Topic report: underwater noise

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Summary of main results

The analysis has evaluated the pressure reductions in the input of continuous noise and impulsive noise by 2030, considering the effects of existing measures and changes in the extent of human activities. A proper analysis of sufficiency of measures has not been possible, as there are no agreed GES thresholds for underwater noise.

Moderate increases are projected for continuous noise 63/125 Hz and 2 kHz. This result is driven by the increase in the extent of the main activities contributing to the input of continuous noise, i.e. shipping, tourism and leisure activities.

Moderate reductions are projected for impulsive noise with peak energy below 10 kHz. The main activities contributing to the input of impulsive noise, i.e. military operations, research, survey and educational activities, and marine and coastal construction, are assumed to stay constant by 2030 as no development scenarios are available. This assumption may not be reasonable.

State components most affected by underwater noise are grey seal, vegetation dominated benthic habitat types and red-throated diver.

Effectiveness of measure types is evaluated to be from low to moderate for all measure types.

Main activities contributing to the input of noise:

> Input of continuous noise: shipping, tourism and leisure activities, fish and shellfish harvesting
>
> Input of impulsive noise: military operations, research, survey and educational activities, marine and coastal construction

Background

Report background

The sufficiency of measures (SOM) analysis assesses improvements in environmental state and pressures that can be achieved with existing measures in the Baltic Sea, and whether these are sufficient to achieve good environmental status (GES). The analysis involves estimating the state of the marine environment in 2030, given measures in existing policies, their implementation status and projected development of human activities over time, which can be compared to the agreed HELCOM threshold for GES, when available.

The main aim of the SOM analysis is to support the update of the HELCOM Baltic Sea Action Plan (BSAP) by identifying potential gaps in achieving environmental objectives with existing measures for the Baltic Sea. In addition, the analysis can indicate both thematically and spatially where new measures are likely needed.

The same overall approach has been applied across all topics included in the SOM analysis to ensure comparability and coherence of the results, while considering topic-specific aspects and making necessary adjustments. The main components of the analysis include assessing the contribution of activities to pressure inputs, the effect of existing measures on pressure inputs, the effect of development of human activities on pressure inputs, and the effect of changes in pressure on environmental state. The SOM approach, model and data collection are described in detail in the methodology report.

The methodology for the SOM analysis is designed to accommodate for the broad array of topics relevant in the HELCOM region and to enable a region-level analysis. It balances between state-of-the-art knowledge, availability of data, and advice taken onboard from various HELCOM meetings and bodies.

The data used in the SOM analysis have been collected using expert elicitation and by reviewing existing literature, model outputs and other data sources. Data availability varies substantially across topics and data components, which is reflected in the presentation of the methods and results in this report.

The SOM analysis presents the first attempt to quantify the effects of existing measures and policies on the environment and achieving policy objectives for various environmental topics in HELCOM and the Baltic Sea area. It is aimed at assessing the overall sufficiency of existing measures at the Baltic Sea level. The results are based mainly on expert elicitation, and thus they should be considered as approximate. Due to the pioneering nature and variable data quality and availability of the SOM analysis, the findings do not provide complete or final answers on the need for new measures, and should be reviewed in relation to the results of other assessments.

This topic report describes the analyses and results for underwater noise in the SOM analysis, providing detailed topic-specific information. First, it presents background information and describes the data and methods for addressing the topic in the SOM assessment, including relevant assumptions and challenges. Second, it presents and discusses the findings for each result component. Third, it provides discussion on the impacts of alternative assumptions and data, evaluates the quality and confidence of the analysis, and provides implications and future perspectives. The annexes contain detailed information on the data components, topic structure and expert surveys for the analysis, as well as supplementary results.

Similar topic reports will be prepared for all nine topics covered in the SOM analysis. In addition, the results are summarized in the main report and the full methodology is described in the methodology report.

Topic background

[Topic team to write, see example on the contents and length in the hazardous substances report]

Description of underwater noise in the SOM assessment

Three types and frequencies of underwater noise are considered in the SOM analysis. Continuous noise is assessed at two frequencies, 63/125 Hz and 2 kHz, and impulsive noise is assessed with peak energy below 10 kHz (Figure 1). No HELCOM core indicator exists for either continuous or impulsive noise, though indicators are under development and qualify as pre-core indicators. However, MSFD criteria D11C1[1] and D11C2[2] provide a structure for assessing both noise types, respectively. As no GES threshold value exists for either noise type, the assessment focuses on the pressure reductions from present conditions achievable with existing measures. The slightly more general pressures *Continuous underwater noise* and *Impulsive underwater noise* could be selected in the expert surveys on pressure-state linkages for other topics when identifying the most significant pressures linked to any of the state components included in the SOM analysis. These pressures are included to capture the overall effects of underwater noise on the environment and to accommodate the varying knowledge of underwater noise of experts in other fields, e.g. marine mammals, fish etc.

Given the lack of persistence in any given sound wave (only lasts from seconds to hours), the pressure inputs, pressure and state components of underwater noise are all considered nearly equivalent in the SOM analysis. For this reason, underwater noise was assessed only to the level of pressures. Thus, the analysis does not include the pressure-state linkages for underwater noise.

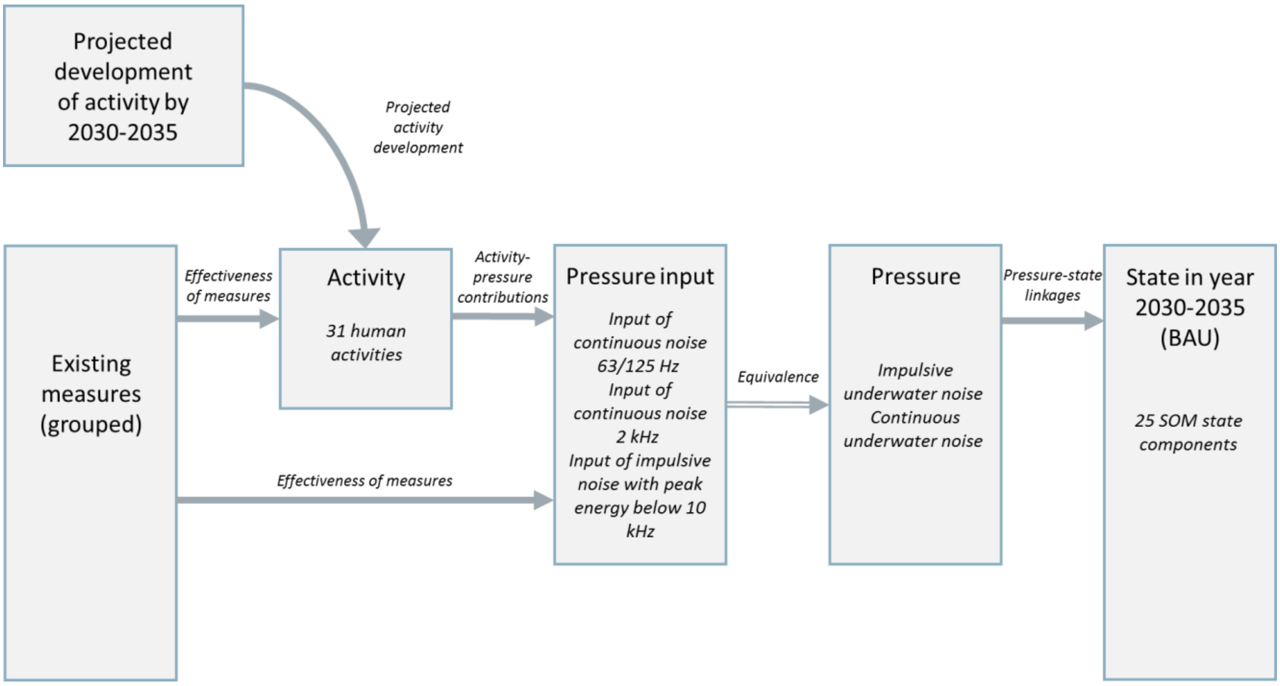

Figure 1. Schematic of the SOM model for the 3 bands of underwater noise. The two types of continuous noise pressure inputs are each assumed to make up half of the continuous noise pressure and the impulsive noise pressure input is assumed to be equivalent to the impulsive noise pressure.

[1] Marine Strategy Framework Directive criteria D11C1 – Primary: The spatial distribution, temporal extent, and levels of anthropogenic impulsive sound sources do not exceed levels that adversely affect populations of marine animals. Member States shall establish threshold values for these levels through cooperation at Union level, taking into account regional or subregional specificities.

[2] Marine Strategy Framework Directive criteria D11C2 – Primary: The spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound do not exceed levels that adversely affect populations of marine animals. Member States shall establish threshold values for these levels through cooperation at Union level, taking into account regional or subregional specificities.

