2. Identified gaps in knowledge and management procedures

In order to identify current gaps in the management of underwater ambient noise a Drivers-Pressures-State change-Impact-Response (DPSIR) analysis was undertaken in BIAS [8]. The DPSIR framework [30] is adapted by the European Environment Agency and widely used to support policy development and priority setting in environmental issues, and to follow up the effects of policy responses. Therefore, it has a good potential to be a suitable framework also for examining the different aspects of underwater noise management with respect to GES. For example, if measurements indicate that GES cannot be achieved or maintained, a regulating response can be made to reduce the pressure, which will lead to a return to acceptable GES levels (cf. Figure 15).

The DPSIR analysis encompassed management of human-induced underwater noise in a wider perspective, including elements not yet considered by the current indicator for ambient noise. The present status is that the DPSIR-loop for ambient noise suffers by two types of gaps, meaning that GES cannot be managed to the full extent. Four of ten of the identified gaps were classified as DPSIR limiting meaning they currently restrain the possibility to achieve GES: the lack of definition of GES, the lack of the regional assessment needed to establish a coherent view on impact and GES, and the lack of means to respond as a region when GES cannot be achieved. Further, EU needs to initiate research efforts that focus on questions related to GES.

The DPSIR non-limiting types do not affect the achievement of GES but rather inhibit a complete view of the human-induced underwater soundscape and may be relevant both on regional and local scales: with indicator 11.2 aiming at commercial shipping in open waters the archipelagos of the Baltic Sea often fall outside of the main target area of the descriptor. Moreover, leisure boat traffic is not identified as a driver according to the TSG Noise recommendations [35]. The pressure from combined sources such as commercial ships and leisure boats together is hence normally not dealt with, implying a management gap relevant specifically for high density areas of leisure boats.



Identified gaps in management of ambient noise:

DRIVER	· Management of coastal marine areas and archipelagos · Management of infrastructures
PRESSURE	· Assessment of particle motion levels · Impact of high-frequency sound sources · Reliable monitoring of noise
STATE	· Regional coherence (*limiting*) · Regional optimization of resources for managing underwater noise
IMPACT	· A definition of GES (*limiting*) · Research related to GES (*limiting*)
RESPONSE	· Regional Response (*limiting*)

Figure 15. The DPSIR loop and the gaps identified in the management of GES. Gaps indicated as limiting, are the ones classified to currently restrain the full achievement of achieving GES. The remaining identified gaps are relevant since they currently inhibit our complete view of human-induced underwater noise.

Another pressure related gap is that high-frequency noise is not covered by the present indicator and, hence, ships with e.g. water jet propulsion are currently excluded. Areas in the Baltic Sea where infrastructures such as bridges and wind farms dominate the soundscape are also currently excluded since the focus of descriptor 11.2 is on shipping.

It is well known that many species are sensitive only to the second component of acoustic sound, namely particle motion [21]. Hence, particle motion is identified as a pressure, but not currently dealt with in the recommended implementation of ambient noise, and therefore another gap to fill.

On the practical and technical side, improvements need to be made of the sensor quality, but also of the required calibration procedures. Moreover, the monitoring needs to be made more reliable in terms of methods and devices protecting the measurement locations from sensor-threatening activities such as trawling.

With many environmental issues needing attention, the financial resources for management of underwater ambient noise are limited. There is an imminent need of regionally optimized resources for handling underwater noise to a minimum cost without jeopardizing the aim of the indicator. With experience building up through the annual monitoring efforts (section 5.1), the potential for fulfilling this gap will be steadily increasing.

6.3. The work ahead

BIAS has in a great detail developed the tools and knowledge necessary for a regional handling of underwater noise in the Baltic Sea. In order to assess the pressure exerted by underwater noise in the region it has to be monitored regularly, and new soundscape maps have to be produced. As long as the existing soundscape model realistically reflects the current conditions the modelling is suggested to be carried out within the annual monitoring efforts (section 5). In the cases when the soundscape model needs to be upgraded (re-calibrated) to new settings, or if the monitoring network needs to be expanded for other reasons, it will be necessary to conduct extensive monitoring efforts. The periodicity of such efforts has yet to be decided.

Several Baltic Sea states continued their monitoring programmes after the BIAS field survey year. The data mine of sound measurements is constantly growing. If a regional handling and assessment of the monitoring data should be maintained, a rapid transfer of the responsibility of the common resources to their definite owner is required (cf. section 5.3).

The transfer of knowledge to HELCOM along the various stages of BIAS (section 1.2) has led to several of the BIAS results becoming part of the implementation in the HELCOM region [22]. The collaboration has also narrowed the gap between GES and the pressure-based monitoring results. The way forward is to focus on closing the gap entirely. Based on the current status of our knowledge on the impact by noise on marine life, it seems that handling of GES will not be attainable in many years. However, this does not rule out a comprehensive management of continuous low frequent sound. Through a regional acceptance of a risk-based assessment of underwater noise, rather than an impact-based assessment, the gap to GES can be decreased further. Such a regionally coherent approach can only be achieved if HELCOM takes the lead and coordinates a joint assessment. Through the combination of measurements and modelling results, BIAS identified two useful statistical properties based on pressure (section 4.1). The start of a risk-based regional assessment could be to use these for defining guidance levels for noise.

The knowledge of the impact of underwater noise on marine life is too limited for allowing conclusions about to what degree underwater noise affects the provision of ecosystem services [7]. This implies a need for further studies on how ambient underwater noise affects marine life. Such studies are also needed as a basis for further work on the benefits of reduced underwater noise that are associated with an increased provision of ecosystem services.

References

BIAS deliverables

These documents are available from the project webpage www.bias-project.eu >> Downloads >> Deliverables.

[1] BIAS Standards for noise measurements:
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