MSFD Common Implementation Strategy
Technical Group on Underwater Noise (TG-NOISE)

Thematic Workshop:

Way forward to define further Indicators for Underwater Noise

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FINAL REPORT

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Authors: Ferreira, M.F., Dekeling, R.P.A., Tasker, M., Werner, S., Gotjé W.

TG Noise acknowledges valuable contributions and revisions from:

Lisette Enserink(Ministry of Infrastructure and the Environment, NL, Member of WG GES), Jakob Tougaard (Aarhus University, Denmark), Manolo de Castellote (NOAA, US), Sónia Mendes (JNCC, UK), Alessio Maglio (SINAY, FR), Jens-Georg Fischer (BSH, DE), Mirjam Müller (UBA, DE), Peter Sigray (FOI, Sweden), Thomas Merck (BfN, DE), Niels Kinneging (RWS,NL), Thomas Folegot (QuietOceans, FR),Michel André (UPC, SP), Frank Thomsen (DHI, DK) Nathan Merchant (CEFAS, UK), Aleksander Klauson (Tallin Uni., EE), Stephen Robinson (NPL, UK), Maria Boethling (BSH, DE) and Lydia Martin-Roumégas (EC DG Environment).

Final editing was done by René Dekeling (RWS, NL), Mark Tasker (JNCC, UK), Stefanie Werner (UBA, DE) and Maria Ferreira (Coastal & Marine Union – EUCC).

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TG NOISE details:

Contact person: René Dekeling, Ministry of Infrastructure and the Environment, Directorate-General for Spatial Development and Water Affairs, Postbox 20901, 2500 EX The Hague, The Netherlands;
rene.dekeling@minienm.nl, +31 6 57994877
Chairs: Mark Tasker (JNCC), email: mark.tasker@jncc.gov.uk and René Dekeling, email: rene.dekeling@minienm.nl

Context

For the implementation of the Marine Strategy Framework Directive EU Member States need to evaluate the extent to which Good Environmental Status (GES) is achieved. Criteria and methodological standards are needed in order to set targets, and to evaluate whether targets are being met in reaching and/or maintaining GES for Descriptor 11 of the MSFD. In 2010 the European Commission decided on such standards for all descriptors (Commission Decision (COMDEC) of September 1, 2010). The COMDEC is currently under review, a revised version will be published later in 2016.

Presently, there are two indicators for underwater noise- one for impulsive noise and one for ambient noise. These indicators both describe the pressure on the environment rather than the impact, and therefore do not yet (directly) describe whether GES is reached. In the new Commission Decision, probably no new indicators will be defined; the first step is to find out how much pressure there is from underwater noise and then to evaluate whether GES is reached. In order to do this, further steps need to be made and potentially additional indicators need to be developed.

In order to contribute to these discussions, TG Noise organised a thematic workshop entitled ***Way forward to define further Indicators for Underwater Noise*** that was generously hosted by UBA/BSH and took place on 7-8th June in Hamburg, Germany.

The workshop was co-chaired by Stefanie Werner (UBA), René Dekeling and Mark Tasker (TG Noise Chairs) and introduced by the European Commission (Lydia Martin-Roumégas). It was attended by 59 delegates including members of the research community, government experts, NGO's (both environmental NGO's and commercial) and representatives from the Regional Seas Conventions (HELCOM, OSPAR, MEDPOL) and other regional agreements (e.g. ASCOBANS and ACCOBAMS) – see Annex 4.

Objectives

The Marine Strategy Framework Directive workshop focused on currently available science, and aimed to establish a common understanding to what extent the current indicators of underwater noise could be used to assess the impacts of anthropogenic noise, whether additional indicators are useful and the most promising ways to develop such indicators.

The participants evaluated the state of knowledge with regard to the different impact categories on marine life (e.g. disturbance, displacement, masking, physical impairment and injury) in order to support Member States and Regional Seas Conventions in their future assessments, e.g. in the MSFD 2018 assessments under preparation.

Specifically the aims of the workshop were as follows:

- To reach a common understanding on the usability of the present indicators and explore how to use these to the maximum
- To reach a common understanding on the need for additional indicators
- To agree on a common view on way(s) forward

The workshop was divided in 4 thematic sessions (topics):

Conceptual basis of indicators
Indicators of impacts of impulsive sound
Indicators of impacts of increased ambient sound
Indicators of impacts of underwater noise on fish and invertebrates

Four international experts provided insight into particular areas, specifically: the use of indicators in the CIS process (Lisette Enserink, Rijkswaterstaat, NL, Member of WG GES), effects of impulsive noise (Jakob Tougaard, Aarhus University, Denmark), impacts of increased ambient sound (Peter Sigray, FOI, Sweden, project leader of BIAS), and the effects of noise on fish and invertebrates (Frank Thomsen, DHI, Denmark, project leader of MaRVEN). The workshop was introduced by Stefanie Werner on behalf of the hosts, and René Dekeling on behalf of the TG Noise chairs followed by a presentation by Lydia Martin-Roumégas on behalf of the EC DG Environment. The presentations are available as annex to this report.