Supplementary activities

[Topic team to write, brief description of the noise action plan and/or noise report]

Methods and data

The section below includes an overview of any topic-specific methodologies. A full description of the general approach, methods and data collection for the SOM analysis is available in this document. Note that the detailed results are presented for the most likely development of human activities and using the expert data on effectiveness of measures.

Activity-pressure input contributions

The contributions of activities to the input of underwater noise for each of the three noise types were determined using surveys that were distributed to national topic experts via the HELCOM Expert Network on Underwater Noise (EN Noise). Responses from individual experts were accepted, but because national responses were preferred, all responses were weighted nationally to standardize the data set. Respondents were asked to assess the maximum, minimum, and most likely contribution of any activity contributing more than 5% to the input of each noise category. Responses to activities contributing below that threshold were invited but not required. Respondents were also asked to assess the extent to which data informed their answer using a five-point scale (1 being very low and 5 very high).

Effectiveness of measures and pressure-state linkages

Measure types (Annex 3) and structural relationships between the measure types and activities and pressure inputs (Annex 7) were designed by the SOM Noise Topic Team in collaboration with HELCOM ACTION WP6. The measure types were informed by the existing measures list (Annex 4), but were also designed to acknowledge the full breadth of potential measures.

For underwater noise habitats, the effectiveness of measures survey structure comprised 19 unique measure types covering 8 activities. The same measure type may be listed under multiple activities and pressure inputs. Altogether this resulted in 67 assessments of measure type effectiveness across the three pressure inputs, *Input of continuous noise 63/125 kHz*, *Input of continuous noise 2 kHz*, and *Input of impulsive noise with peak energy below 10 kHz*. The exact list of measure types, and their grouping by activities and pressure inputs is shown in Annex 7. The effectiveness of measures survey itself is included as Annex 8.

Effectiveness of the measure types and links between the pressures and state components were determined using online expert surveys implemented in December 2019 – February 2020 with follow-up surveys conducted in the spring 2020. The expert pool consisted of the HELCOM Expert Network on Underwater Noise and nationally nominated experts. Additionally, the project received survey responses from experts not on the original invitation list; these responses were also included in the analysis. The full description of the methodology and data collection is available as part of the SOM methodology report.

Topic specific model structure, assumptions and challenges

The SOM assessment of underwater noise uses a simplified single metric of percent reduction in place of the interacting metrics of decibels and hertz, and combined noise injury and disturbance into the single pressure of impulsive noise. While this simplification is useful for managing the size of the analysis and corresponds better with the analysis structure for other topics in the SOM analysis, it does limit the applications of the assessment and the ability to incorporate literature estimates of the effectiveness of measures into the analysis. As a result of this simplification, the SOM noise results should not be used in place of a literature backed cost-benefit analysis or environmental impact assessment. Further reflection on this issue can be found in the section Lessons learned.

Using the standard SOM activity list, the passive generation of continuous noise by all marine structures would be diluted across too many activities to allow for a quantitative assessment. To account for this issue, marine and coastal infrastructure (excluding military infrastructure) was created as an activity for the SOM assessment on underwater noise. Marine and coastal infrastructure includes 11 standard SOM activities: transport – shipping infrastructure, tourism and leisure infrastructure, offshore structures, extraction of oil and gas, aquaculture – marine, renewable energy generation, transmission of electricity and communications, canalisation and other watercourse modifications, coastal defence and flood protection, transport – air, transport – land. See Annex 2 for full activity names and comparison of the standard SOM activity list and the modified list used for the assessment of continuous noise.

Human development scenarios were created for the predominant activities in the SOM analysis as a whole. On an individual topic level, this resulted in variation across topics in how well the main activities contributing to the pressures are covered in the development scenarios, but variation within a topic has generally been low. This is not the case for underwater noise. Continuous noise is well represented, with 70-90% of the activities contributing to its input covered by the human development scenarios, but activities contributing to impulsive noise are poorly represented with 0-4% of activities covered. This presents challenges when interpreting the results. Further discussion of this issue can be found throughout the Discussion section.

Overview of data

The SOM analysis for underwater noise evaluates the pressure reductions achievable by 2030, considering the effects of existing measures and future development of human activities.

Table 1 shows the origin and spatial resolution for the data components in the SOM analysis for underwater noise. Activity-pressure input contributions are based on expert data. Information on existing measures comes from literature reviews and Contracting Parties, and development of human activities is based on existing literature, data and projections.

Estimates of the effectiveness of measures were collected both via expert surveys and a literature review for all topics included in the SOM analysis. The aim of the literature review was to compile information from scientific articles and reports providing estimates on the effects of measures in reducing pressure inputs that could be used in the SOM analysis, either by including the estimates in the SOM model or by providing comparison points. The literature review was conducted by topic, with the information collected into structured excel files (see the methodology document, Annex 5 and Annex 6 for more information). For underwater noise, 143 effectiveness estimates from 18 studies were compiled. Out of these, no estimates could be included in the model due to the inability to realistically convert the change in noise frequency and intensity found in literature to the single percent change value required for the SOM assessment. This issue is further discussed in the section Lessons learned.

The spatial resolution (level of detail) differs across the data components of the SOM analysis. All assessment areas are based on the 17 HELCOM scale 2 sub-basins and the assessment area ranges from the single Baltic Sea to individual sub-basins. The activity-pressure contributions for underwater noise are assessed across 5 sub-areas of the Baltic Sea (Figure 2), while the effectiveness of measure types in reducing pressures and the effect of development of human activities are assessed at the Baltic Sea scale. Table 1 shows the origin and spatial resolution for the data components in the SOM analysis for underwater noise.

Table 1. Data for underwater noise (more information on data collection is available in the methodology document)

Data component	Origin of data	Spatial resolution
Activity-pressure contributions	Expert evaluation	5 sub-areas (Figure 2)
Existing measures	Literature review, Contracting Parties	17 sub-basins
Effectiveness of measures	Expert evaluation	Whole Baltic Sea
Development of human activities	Literature review, existing data and projections	Whole Baltic Sea
Pressure-state links	NA	NA

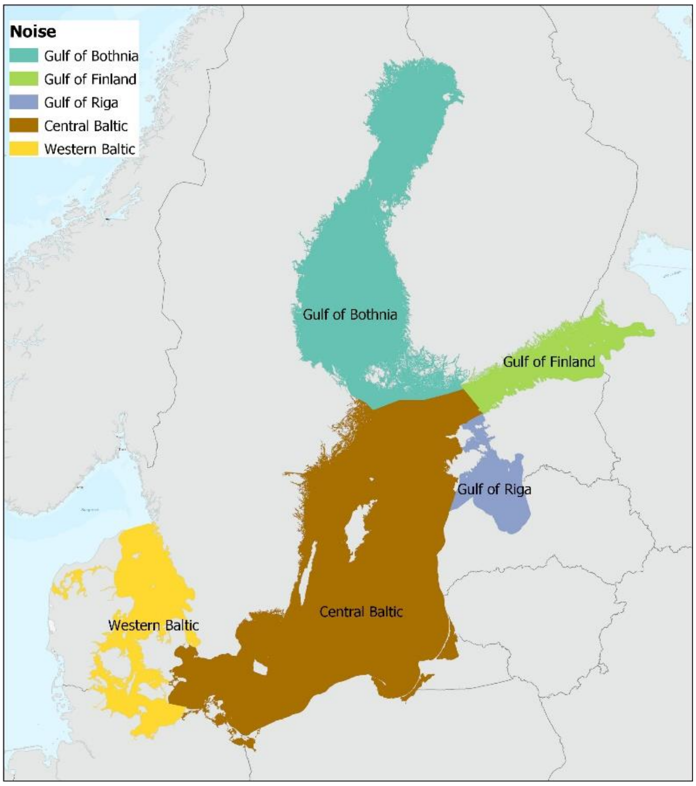

Figure 2. Spatial division of the Baltic Sea used for determining contributions of human activities to the input of three underwater noise types. The five areas are: Western Baltic (Kattegat, Great Belt, The Sound, Kiel Bay, Bay of Mecklenburg); Central Baltic (Arkona Basin, Bornholm Basin, Gdansk basin, Eastern Gotland Basin, Western Gotland Basin, Northern Baltic Proper); Gulf of Riga: Gulf of Finland; and Gulf of Bothnia (Åland Sea, Bothnian Sea, The Quark, Bothnian Bay).

Development of human activities

In addition to existing measures, changes in the extent of human activities may affect pressure inputs over time. Four scenarios for future changes in human activities were developed: 1) no change, 2) low change, 3) moderate (most likely) change, and 4) high change. These alternative scenarios aim to capture uncertainties and variation in the future development of human activities. The results of the SOM analysis were estimated for each of the four scenarios to assess how the alternative assumptions on the development of human activities affects the findings. Detailed results are presented for the most likely development scenario, and implications of using the other scenarios on the results are reviewed in the discussion section.

The scenarios specify a percent change in each activity in 2016–2030 based on existing information and projections from the Baltic Sea region. Change scenarios were made only for predominant activities in the Baltic Sea region, including agriculture, forestry, waste waters, (commercial) fish and shellfish harvesting, aquaculture, renewable energy production, tourism and leisure activities, transport shipping and transport infrastructure. Other activities are assumed to stay unchanged. This means that only 9 of the 31 standard SOM activities have change scenarios in the SOM analysis. This results in varying influence of these scenarios on the results across topics, pressures and state components, depending on the significance of the activities to the pressure inputs relevant to the topic.

The coverage of activities that contribute to the input of noise in the development scenarios is high for continuous noise and very low for impulsive noise. The main activities contributing to continuous noise, i.e. shipping, tourism and leisure activities, and fish and shellfish harvesting, have all been included, and thus 70-90% of the activities contributing to the input of continuous noise have development scenarios. Shipping is expected to increase by 20% and tourism and leisure activities by 30% by 2030, while fish and shellfish harvesting is expected to remain constant in the most likely scenario. The situation is different for impulsive noise, which is mainly affected by military operations, research, survey and educational activities, and marine and coastal construction. The joint contribution of these activities to the input of impulsive noise is 65-90%, depending on the sub-area. None of these have development scenarios and their extent is thus assumed to stay constant until 2030. Overall, only 0-4% of the activities contributing to the input of impulsive noise are covered by human development scenarios. This is a considerable deficiency in the analysis. The difference in the existence of development scenarios for the activities contributing to the noise input across the noise types should be kept in mind when examining and interpreting the results.

The current situation with COVID-19 and its possible implications to the development of human activities is not reflected in the scenarios, as there is no information on the long-term effects it may have on the economy or activities. The current situation poses a challenge for choosing the most likely scenarios for the development of human activities, which has been done based on currently available information.

Results and interpretation

Background

The SOM results are presented in the format of percent shares or probabilities. The main finding of the analysis is the probability to achieve GES or specific state improvements/pressure input reductions, taking into consideration the effects of existing measures and changes in the activities on pressure inputs. The contribution of activities to pressure inputs, the effect of measures on pressure inputs, and the significance of pressures to state components are presented as percent values (e.g. how many percent would the measure reduce the pressure input). Results are presented mainly in tables, which show the the most likely (expected) values and standard deviations. Standard deviation is a way of showing the variation in the values. When it is high, values are spread over a wider range, and when it is low, values are closer to the most likely value. Figures and graphs presenting distributions are included in the annexes. They show the same results as the tables but allow either more detailed information or alternative visualisation of the results.

For the data that are based on expert surveys, the confidence rating gives the most common answer to experts' assessment of the confidence in their own survey responses on a low-moderate-high scale. More detailed information on how each result has been calculated is presented in a separate document.

This document presents the detailed results based on the expert-based data (survey responses). Literature data on the effectiveness of measures has been collected and included in an alternative model estimation. The impacts of using the literature data are evaluated in the discussion section. In the detailed results, the projected development of human activities is based on the most likely future development until 2030 (for details, see the methodology document), and the impacts of alternative scenarios on human activities are examined in the discussion section.

Format of presentation

The format the results are reported in (not presented, qualitative/semi-quantitative, quantitative) depends on the type of result and the number of participating experts. Further, for all results utilizing other SOM results as input data, reporting is done at the most conservative standard used in the input data. In practice this means that if one input data point is reported as 'insufficient data', all results using that data point will also be reported as 'insufficient data'; similarly for qualitative/semi-quantitative data points. However, note that this standard is only applied in the case of data points actively used to calculate another result. For example, many measure types are hypothetical or otherwise not implemented in the Baltic Sea and therefore do not factor into results on projected pressure input reductions from existing measures. Insufficient data for such measure types does not affect reporting other results that rely on data for effectiveness of measure types. Results that do not meet the data standards described here and in greater detail below are marked with 'insufficient data' in the report. All the data components for underwater noise meet the thresholds for fully quantitative presentation.

For results concerning required pressure reductions and significance of pressures to state components, results with 2 or fewer respondents are not reported; results with 3 to 4 respondents will be either not reported, or qualitatively/semi-quantitatively reported based on feedback from the SOM topic teams or other HELCOM expert body; results with 5 or more respondents are reported quantitatively. This standard allows flexibility for reporting on assessments that are of spatially limited areas and therefore have fewer experts available to survey, while also being somewhat conservative in reporting fully quantitative results.

For expert-based effectiveness of measures results, measure types with 5 or more respondents are reported quantitatively and those with 4 or fewer respondents are listed as having insufficient data.

For expert-based activity-pressure input results, expert responses where primarily sought through the HELCOM expert networks in the form of national responses. Individual expert responses were accepted but were consolidated into average responses by country to conform to the format of other responses. Thus, the maximum number of responses is 9. This maximum is rarely reached due to responses typically only applying to areas adjacent to the specific country. Acknowledging this, activity-pressure input relationships are reported if there are expert responses from 3 or more countries or if the number of countries providing expert responses is greater than 1/2 the number of countries bordering any given sub-area (see Table 2 below; responses from experts based in any HELCOM country will be counted toward the reporting threshold, i.e. the reporting assessment is not limited to responses from bordering countries).

Table 2. Required number of countries providing expert responses to the activity-pressure input survey to meet the minimum data threshold for reporting.

Bordering countries	Required number of countries providing expert responses to meet minimum data threshold	Example areas
1	1	Western Gotland Basin
2	2	Bothnian Sea, Gulf of Riga
3	2	Gulf of Finland
4+	3	Eastern Gotland Basin, Baltic Sea

What are the reductions in pressure inputs from existing measures?

There are no GES thresholds for any of the underwater noise types, and therefore a proper analysis of sufficiency of measures has not been possible. Additionally, no status assessment was made during the most recent HOLAS assessment period; with the sources and potential impact of underwater noise only described. The focus of the SOM analysis has been to evaluate the changes in the input of noise in 2016-2030, considering the effects of existing measures and changes in the extent of human activities. Table 3 shows the projected reductions in the input of noise, further differentiated into continuous noise 63/125 Hz, continuous noise 2 kHz, and impulsive noise with peak energy below 10 kHz.

Pressure increases are projected for the *input of continuous noise 63/125 Hz and input of continuous noise 2 kHz* in all sub-areas, as shown by the negative values. In this case, the pressure reductions from existing measures cannot compensate for the increases caused by the projected future development of activities. Few existing measures controlling continuous noise were reported. In addition, shipping and tourism and leisure activities are expected to increase by 20% and 30% by 2030, respectively, in the most likely scenario. As these cover 70-90% of the activities contributing to the input of continuous noise (see Table 6) and there are few existing measures, the projected changes are mainly driven by the changes in the extent of the activities.

Low reductions in the *input of impulsive noise with peak energy below 10 kHz* are expected in all sub-areas. For impulsive noise, no development scenarios have been made for the main activities contributing to its input, and thus activities such as military operations, marine and coastal construction, and research, survey and educational activities are expected to remain constant until 2030. This may not be accurate. Increases in the extent of transport infrastructure and offshore windfarms by 2030 are expected, which could indicate increase in marine and coastal construction. If this is the case, lower reductions (or potentially increases) in the input of impulsive noise would be projected. Further, no existing measures were reported for the direct to impulsive noise measure types (Table 5.4), so no additional species-specific pressure reductions are estimated to occur for noise sensitive mammals due to these measure types. It is worth noting that some mitigation measures for impulsive noise may be in place, but they were not included in the list of existing measures.

Overall, the different results for the projected changes in the input of continuous and impulsive noise seem to stem mainly from the projected changes in the extent of the activities contributing to their input, and how well the SOM analysis has been able to account for the activities in the development scenarios.

The calculations are based on the activity-pressure contributions, effectiveness of measure types, links between existing measures and measure types, and projected development of human activities. The activity-pressure data are at the level of five sub-areas (Figure 2), and the effectiveness of measures data at the Baltic Sea level, and thus the total pressure reductions are presented for the five sub-areas.

The projected reductions account for the joint impacts across the measure types, as well as the spatial area where the pressure inputs can be reduced to avoid overestimating the pressure input reductions. Pressure input reductions can in principle be positive, negative or zero, depending on the combined effect of existing measures and changes in the extent of human activities. When the reduction in pressure inputs from existing measures is larger than the increase from changes in human activities, pressure inputs are reduced.

Further details on the effectiveness of different measure types and activity-pressure input contributions can be found in Tables 5 and 6.

[Further discussion and interpretation of the results, input from topic team]

Table 3. Projected total pressure reductions (%) of noise from existing measures. The table depicts the most likely/expected total pressure reduction, and standard deviation is given in parenthesis.