Main Workshop Outcomes

Conceptual basis of indicators

- There is general consensus about the usability and need for further implementation of the present pressure indicators.
- A step-by-step approach is recommended as the way forward, e.g.: description of the relevant impacts for indicator species including disturbance, masking, hearing impairment, definition of relevant level in terms of population displacements (although this will be hard to reach in the short term), and finally definition of GES.
- It is recommended to build upon existing scientific understanding, to learn from past examples and other descriptors approaches (e.g. D5 and D8) and to consider the involvement of policy makers in the process.

Indicators of impacts of impulsive sound

- The impulsive noise register at ICES is ready for use and data collection has started; this will initially provide information on temporal and spatial distribution of impulsive noise sources, through the year, across activities and throughout regional seas (OSPAR and HELCOM at least).
- To enable assessment of possible cumulative impacts of displacement on marine species at the population level, more parameters could be considered, such as noise propagation modelling and species distribution. Such a step-by-step approach might enable an assessment of exposure of populations of animals, description of the scale of potential for disturbance, and some suggestions for assessing (G)ES.
- Once cumulative impacts on disturbance are assessed, the next step could be to consider cumulative impact across noise impact categories (e.g. disturbance, impairment and injury), and possibly even wider outside the underwater sound effects (e.g. bycatch).
- Further assessments and target setting may be done at the regional or sub-regional level (depending size of regions), larger scale assessment and target setting is not feasible or sensible.

Indicators of impacts of increased ambient sound

- For future assessment and target setting, implementation of monitoring of the current indicator (11.2.1: continuous noise) remains essential.
- Actual monitoring of continuous low frequency noise (ambient noise) was taken up first in the HELCOM area by the BIAS project (Life+). The noise maps developed in the BIAS project enable determination of the anthropogenic component of the total environmental sound.
- There are large seasonal and likely annual variations in ambient noise levels. Identifying statistically significant trends (if they exist) in ambient noise levels remains challenging and probably will take many years.
- Noise maps may be used to identify changes of the acoustic habitat; development of an impact indicator addressing habitat changes (deterioration including from acoustic masking) look promising.
- Assessments and target setting may be done at the regional or sub-regional level (depending size of regions), larger scale assessment and target setting is not sensible**.**

Indicators of impacts of underwater noise on fish and invertebrates

- Currently most attention is given to impacts on marine mammals. For potential effects at the ecosystem level other species may be of more relevance as there are known effects of underwater noise on fish and invertebrates.
- Development and implementation of impact indicators on these groups is not feasible in the short term.

Thematic Sessions and Break-out Sessions

The workshop was divided into four thematic sessions. There was a general plenary discussion regarding the conceptual basis of indicators. Then the workshop attendees were divided into three break-out groups, following each of the invited speakers' presentations in sessions 2 to 4. Each of the break-out groups were requested to focus on one main question relating to each of the discussion themes in turn. The results of the discussions of the plenary discussion of session 1 and the outcomes identified by each group are reported below per session theme.

Session 1: Conceptual basis of indicators

This session discussed the following issues:

- general principles for the design of indicators
- closer look at the use of existing pressure indicators
- underlying concepts/principles for the development of impact indicators and concepts to derive meaningful biological thresholds

Chair: Mark Tasker
Invited Speaker: Lisette Enserink (Rijkswaterstaat, the Netherlands, Member of WG GES)

Summary of presentation: **Conceptual basis of Indicators**
Lisette Enserink, Rijkswaterstaat

The formal basis for the D11 indicators is the MSFD Commission Decision and its revision, the latter currently is in an advanced stage for adoption in October 2016. Concerning the development of indicators for the impact of noise its states: […] 'criteria relating to the environmental impacts of noise still need to be defined.' No further guidance is given.

The chairs of TG Noise have developed a useful set of criteria for the selection of GES criteria, which was tabled at WG GES in 2014: 1. Scale (activities causing noise occur at large scale), 2. Evidence of impact (long term, on populations and habitats, or an indication of potential long term impact), and 3. Added value (not regulated elsewhere, or contributing to e.g. assessment of cumulative impact). Criteria for the development of state/impact indicators have been refined over the years, e.g. by ICES. Indicators should be measurable, applicable in a wider area, responsive to (changes in) human activities and easy to communicate to stakeholders (Annex 1: Criteria for a good (state) indicator).