Pressure Sub-area	Input of continuous noise 63/125 Hz	Input of continuous noise 2 kHz	Input of impulsive noise with peak energy below 10 kHz
Western Baltic	-13 (3) ●●●	-13 (4) ○●●	18 (9) ○●●
Central Baltic	-9 (4) ○●●	-9 (5) ○●●	14 (7) ○●●
Gulf of Riga	-18 (1) ●●●	-19 (2) ●●●	0 (0)
Gulf of Finland	-8 (6) ○○●	-8 (7) ○○●	11 (7) ○○●
Gulf of Bothnia	-4 (10) ○○●	-2 (13) ○○●	13 (7) ○●●

Colour scale for the pressure reductions in percent (based on the expected value):
<0%, 0-10%, 10-20%, 20-40%, 40-60%, 60-100%
Categories for the certainty of the pressure reductions (based on the relative size of the standard deviation to the expected value): low: ○○●, moderate: ○●●, high: ●●●
Data used: activity-pressure input contributions, effectiveness of measure types, information on existing measures, development of human activities

What are the state components most affected by underwater noise?

The data from the pressure-state expert surveys for hazardous substances, benthic habitats, birds, fish and mammals allow for identifying the state components most affected by underwater noise. These five expert surveys provide expert views on the significance of various pressures to the state components in the SOM analysis.

Table 4 shows the state components most affected by continuous and impulsive noise. The most affected state components are grey seal, vegetation dominated benthic habitat types and red-throated diver.

[Further discussion and interpretation, input from topic team]

Table 4. Top five state components most affected by underwater noise. Listing is based on Baltic-wide averages of the significance of pressures to state components presented in each respective topic report. Average number of expert responses for the state component is given in parenthesis (total response count for the state component divided by the number of geographic areas for the state component).

Pressure	1st most affected state component	2nd most affected state component	3rd most affected state component	4th most affected state component	5th most affected state component
Continuous underwater noise	Hard substrate vegetation dominated community (5.8)	Soft substrate vegetation dominated community (3.8)			
Impulsive underwater noise	Grey seal (5.0)	Red-throated diver (6.0)			

Data used: expert responses on significance of pressures to state components for all topics
Less than five most affected state components are presented in cases where there is insufficient data for some state component(s) affected by the pressure, i.e. there are not enough expert responses to the significance of pressures to the state component in the survey (e.g. some mammals species). This corresponds to the criteria for the format of presentation.

How effective are measure types in reducing pressure inputs?

This section presents the percent effectiveness of measure types in reducing the *input of continuous noise 63/125 Hz, input of continuous noise 2 kHz, input of impulsive noise with peak energy below 10 kHz,* and *direct to impulsive noise to porpoises and seals* from a specific activity. The estimates are presented per activity, i.e. they portray the percent reduction in the pressure input from the activity in question, and not in the total input across all activities. Information on the reductions over all activities contributing to the pressure input is given in the section on the impacts of measure types. Data on the effectiveness of measure types originate from expert surveys on effectiveness of measures.

Tables 5.1-5.4 present the most likely percent effectiveness and its standard deviation per noise type, activity and measure type, and pooled over experts. The effectiveness estimates can be compared across measure types to assess, on average, how effective they are in relation to each other in reducing the pressure input from the specific activities, or across activities to assess which measure type could be the most effective for each activity. Confidence depicts the most common rating of expert's confidence in their own responses to the effectiveness of measure types question. Annex 10 presents the distributions of the effectiveness of measure types in controlling the input of noise for additional information.

Most of the measure types have a low or moderate effectiveness in reducing the input of continuous noise 63/125 Hz from the activities (Table 5.1). *Promotion of alternative/low noise technologies* could reduce noise input from all six activities with a low to moderate effectiveness. *Spatial/temporal restrictions for sensitive areas and species* seems to be the most effective in reducing the input of noise from shipping.

The measure types to reduce the input of continuous noise 2 kHz are the same as those to reduce input of continuous noise 63/125 Hz (Table 5.2). Effectiveness of all measure types to reduce the input of continuous noise 2 kHz ranges from low to moderate. There seem to be several effective measure types for reducing the input of noise from tourism and leisure activities.

Measures reducing the input of continuous noise are not currently widely implemented in the Baltic Sea region, as indicated in tables 5.1-5.2 (Has corresponding existing measures in the SOM analysis (Yes/No)). However, there is a range of available measures to choose from, as the region considers action on this topic.

Table 5.3 shows the effectiveness of measure types in reducing the input of impulsive noise with peak energy below 10 kHz. Most have low or moderate effectiveness. Measure types that target research, survey and educational activities seem to have rather low effectiveness.

The effectiveness of measure types in reducing the direct pressure of noise to porpoises and seals is generally low (Table 5.4). These measure types reduce the pressure directly by limiting the amount of received noise rather than the amount of noise created. While this may reduce injury caused by impulsive noise, disturbance is likely unaffected or possibly increased due to these measures. Their assessment given the SOM structure of a combined metric of disturbance and injury is uncertain. Further work is required before these values are used for any purpose outside this analysis. More reflection can be found in the section Lessons learned.

Overall, the effectiveness of the measure types in reducing the input of noise ranges from low to moderate, and the uncertainty of the effectiveness is rather high based on the standard deviations. Expert's confidence in their assessment is on average moderate but varies across the noise type and activity.

Estimates of the effectiveness of measure types are used to assess the effects of existing measures in reducing the input of noise to the Baltic Sea and calculate the reductions from existing measures by 2030.

[Further discussion and interpretation of the results, input from topic team]

Table 5.1 Effectiveness of measure types (%) in reducing the *input of continuous noise 63/125 Hz*. The effectiveness of a measure type is the percent reduction in the pressure resulting from a specific activity. The table depicts the most likely/expected effectiveness, and standard deviation is given in parenthesis.

Measure type ID	Activity Measure type	Fish and shellfish harvesting	Extraction of minerals	Restructuring of seabed morphology	Tourism and leisure activities	Transport – shipping	Marine and coastal construction	Has corresponding existing measures in the SOM analysis (Yes/No)
150	Promotion of alternative/low noise technologies	24 (18) ○○●	23 (18) ○○●	18 (12) ○○●	16 (8) ○●●	29 (19) ○○●	19 (14) ○○●	Yes
151	Implementation of restrictions/permitting based on ship noise classifications	21 (11) ○●●	Not assessed	Not assessed	20 (11) ○●●	32 (13) ○●●	Not assessed	No
152	Use of shore-based power while in port	Not assessed	Not assessed	Not assessed	Not assessed	11 (10) ○○●	Not assessed	No
153	Optimized scheduling to reduce time spent at anchorage sites	Not assessed	Not assessed	Not assessed	Not assessed	15 (10) ○○●	Not assessed	No
154	Spatial/temporal restrictions for sensitive areas and species	30 (14) ○●●	Not assessed	Not assessed	23 (9) ○●●	43 (19) ○●●	Not assessed	No
155	Speed limits in sensitive areas or times	21 (9) ○●●	Not assessed	Not assessed	20 (9) ○●●	34 (12) ○●●	Not assessed	No
156	Raise consumer awareness about noise input and effects	Not assessed	Not assessed	Not assessed	Not assessed	17 (12) ○○●	Not assessed	No
157	Improve awareness of ship owners/companies about noise input, effects, and avoidance	15 (10) ○○●	Not assessed	Not assessed	14 (10) ○○●	23 (12) ○●●	Not assessed	No
158	Introduce engine noise standards	Not assessed	Not assessed	Not assessed	19 (7) ○●●	Not assessed	Not assessed	No
	Confidence	Moderate	Moderate - Low	Low	Moderate	Moderate	Moderate - Low	
	Number of experts	7	7	7	7	8	7	

Colour scale for the effectiveness of a measure type in percent (based on the expected value): 0-10%, 10-20%, 20-40%, 40-60%, 60-100%

Categories for the certainty of the effectiveness estimate (based on the relative size of the standard deviation to the expected value): low: ○○●, moderate: ○●●, high: ●●●

Data used: expert responses on the effectiveness of measure types

Full activity names:

- Fish and shellfish harvesting (all gears; professional, recreational)
- Extraction of minerals (rock, metal ores, gravel, sand, shell)
- Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material)

- Tourism and leisure activities (boating, beach use, water sports, etc.)
- Transport – shipping (incl. anchoring, mooring)
- Marine and coastal construction

Table 5.2 Effectiveness of measure types (%) in reducing the *input of continuous noise 2 kHz*. The effectiveness of a measure type is the percent reduction in the pressure resulting from a specific activity. The table depicts the most likely/expected effectiveness, and standard deviation is given in parenthesis.

Measure type ID	Activity Measure type	Fish and shellfish harvesting	Extraction of minerals	Restructuring of seabed morphology	Tourism and leisure activities	Transport – shipping	Has corresponding existing measures in the SOM analysis (Yes/No)
150	Promotion of alternative/low noise technologies	23 (21) ○○●	25 (24) ○○●	31 (21) ○○●	34 (21) ○○●	30 (26) ○○●	Yes
151	Implementation of restrictions/permitting based on ship noise classifications	23 (23) ○○●	Not assessed	Not assessed	36 (16) ○●●	26 (21) ○○●	No
152	Use of shore-based power while in port	Not assessed	Not assessed	Not assessed	Not assessed	10 (15) ○○●	No
153	Optimized scheduling to reduce time spent at anchorage sites	Not assessed	Not assessed	Not assessed	Not assessed	12 (11) ○○●	No
154	Spatial/temporal restrictions for sensitive areas and species	31 (23) ○○●	Not assessed	Not assessed	38 (14) ○●●	31 (21) ○○●	No
155	Speed limits in sensitive areas or times	13 (14) ○○●	Not assessed	Not assessed	39 (17) ○●●	27 (19) ○○●	No
156	Raise consumer awareness about noise input and effects	Not assessed	Not assessed	Not assessed	Not assessed	13 (12) ○○●	No
157	Improve awareness of ship owners/companies about noise input, effects, and avoidance	14 (11) ○○●	Not assessed	Not assessed	29 (14) ○●●	20 (16) ○○●	No
158	Introduce engine noise standards	Not assessed	Not assessed	Not assessed	36 (17) ○●●	Not assessed	No
	Confidence	Moderate	Moderate - Low	Low	High	Moderate	
	Number of experts	5	7	7	5	6	

Colour scale for the effectiveness of a measure type in percent (based on the expected value): 0-10%, 10-20%, 20-40%, 40-60%, 60-100%
Categories for the certainty of the effectiveness estimate (based on the relative size of the standard deviation to the expected value): low: ○○●, moderate: ○●●, high: ●●●
Data used: expert responses on the effectiveness of measure types

Full activity names:

- Fish and shellfish harvesting (all gears; professional, recreational)
- Extraction of minerals (rock, metal ores, gravel, sand, shell)
- Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material)
- Tourism and leisure activities (boating, beach use, water sports, etc.)
- Transport – shipping (incl. anchoring, mooring)

Table 5.3 Effectiveness of measure types (%) in reducing the *input of impulsive noise with peak energy below 10 kHz*. The effectiveness of a measure type is the percent reduction in the pressure resulting from a specific activity. The table depicts the most likely/expected effectiveness, and standard deviation is given in parenthesis.

Measure type ID	Activity Measure type	Restructuring of seabed morphology	Military operations	Research, survey and educational activities	Marine and coastal construction	Has corresponding existing measures in the SOM analysis (Yes/No)
150	Promotion of alternative/low noise technologies	30 (24) ○○●	36 (26) ○○●	20 (16) ○○●	Not assessed	Yes
154	Spatial/temporal restrictions for sensitive areas and species	36 (28) ○○●	Not assessed	23 (18) ○○●	43 (13) ●●●	No
159	Regionally harmonized and intensified noise monitoring and noise restrictions during marine and coastal construction	Not assessed	Not assessed	Not assessed	30 (11) ○●●	Yes
160	Regionally harmonized and intensified consideration of alternative/low noise technology in permit applications	29 (23) ○○●	Not assessed	19 (18) ○○●	37 (12) ○●●	No
161	Technological noise mitigation measures (e.g. bubble curtains, coffer damns, etc.)	Not assessed	Not assessed	Not assessed	39 (11) ●●●	Yes
162	Inclusion of noise impact risks for sensitive species in EIAs	20 (14) ○○●	Not assessed	12 (15) ○○●	24 (10) ○●●	Yes
163	Optimized scheduling (max intensity vs duration)	Not assessed	Not assessed	Not assessed	31 (15) ○●●	No
164	Mandatory noise monitoring and noise restrictions	35 (25) ○○●	Not assessed	20 (15) ○○●	Not assessed	Yes
165	Spatial/temporal restrictions of testing, training, and exercises for sensitive areas and species	Not assessed	35 (21) ○○●	Not assessed	Not assessed	Yes
166	Best practice for ship shock trials	Not assessed	21 (22) ○○●	Not assessed	Not assessed	No

167	Best environmental practices for UXO disposal	Not assessed	33 (23) ○○●	Not assessed	Not assessed	No
	Confidence	High	Moderate	Moderate	High	
	Number of experts	7	6	7	5	

Colour scale for the effectiveness of a measure type in percent (based on the expected value): 0-10%, 10-20%, 20-40%, 40-60%, 60-100%
Categories for the certainty of the effectiveness estimate (based on the relative size of the standard deviation to the expected value): low: ○○●, moderate: ○●●, high: ●●●
Data used: expert responses on the effectiveness of measure types
Full activity names:

- Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material)
- Military operations (infrastructure, munitions disposal)
- Research, survey and educational activities (seismic surveys, fish surveys)
- Marine and coastal construction

Table 5.4 Effectiveness of measure types (%) in reducing the *direct pressure of noise to porpoises and seals.* The measure types reduce the pressure directly by limiting the amount of received noise rather than the amount of noise created. The effectiveness of a measure type is the percent reduction in the specific pressure. The table depicts the most likely/expected effectiveness, and standard deviation is given in parenthesis. Further methodological development is required before these values are used for any purpose outside this analysis.

Measure type ID	**Pressure** **Measure type**	**Direct to impulsive noise pressure (porpoises)**	**Direct to impulsive noise pressure (seals)**	**Has corresponding existing measures in the SOM analysis (Yes/No)**
168	Use of acoustic deterrence devices and measures (e.g. ramp up procedure, warning blasts, etc.)	15 (13) ○○●	17 (11) ○○●	No
169	Optimized use and specifications for acoustic deterrence devices and measures (e.g. ramp up procedure, warning blasts, etc.)	11 (8) ○○●	17 (14) ○○●	No
	Confidence	Moderate	Moderate	
	Number of experts	5-6	6	

Colour scale for the effectiveness of a measure type in percent (based on the expected value):0-10%, 10-20%, 20-40%, 40-60%, 60-100%
Categories for the certainty of the effectiveness estimate (based on the relative size of the standard deviation to the expected value): low: ○○●, moderate: ○●●, high: ●●●
Data used: expert responses on the effectiveness of measure types

Which activities contribute to pressure inputs?

Table 6 shows the contribution of activities to the input of underwater noise, based on expert elicitation. The Baltic Sea was divided into five sub-areas for the activity-pressure assessment (see Figure 2). The direct impulsive noise (porpoises and seals) from measures that use acoustic deterrence devices affects the species directly, not through activities, and thus the activity-pressure contribution is not relevant.

The results are similar for the two frequency types of continuous noise. Eight activities were identified to contribute to the input of continuous noise. *Shipping* was considered to contribute the most in all five areas of the Baltic Sea. Besides s*hipping*, *tourism and leisure activities* and *fish and shellfish harvesting* had a relatively high impact in some sub-areas. The contribution of other activities (*restructuring of seabed morphology*, *military operations*, *research and educational activities*, *marine and coastal constructions,* as well as *infrastructure*) was rather small.

Seven different activities were identified to contribute to the input of impulsive noise, and these are to some extent different from the activities contributing to continuous noise. The activities with the highest contribution to impulsive noise vary across the five areas. The three main activities contributing to the input of impulsive noise are *military operations*, *research, survey and educational activities* and *marine and coastal construction*. *Military operations* have a high contribution in the Gulf of Riga and Gulf of Finland, and *research and educational activities* in the Gulf of Bothnia. The contribution of the other activities is rather low.

The certainty of the activity-pressure contribution estimates ranges from low to high.

[Further discussion and interpretation of the results, input from topic team]

Table 6. Activity-pressure contributions (%). The activity-pressure contributions show the percentage share the activity contributes to the input of underwater noise. The table depicts the most likely/expected contribution and standard deviation is given in parenthesis. Zero values mean that the contribution is less than 0.5%.