Going back to the early years of OSPAR, when protection of the sea primarily focused on pollution by hazardous substances and nutrients, we see two parallel management strategies: measures at source (pressures) and monitoring and assessment of water quality (state). Both strategies had their indicators and targets and the quantitative link between pressure and state was largely unknown (precautionary approach). Since the 1995 Esbjerg Declaration[1] the ecosystem approach to the management of human activities (starting with fisheries) is used as a leading concept. This requires quantitative evidence of causal relations between pressure and state and is most advanced in the regulation of fisheries through the assessment of fish stocks and setting limits to the amount of fish caught. The precautionary approach was never abandoned, but the emphasis now lies on understanding causal relationships and evidence-based measures.

[1] Ministerial Declaration of the Fourth International Conference on the Protection of the North Sea.

Did we succeed in implementing this concept? The most advanced examples are fisheries and eutrophication. In the case of eutrophication we now have a system of indicators, including pressures (inputs and concentrations of nutrients) and impacts (e.g. algal biomass, blooms of nuisance algae, oxygen depletion). We have (historic) background levels and assessment levels. There are models to predict the effectiveness of reduction measures and to estimate the transport of nutrients. Although there is still scientific and political debate, targets for pressures and impacts are increasingly well aligned in a quantitative manner.

In the case of hazardous substances however, chronic effects of substances appear to be very hard to detect in the marine environment, with the exception of some well-known cases (anti-fouling agents in whelks and persistent organic pollutants in top predators). Assessment levels are based on quantitative dose-effect relations for individual organisms, which are established in laboratory studies. Indicators on 'biological effects' measured in the marine environment usually also react to other parameters than hazardous substances, e.g. food availability and temperature. Knowledge of the effects of hazardous substances on the level of populations and marine ecosystems is still very limited.

What can we learn from these examples? First of all, that we should be pragmatic. Progress on the basis of knowledge currently available on noise pressures and impacts. Do not expect to have full or even sufficient understanding of impacts of noise on populations and ecosystems in the near future. Learn from assessment schemes for other 'pollutants', i.e. hazardous substances and eutrophication. Involve policy makers. Past experience has shown that (initial) assessment levels for indicators can be set on the basis of political will and incomplete understanding of causal mechanisms. And continue to work on the pressure indicators: source registration and sound mapping.

Key points to retain:
There is general consensus about the usability and need for further implementation of the present pressure indicators. A step-by-step and regional based approach is recommended as the way forward to predict for relevant impacts, such as including: description of disturbance, definition of level for relevant impacts e.g. in terms of population displacements, and finally definition of GES. In order to proceed it is recommended to build upon existing scientific understanding, to learn from past examples and other descriptors approaches (e.g. D5 and D8) and to consider the involvement of policy makers in the process.

Way forward:

- Be pragmatic; learn from past examples, build on existing scientific understanding, and involve policy makers in the process
- There are lessons to be learned by experience in indicator development: e.g. D5 and D8 pressure (inputs) and impact (effect indicators)
- Moving ahead with the present pressure indicators should support the learning process regarding the level of current evidence (that is not available yet) which will help to reach GES

Session 2: Indicators of impacts of impulsive sound

This session discussed the following issues:

- evaluate to what extent recent evidence of the effects of impulsive noise can be used to evaluate Environmental Status using the present pressure indicator (including options for cumulative effects);
- explore options to derive meaningful biological thresholds
- explore potential for new indicators describing impact and the potential scales at which such indicators for impulsive noise should be defined (EU-wide, regional, sub-regional)

Chair: René Dekeling
Invited Speaker: Jakob Tougaard (Aarhus University, Denmark)

Summary of presentation: **Indicator 11.1 (impulsive noise) - Marine mammals**
Jakob Tougaard, Aarhus University

The indicator 11.1 of the MSFD is a pressure indicator intended to monitor the pressure on the marine environment from man-made impulsive sound. The current way the descriptor is quantified is the yearly proportion of days where man-made impulsive sound in pre-determined areas exceeds a level likely to entail significant impact on marine animals. Reporting of development in this indicator has been facilitated by the development of an international database, hosted by ICES, which will allow member states (in the OSPAR and HELCOM regions initially) to deposit information about relevant activities and subsequently extract this information for assessment of GES in regional seas. The relevant activities for inclusion in the database are pile driving, seismic surveys, underwater explosions and certain types of military sonars (below 10 kHz).