Activity Noise type and area	Fish and shellfish harvesting	Restructuring of seabed morphology	Tourism and leisure activities	Transport – shipping	Military operations	Research, survey and educational activities	Marine and coastal construction*	Marine and coastal infrastructure*	Extraction of minerals	Other/ not determined	Number of experts
Continuous noise 63/125 Hz Western Baltic	7 (4) ○●●	2 (2) ○○●	4 (2) ○●●	77 (5) ●●●	2 (2) ○○●	0 (0) ●●●	0 (0) ●●●	2 (2) ○○●		5 (1) ●●●	4
Continuous noise 63/125 Hz Central Baltic	10 (7) ○○●	2 (2) ○○●	3 (2) ○○●	76 (8) ●●●	2 (2) ○○●	2 (2) ○○●	1 (1) ○○●	1 (1) ○○●		3 (3) ○○●	7
Continuous noise 63/125 Hz Gulf of Riga	16 (4) ●●●	1 (1) ○○●	30 (5) ●●●	44 (5) ●●●	2 (2) ○○●	1 (1) ○○●	1 (0) ○○●	1 (0) ○○●		5 (5) ○○●	2
Continuous noise 63/125 Hz Gulf of Finland	8 (2) ●●●	3 (2) ○○●	7 (3) ○●●	76 (4) ●●●	1 (0) ○○●	1 (1) ○○●	1 (0) ○○●	1 (0) ○○●		3 (2) ○○●	2
Continuous noise 63/125 Hz Gulf of Bothnia	4 (4) ○○●		19 (18) ○○●	69 (17) ●●●						8 (4) ○●●	3
Continuous noise 2 kHz Western Baltic	7 (3) ○●●	2 (2) ○○●	15 (7) ○●●	60 (10) ●●●	5 (7) ○○●	1 (0) ●●●	1 (0) ●●●	2 (2) ○○●		8 (4) ○●●	4
Continuous noise 2 kHz Central Baltic	10 (7) ○●●	2 (2) ○○●	8 (4) ○●●	66 (9) ●●●	4 (5) ○○●	3 (4) ○○●	1 (1) ○○●	1 (1) ○○●		5 (4) ○○●	7
Continuous noise 2 kHz Gulf of Riga	10 (3) ●●●	2 (2) ○○●	32 (8) ●●●	45 (7) ●●●	3 (2) ○○●	1 (1) ○○●	1 (1) ○○●	1 (0) ○○●		5 (5) ○○●	2
Continuous noise 2 kHz Gulf of Finland	7 (2) ○●●	1 (0) ○○●	13 (6) ○●●	69 (7) ●●●	3 (2) ○○●	1 (0) ○○●	1 (1) ○○●	1 (1) ○○●		5 (5) ○○●	2
Continuous noise 2 kHz Gulf of Bothnia	4 (3) ○○●	0 (0) ●●●	9 (9) ○○●	78 (8) ●●●	0 (0) ●●●	0 (0) ●●●		0 (0) ●●●		8 (3) ○●●	3
Impulsive noise Western Baltic					29 (21) ○○●	35 (22) ○○●	24 (21) ○○●			12 (8) ○○●	4
Impulsive noise Central Baltic	2 (3) ○○●	5 (8) ○○●	2 (3) ○○●		14 (9) ○○●	36 (20) ○●●	17 (15) ○○●		2 (3) ○○●	8 (5) ○○●	6
Impulsive noise Gulf of Riga		3 (3) ○○●			64 (12) ●●●	16 (7) ○●●	6 (7) ○○●		1 (1) ○○●	10 (10) ○○●	2
Impulsive noise Gulf of Finland		3 (3) ○○●			77 (7) ●●●	11 (3) ●●●	6 (6) ○○●		1 (1) ○○●	3 (2) ○○●	2
Impulsive noise Gulf of Bothnia					13 (10) ○○●	73 (10) ●●●	6 (6) ○○●			8 (3) ○●●	3

*Unique or modified activities for noise (from the activity-pressure survey): Marine and coastal construction, i.e. pile driving, vehicle operation, excavation, etc.; Marine and coastal infrastructure, i.e. platforms, offshore renewables, bridges, tunnels, harbours etc. excluding military infrastructure.

Colour scale for the contribution of the activity to the pressure in percent (based on the expected value): 0-10%, 10-20%, 20-40%, 40-60%, 60-100%

Categories for the certainty of the activity-pressure contributions (based on the relative size of the standard deviation to the expected value): low: ○○●, moderate: ○●●, high: ●●●

Data used: expert responses to activity-pressure contributions

Full activity names:

- Fish and shellfish harvesting (all gears; professional, recreational)
- Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material)
- Tourism and leisure activities (boating, beach use, water sports, etc.)
- Transport – shipping (incl. anchoring, mooring)
- Military operations (infrastructure, munitions disposal)
- Research, survey and educational activities (seismic surveys, fish surveys)
- Marine and coastal construction
- Marine and coastal infrastructure
- Extraction of minerals (rock, metal ores, gravel, sand, shell)

What are the impacts of measure types?

The impacts of measure types show the impact of measure types on reducing the input of noise in the Baltic Sea. They include the effectiveness of measure types and the contribution of activities to the input of noise. Thus, the impact shows how much the measure type reduces the pressure input across all activities contributing to the input, and gives indications on which measures could be the most relevant in addressing underwater noise.

For the input of continuous noise 63/125 Hz, *spatial/temporal restrictions for sensitive areas and species* seems to be the most impactful measure type in all sub-areas. Other measure types having a relative high impact are *speed limits in sensitive areas or times*, *implementation of restrictions/permitting based on ship noise classifications*, and *promotion of alternative/low noise technologies*. The results are rather similar for the input of continuous noise 2 kHz as the same four measure types are among the most impactful, but there are less differences in the impacts across them.

For the input of impulsive noise with peak energy below 10 kHz, there is quite a lot of variation in the impacts of measure types across sub-areas. *Promotion of alternative/low noise technologies*, *spatial/temporal restrictions for sensitive areas and species*, and *regionally harmonized and intensified consideration of alternative/low noise technology in permit applications* are among the most impactful measures in several areas. In addition, *best environmental practices for UXO disposal* is considered to have rather high impact in some sub-areas.

Detailed information on the impacts of measures are given in Annex 11.

[Discussion on existing measures and their impact, which existing measures are driving pressure input reductions, which HELCOM measures are important but not yet implemented]

Background of respondents

For the effectiveness of measures survey for underwater noise, altogether 11 survey responses with 12 individual contributing experts were received. Two of the answers were a group response, with two and three contributing experts. Some experts participated in more than one response of the activity-pressure survey; seven responses were received from five different contracting parties. The number of experts contributing to the two types of noise surveys by contracting parties is shown in Table 7, with the sub-topic division and geographic area presented in Table 8.

Table 7. Number of experts contributing to the noise surveys

Survey	DE	DK	EE	FI	LT	LV	PL	RU	SE	Total
Effectiveness of measures	3	1	2	-	1	2	-	-	3	12
Activity-pressure contributions	1	1	1	-	-	-	2	-	2	7

Table 8. Number of experts contributing to the noise surveys

Survey	Sub-topic	Geographic area	Response count
Effectiveness of measures	Continuous noise 63/125 Hz	Whole Baltic	9
	Continuous noise 2 kHz	Whole Baltic	7
	Impulsive noise with peak energy below 10 kHz	Whole Baltic	9

For the experts participating in the effectiveness of measures survey, more detailed information about their background is available (Table 9). Experts stated acoustics, environmental protection, marine biology or monitoring and assessment as their field. About half of the experts had at least 10 years of experience in their field. Experts represented research institutions, museums, government institutes, state agencies or ministries.

Table 9. Years of experience in the field for noise surveys

	Effectiveness of measures survey	
Years	**Number of experts**	**Share of experts**
0-2 years	1	8 %
3-5 years	1	8 %
5-10 years	4	33 %
10-20 years	4	33 %
over 20 years	2	17 %

Discussion

Impact of alternative scenarios for development of human activities

The detailed results are presented for the most likely development scenario for the extent of human activities in 2016–2030. In addition, three other development scenarios were estimated: no change, low change and high change scenarios. These scenarios cover 9 out of the 31 activities in the SOM analysis. The extent of other activities is assumed to remain constant in all scenarios.

As activities contribute to pressure inputs, their assumed change over time affects the pressure input reductions and probability to achieve GES or state improvements. The impact depends on to what extent the activities contributing to the specific pressure input are covered in the change scenarios. The coverage of activities that contribute to the input of noise differs between noise types, being high for continuous noise and very low for impulsive noise.

The impact of alternative development scenarios is significant for continuous noise. Compared to the results based on the most likely development scenario, assuming no change in human activities by 2030 results in low or very low projected reductions in the input of continuous noise, depending on the frequency and sub-area. In the low development scenario, projected pressure reductions are close to zero, and sometimes negative or positive depending on the sub-area. With the high development scenario, approximately 10% larger pressure increases are projected compared to the most likely development. Thus, the assumption on the changes in human activities drives the results on the projected pressure reductions for the input of continuous noise.

For impulsive noise, the impact of alternative scenarios to the projected pressure reductions is negligible for all sub-areas due to the low coverage of the activities contributing to its input in the development scenarios.

Evaluation of quality and confidence

The SOM analysis for underwater noise has evaluated the pressure reductions, taking into consideration the effects of existing measures and changes in the extent of human activities by 2030. Proper sufficiency of measures analysis has not been possible due to a lacking GES threshold. Main elements of the results have been presented in a quantitative format, as the data have been deemed to suffice for that.

The overall certainty of the assessment for noise could generally be characterized as low (impulsive noise) or moderate (continuous noise). The number of expert responses to the effectiveness of measures survey is relatively high, and experts from six coastal countries have contributed to the assessment. Seven experts from five countries responded to the activity-pressure contribution survey. For the individual results, the average certainty ranges from low to high for the activity-pressure contributions, and from low to moderate for the effectiveness of measures types. The most common confidence level experts reported for their own evaluations for the effectiveness of measures is low or moderate.

The main factor causing uncertainty and potential inaccuracy in the results is the fact that the extent of the main activities contributing to the input of impulsive noise are assumed to remain constant until 2030, as no development scenarios have been made for them. This is a problem in particular with regard to marine and coastal construction, which could be expected to increase, as increases in both transport infrastructure and offshore windfarms are projected in the most likely scenario. These increases are high for offshore windfarms. Thus, ability to account for the changes in marine and coastal construction by 2030 would result in lower (or potentially negative) projected pressure reductions for impulsive noise. The situation is different for continuous noise, as the main activities contributing to its input are covered in the development scenarios. The accuracy of the results for impulsive noise could be improved by literature-backed up development scenarios for the main activities.

There were some technical challenges that affected the survey implementation. Firstly, there was a problem in the survey software for the effectiveness of measure types survey that resulted in losing some responses. The original responses became often unusable, as it was not possible to identify which items had been skipped on purpose and which were lost data. This issue was addressed by sending follow-up invitations for experts to review and, when needed, complement their original saved response. Not all experts participated in the review, and thus their response had to be deleted from the final sample. Secondly, the simultaneous assessment of effectiveness of a measure type and certainty of that effectiveness proved in some cases difficult, as it required placing non-quantitative dots in a coordinate system to generate quantitative estimates. The dots were translated into effectiveness and certainty values between 0 and 100. Some experts would have preferred that the quantitative estimates would have been visible and could have been transparently influenced.

When interpreting the results, the assumptions and generalizations that were made when collecting the input data and defining and using the data on activity-pressure input contributions, measure type effectiveness and pressure-state linkages need to be taken into account. The input data are based mainly on expert elicitations rather than existing models and data, and reflect substantial uncertainty. For more information on the SOM methodology, data collection and assumptions, see this document.

[Add information on the credibility of the results and how they should (and should not) be interpreted, input from topic team]

Reflection on measure types

Generally, the measure types for underwater noise appear to have struck a balance between specificity and general applicability, and as a whole do not show any systemic design flaws. However, there are concerns about the effectiveness assessments for the direct to pressure measure types (168 and 169, Table 5.4). The SOM approach was designed to allow these types of measures to exist, but they have only been used in the SOM noise assessment. The measure structure is correctly applied, but in the case of noise, where the separate issues of injury and disturbance have been combined into a single pressure, the topic structure masks the trade-offs implicit in these measure types. This is likely not solvable without separating the aspects of injury and disturbance, at least in the case of impulsive noise. The somewhat flawed implementation of these direct to pressure measure types is nevertheless a valuable learning opportunity for future development of measures affecting pressures directly, which are less common than measures affecting activities or state.

[Add further reflection on the measure types, input from topic team]

Lessons learned

Noise will be an interesting topic regarding future development. On one hand, compared to some other topics, noise topic experts were relatively comfortable working with the simplifications present in the SOM approach. On the other hand, further development of the topic seems tied to a much more detailed and technical approach independently investigating some or all of the input and effects of intensity, frequency, disturbance, and injury. This is particularly clear in the case of the direct to pressure measure types discussed above and for the use of literature data in the model. The model was not able to incorporate any of the large number of literature data points because the data structure fundamentally conflicted with the SOM approach (effectiveness of measures estimates in terms of reductions hertz and decibels versus percent reduction in the input of noise). Some conversion might have been possible, but the non-linear nature of dB is particularly difficult to fit into the current SOM approach. Targeted development of this topic with the deep involvement of topic experts will be required for future improvements.

The most important activities for impulsive noise currently lack human development scenarios and the data required to create such scenarios may not be readily available. Unfortunately, this topic is likely to see large increases in human impact in the future. Future improvement in human development scenarios should include consideration of ways to approximate changes in coastal construction, military activity, and research and survey activities.

[Add further reflections, input from topic team]

Use of results, implications and future perspectives

[Add information on how and to what purposes the results could be used and on the practical implications of the work, input from topic team]

[Add future perspectives and what are the information gaps to be tackled in the future, input from topic team]

It is worth noting that some of the SOM noise results should not be used in place of a literature backed cost-benefit analysis or environmental impact assessment, due in part due to the simplifications of using a single metric of percent reduction in place of the interacting metrics of decibels and hertz and the combination of noise injury and disturbance into the single pressure of impulsive noise.

Annexes

Annexes 1–9 contain the expert surveys as well as information on the measure types and the literature review. They are available on the SOM Platform workspace.

Annexes 10–11 contain graphs and tables that provide additional information and perspectives on the results.

Annex 1 Activity-pressure survey

Excel used as a template for receiving data for the activity-pressure input survey.

Annex 2 Modified activity list (if modified)

Excel containing the modified human activities list use for *Underwater noise*.

Annex 3 Measure types list

PDF containing the measure types used in the assessment of the effectiveness of measures for *Underwater noise*. Document includes examples of existing measures that if implemented would be included in the corresponding measure type.

Annex 4 Linking existing measures to measure types

Excel containing the identified existing measures and their relationship to the measure types used in the SOM analysis.

Annex 5 Literature review search terms

Excel containing the search terms used during the literature review on effectiveness of measures for *Underwater noise*.

Annex 6 Literature review summary

Excel document containing the effectiveness of measures data retrieved from the literature review.

Annex 7 Topic structure

Excel containing the relationships between measure types, activities, pressure inputs, state components, and sub-basins. Also contains information on GES thresholds.

Annex 8 Effectiveness of measures survey

PDF of the Effectiveness of measures survey for *Underwater noise*.

Annex 9 Pressure-state survey

No state assessment was conducted for *Underwater noise*, so no pressure-state survey is available.

Annex 10 Supplementary results for effectiveness of measures

[updated graphs to be included later]

[include in all figures and graphs the number of experts contributing to the result, include standard deviations or confidence intervals in the graphs, where appropriate]

Annex 11 Impacts of measure types

Table A11. Impacts of measure types (%) in reducing the input of underwater noise. The impact shows how much the measure type reduces the pressure input across all activities contributing to the pressure input.

Pressure for noise *(geographic area)*	**Measure type**	**Mean (Standard deviation)**
Input of continuous noise 63/125 Hz *(Central Baltic)*	Spatial/temporal restrictions for sensitive areas and species	37 (14)
	Speed limits in sensitive areas or times	28 (10)
	Implementation of restrictions/permitting based on ship noise classifications	27 (10)
	Promotion of alternative/low noise technologies	26 (15)
	Improve awareness of ship owners/companies about noise input, effects, and avoidance	20 (10)
	Raise consumer awareness about noise input and effects	13 (9)
	Optimized scheduling to reduce time spent at anchorage sites	11 (8)
	Use of shore-based power while in port	9 (8)
	Introduce engine noise standards	1 (1)
Input of continuous noise 63/125 Hz *(Gulf of Finland)*	Spatial/temporal restrictions for sensitive areas and species	37 (14)
	Speed limits in sensitive areas or times	29 (10)
	Implementation of restrictions/permitting based on ship noise classifications	28 (10)
	Promotion of alternative/low noise technologies	26 (15)
	Improve awareness of ship owners/companies about noise input, effects, and avoidance	20 (10)
	Raise consumer awareness about noise input and effects	13 (9)
	Optimized scheduling to reduce time spent at anchorage sites	11 (7)
	Use of shore-based power while in port	9 (8)
	Introduce engine noise standards	1 (1)
Input of continuous noise 63/125 Hz *(Gulf of Riga)*	Spatial/temporal restrictions for sensitive areas and species	31 (9)
	Speed limits in sensitive areas or times	24 (6)
	Implementation of restrictions/permitting based on ship noise classifications	23 (7)
	Promotion of alternative/low noise technologies	22 (10)
	Improve awareness of ship owners/companies about noise input, effects, and avoidance	17 (7)
	Raise consumer awareness about noise input and effects	8 (6)
	Optimized scheduling to reduce time spent at anchorage sites	6 (4)
	Introduce engine noise standards	6 (2)
	Use of shore-based power while in port	5 (4)
Input of continuous noise 63/125 Hz *(Western Baltic)*	Spatial/temporal restrictions for sensitive areas and species	37 (15)
	Speed limits in sensitive areas or times	28 (10)
	Implementation of restrictions/permitting based on ship noise classifications	27 (10)
	Promotion of alternative/low noise technologies	25 (15)
	Improve awareness of ship owners/companies about noise input, effects, and avoidance	20 (10)
	Raise consumer awareness about noise input and effects	13 (10)
	Optimized scheduling to reduce time spent at anchorage sites	11 (7)
	Use of shore-based power while in port	9 (8)
	Introduce engine noise standards	1 (1)
Input of continuous noise 63/125 Hz *(Gulf of Bothnia)*	Spatial/temporal restrictions for sensitive areas and species	35 (14)
	Speed limits in sensitive areas or times	28 (9)
	Implementation of restrictions/permitting based on ship noise classifications	27 (10)
	Promotion of alternative/low noise technologies	24 (14)