For impulsive noise there are three main effects relevant for discussing GES. The first effect is behavioural disturbance caused by impulsive sounds. The effect on the affected animals from exposure to a single impulse is a small loss of opportunity to feed, nurse or other important activities. In itself this disturbance is unlikely to have any effect on the long term survival and reproductive success of the individual, but as the disturbances and associated metabolic losses are cumulative, the combined effect of repeated disturbance will at some point reach a level where effects on vital parameters occur. The cumulative effect may be exacerbated by the often very large impact distances, which can be tens of km for loud impulsive sounds, and therefore disturbance is now thought to be the most relevant effect when assessing whether GES is reached. The second negative effect caused by impulsive noise is noise induced hearing loss, either temporary (TTS) or permanent (PTS). The long term consequences of TTS and PTS are unknown, but it appears unlikely that the long term impact from a shorter lasting TTS (hours to possibly days) or a smaller (few dB) of low frequency PTS would be large. The third effect from loud impulsive sounds is direct injury and in the worst case death. This is a real concern for underwater explosions and under some circumstances for specific combinations of sonars and cetaceans (in particular beaked whales). These events, however, are comparatively rare and of stochastic nature and may therefore be difficult to include in a meaningful way in assessment of GES.

When it comes to assessment of GES the approaches can be grouped into three groups, based on pressure, risk or population impact. There is some overlap between the three and it is not of particular importance to draw sharp borders between them. They should be seen as a tool to organize thinking, rather than a formal classification.

Questions discussed in break-out groups:

1. *Do we agree that the present pressure indicator can be used, to some extent to characterize/quantify impact? If so, what are the most promising ways forward?*
2. *With the present evidence, can we identify potential directions for dedicated impact indicators?*
3. *Monitoring/registration has started at regional level, but should assessment be done at the same scale or at sub-regional scale?*

Key discussions outcomes:

The impulsive noise register can in principle be used to characterize impact as to some extent the pressure can be used as proxy for behavioural response. However, there are still outstanding questions on how to relate the pressure to the response (e.g. sound received level not the only factor determining the probability and magnitude of a response). To make progress on the question, a step-wise approach was discussed. This would include the noise (register) distribution mapping, potentially some noise propagation modelling (although this can be considerably simplified and need not be complex), and species distribution, measured and modelled (habitat suitability mapping).

There is agreement about the possibility to identify potential directions for impact indicators, however there are many issues/assumptions to take into account. Further parameters, other than marine mammal displacement to define impact indicators may be worth considering. Opinions on the possibility how these might be used as indicators were divided. Whereas some attendees had difficulties to see how that could work, others felt clearly, that at least some aspects are worth exploring:

- Loss of communication space (masking)
- % loss of habitat
- Habitat degradation index

Additional relevant parameters to explore could include:

- Changing in vocalizations (any changes, frequency, rate, etc.)
- Increase in stress (hormones concentrations, heart rate etc.)
- Threshold shift (TTS and PTS)
- Shift in migration routes
- Change in behavioural state (foraging, resting etc.)
- Habitat-use based analysis

Deriving impact indicators from stranded animals or species abundance trends is for a variety of reasons not feasible. Some suggestions were made as way forward that include standardizing existing approaches: e.g. number of disturbance days and extent of habitat impacted (considering any spatial and temporal differences in ecological importance, if known) and the development of a habitat degradation index. The approach of a habitat degradation index is important for both defining impacts for impulsive and even more for ambient noise. Approaches using population modelling could also be worth exploring (e.g. iPcoD, DEPONS).

Regarding monitoring/registration scales, the conclusion is that it may be justified to assess at a regional (e.g. Baltic) or sub-regional scale (e.g. OSPAR sub-regions). The reasons to report at smaller scale may include: scientific evidences (ecosystem differences, acoustic environment differences), or/and practical reasons (e.g. to align with other GES assessments, political, linked to management of activities, e.g. for important/critical habitats, operational, e.g. joint North Europe database). The assessment and reporting should be encouraged at regional/sub-regional level, and countries with adjacent marine areas should collaborate.

This approach will be easier to apply in the whole Baltic and North Seas rather than in the Mediterranean Sea as there are many non-EU countries involved there. It was noted that although MSFD assessment should be done at a relatively large scale, this would not be suitable for assessing impacts at a smaller scale.