Pressure for noise ***(geographic area)***	**Measure type**	**Mean (Standard deviation)**
	Improve awareness of ship owners/companies about noise input, effects, and avoidance	19 (9)
	Raise consumer awareness about noise input and effects	12 (9)
	Optimized scheduling to reduce time spent at anchorage sites	10 (7)
	Use of shore-based power while in port	8 (7)
	Introduce engine noise standards	4 (4)
Input of continuous noise 2 kHz *(Central Baltic)*	Spatial/temporal restrictions for sensitive areas and species	27 (14)
	Promotion of alternative/low noise technologies	25 (17)
	Implementation of restrictions/permitting based on ship noise classifications	23 (14)
	Speed limits in sensitive areas or times	22 (13)
	Improve awareness of ship owners/companies about noise input, effects, and avoidance	17 (11)
	Raise consumer awareness about noise input and effects	8 (8)
	Optimized scheduling to reduce time spent at anchorage sites	8 (8)
	Use of shore-based power while in port	7 (10)
	Introduce engine noise standards	3 (2)
Input of continuous noise 2 kHz *(Gulf of Finland)*	Spatial/temporal restrictions for sensitive areas and species	29 (15)
	Promotion of alternative/low noise technologies	27 (18)
	Speed limits in sensitive areas or times	25 (13)
	Implementation of restrictions/permitting based on ship noise classifications	25 (15)
	Improve awareness of ship owners/companies about noise input, effects, and avoidance	19 (11)
	Raise consumer awareness about noise input and effects	9 (9)
	Optimized scheduling to reduce time spent at anchorage sites	9 (8)
	Use of shore-based power while in port	7 (10)
	Introduce engine noise standards	5 (3)
Input of continuous noise 2 kHz *(Gulf of Riga)*	Spatial/temporal restrictions for sensitive areas and species	29 (11)
	Promotion of alternative/low noise technologies	28 (14)
	Speed limits in sensitive areas or times	26 (10)
	Implementation of restrictions/permitting based on ship noise classifications	26 (11)
	Improve awareness of ship owners/companies about noise input, effects, and avoidance	20 (9)
	Introduce engine noise standards	12 (6)
	Raise consumer awareness about noise input and effects	6 (6)
	Optimized scheduling to reduce time spent at anchorage sites	6 (5)
	Use of shore-based power while in port	5 (7)
Input of continuous noise 2 kHz *(Western Baltic)*	Spatial/temporal restrictions for sensitive areas and species	27 (13)
	Promotion of alternative/low noise technologies	25 (16)
	Speed limits in sensitive areas or times	23 (12)
	Implementation of restrictions/permitting based on ship noise classifications	23 (13)
	Improve awareness of ship owners/companies about noise input, effects, and avoidance	18 (10)
	Raise consumer awareness about noise input and effects	8 (8)
	Optimized scheduling to reduce time spent at anchorage sites	8 (7)
	Use of shore-based power while in port	6 (9)
	Introduce engine noise standards	5 (4)
Input of continuous noise 2 kHz	Spatial/temporal restrictions for sensitive areas and species	29 (16)
	Promotion of alternative/low noise technologies	27 (20)

Pressure for noise (geographic area)	Measure type	Mean (Standard deviation)
(Gulf of Bothnia)	Speed limits in sensitive areas or times	25 (15)
	Implementation of restrictions/permitting based on ship noise classifications	24 (16)
	Improve awareness of ship owners/companies about noise input, effects, and avoidance	19 (13)
	Raise consumer awareness about noise input and effects	10 (10)
	Optimized scheduling to reduce time spent at anchorage sites	10 (9)
	Use of shore-based power while in port	8 (11)
	Introduce engine noise standards	3 (4)
Input of impulsive noise with peak energy below 10 kHz *(Central Baltic)*	Promotion of alternative/low noise technologies	19 (13)
	Spatial/temporal restrictions for sensitive areas and species	17 (10)
	Regionally harmonized and intensified consideration of alternative/low noise technology in permit applications	15 (10)
	Spatial/temporal restrictions of testing, training, and exercises for sensitive areas and species	10 (10)
	Inclusion of noise impact risks for sensitive species in EIAs	10 (8)
	Best environmental practices for UXO disposal	9 (10)
	Mandatory noise monitoring and noise restrictions	9 (8)
	Technological noise mitigation measures (e.g. bubble curtains, coffer damns, etc.)	7 (7)
	Best practice for ship shock trials	6 (8)
	Optimized scheduling (max intensity vs duration)	5 (6)
	Regionally harmonized and intensified noise monitoring and noise restrictions during marine and coastal construction	5 (5)
Input of impulsive noise with peak energy below 10 kHz *(Gulf of Finland)*	Promotion of alternative/low noise technologies	31 (21)
	Spatial/temporal restrictions of testing, training, and exercises for sensitive areas and species	27 (17)
	Best environmental practices for UXO disposal	25 (18)
	Best practice for ship shock trials	16 (17)
	Spatial/temporal restrictions for sensitive areas and species	6 (4)
	Regionally harmonized and intensified consideration of alternative/low noise technology in permit applications	5 (3)
	Inclusion of noise impact risks for sensitive species in EIAs	3 (2)
	Mandatory noise monitoring and noise restrictions	3 (2)
	Technological noise mitigation measures (e.g. bubble curtains, coffer damns, etc.)	2 (3)
	Optimized scheduling (max intensity vs duration)	2 (2)
	Regionally harmonized and intensified noise monitoring and noise restrictions during marine and coastal construction	2 (2)
Input of impulsive noise with peak energy below 10 kHz *(Gulf of Riga)*	Promotion of alternative/low noise technologies	27 (18)
	Spatial/temporal restrictions of testing, training, and exercises for sensitive areas and species	22 (14)
	Best environmental practices for UXO disposal	21 (16)
	Best practice for ship shock trials	14 (14)
	Spatial/temporal restrictions for sensitive areas and species	7 (5)
	Regionally harmonized and intensified consideration of alternative/low noise technology in permit applications	6 (4)
	Mandatory noise monitoring and noise restrictions	4 (3)
	Inclusion of noise impact risks for sensitive species in EIAs	4 (3)
	Technological noise mitigation measures (e.g. bubble curtains, coffer damns, etc.)	2 (3)

Pressure for noise ***(geographic area)***	**Measure type**	**Mean (Standard deviation)**
	Regionally harmonized and intensified noise monitoring and noise restrictions during marine and coastal construction	2 (2)
	Optimized scheduling (max intensity vs duration)	2 (2)
Input of impulsive noise with peak energy below 10 kHz *(Western Baltic)*	Spatial/temporal restrictions for sensitive areas and species	18 (11)
	Promotion of alternative/low noise technologies	17 (13)
	Regionally harmonized and intensified consideration of alternative/low noise technology in permit applications	15 (10)
	Inclusion of noise impact risks for sensitive species in EIAs	10 (8)
	Spatial/temporal restrictions of testing, training, and exercises for sensitive areas and species	10 (11)
	Technological noise mitigation measures (e.g. bubble curtains, coffer damns, etc.)	10 (9)
	Best environmental practices for UXO disposal	9 (11)
	Optimized scheduling (max intensity vs duration)	7 (8)
	Regionally harmonized and intensified noise monitoring and noise restrictions during marine and coastal construction	7 (7)
	Mandatory noise monitoring and noise restrictions	7 (8)
	Best practice for ship shock trials	6 (9)
Input of impulsive noise with peak energy below 10 kHz *(Gulf of Bothnia)*	Spatial/temporal restrictions for sensitive areas and species	19 (14)
	Promotion of alternative/low noise technologies	19 (13)
	Regionally harmonized and intensified consideration of alternative/low noise technology in permit applications	16 (13)
	Mandatory noise monitoring and noise restrictions	15 (12)
	Inclusion of noise impact risks for sensitive species in EIAs	10 (11)
	Spatial/temporal restrictions of testing, training, and exercises for sensitive areas and species	5 (5)
	Best environmental practices for UXO disposal	4 (5)
	Best practice for ship shock trials	3 (5)
	Technological noise mitigation measures (e.g. bubble curtains, coffer damns, etc.)	2 (3)
	Optimized scheduling (max intensity vs duration)	2 (2)
	Regionally harmonized and intensified noise monitoring and noise restrictions during marine and coastal construction	2 (2)
Direct to impulsive noise pressure – porpoise *(Baltic Sea)*	Use of acoustic deterrence devices and measures (e.g. ramp up procedure, warning blasts, etc.)	15 (13)
	Optimized use and specifications for acoustic deterrence devices and measures (e.g. ramp up procedure, warning blasts, etc.)	11 (8)
Direct to impulsive noise pressure – seals *(Baltic Sea)*	Optimized use and specifications for acoustic deterrence devices and measures (e.g. ramp up procedure, warning blasts, etc.)	17 (14)
	Use of acoustic deterrence devices and measures (e.g. ramp up procedure, warning blasts, etc.)	17 (11)