Session 3: Indicators of impacts of increased ambient sound

This session discussed the following issues:

- evaluate experiences and options to monitor increased ambient noise levels
- evaluate existing knowledge on impacts and explore to what extent it will be possible to evaluate Environmental Status using the present pressure indicator
- explore potential for new indicator(s) describing impact, and the potential scales at which such indicators for increased ambient noise should be defined (EU wide, regional, sub-regional)

Chair: Stefanie Werner
Invited Speaker: Peter Sigray (FOI, Sweden, project leader of BIAS)

Summary of the **BIAS project experience**
Peter Sigray, FOI Sweden

The Baltic Sea is a semi-enclosed ocean with nine states bordering the sea. It consists of 8 sub-catchment areas (basins) and numerous harbours. The density of ships is one of the highest in Europe. It is estimated that about 2000 sizeable ships are at sea at any one time. Further, several large wind farms are planned to be erected adding further noise to the marine environment. Undoubtedly, due to the widespread character of noise it has to be assessed on a regional scale.

The EU-supported BIAS project addressed three main goals: firstly to establish a regional implementation of noise management (Descriptor 11 of the Marine Strategy Framework Directive), which includes development of user-friendly tools for management and to measure sound levels in the Baltic Sea; secondly to establish regional standards and methodologies that will allow for cross-border handling of data and results, which is necessary for efficient joint management; and finally to model the soundscape and thereby allow assessment of the entire Baltic Sea.

During 2014, the BIAS project ran a field programme where 39 sensors were deployed offshore throughout the Baltic Sea. The sensors were serviced every third month for maintenance and data recovery before being redeployed. The data has been used to establish monthly noise levels as well as to “calibrate” a numerical model of sound in the Baltic Sea. Soundscape maps were produced for the whole Baltic Sea. Monthly maps for 64, 125 and 2000 Hz were produced for three depth intervals. The results shows that the shipping lanes dominate the noise, but there are large variations in noise levels.

The soundscape maps constitute the cornerstones of the web-based planning tool, which facilitates a user-friendly interface between results and managers. The newly developed tool can be used to analyse the soundscape both spatially and temporally. Hence, the tool is designed to link pressure to impact in a user-friendly way. It can already be used to obtained statistical estimates on pressure that relates to species specific thresholds – one step closer to GES.

Questions discussed in break-out groups:

1. *Do we agree that the present pressure indicator can be used, to some extent to characterize/quantify impact? If so, what are the most promising ways forward?*
2. *With the present evidence, can we identify potential directions for dedicated impact indicators?*
3. *Monitoring will probably start at sub-regional level/'acoustic basin'; should assessment be done at the same scale?*

Key discussions outcomes:

The present pressure indicator on its own cannot characterise/quantify impact. There are a number of other features of the pressure that if measured, would improve the ability to assess impact. These features include: higher spectral resolution, higher temporal resolution and higher spatial resolution.

- Higher spectral resolution: The noise maps developed in the BIAS project (LIFE+) enabled the determination of the anthropogenic component of the total environmental sound. The BIAS project also investigated monitoring of an additional frequency band (2 kHz), but the added value of this 3rd frequency still needs to be demonstrated.
- Higher temporal resolution: There are large seasonal and likely inter-annual variations in ambient noise levels. Identifying statistically significant trends in ambient noise levels remains challenging and will take many years. Noise maps may be used to identify changes of the acoustic habitat; and may be promising in developing an impact indicator for habitat change (deterioration). It may be easier to develop an impact indicator based on percentiles of the pressure indicator (rather than a single value of the (arithmetic) mean).
- Higher spatial resolution: Higher spatial resolution may be needed if higher resolution is required in the assessment of impact, because there is a low variability of noise along major shipping lanes and large seasonal variability away from shipping lanes. Furthermore the nature of the noise can be very different from place to place and ambient noise depends on many environmental conditions (bathymetry, sediment, halocline, waves, etc.) Modelling can help. Characterisation of sources of natural sound would need extra effort in some places.

The anthropogenic contribution to the total noise budget is relevant when assessing impact. Important is also to identify the origin of noise (e.g. number of vessel, size, speed, category, time spent in an area, etc.). It has been suggested to link the origin of noise to dB to try to elaborate decision aiding rules. AIS and VMS data are commonly available for commercial and fishing vessels – however only limited for small recreational vessels. In general where possible, AIS/VMS data collection and storage should be supported and encouraged.

Assessment is already possible for relevant impacts such as %loss of habitat, habitat degradation (index) and communication space masking based on hearing thresholds for key species (e.g. harbour porpoise, cod, bottlenose dolphins, minke whales). Auditory diagrams are therefore a good starting point to assess impact on masking for key species and threatened fish and/or fish of commercial interest, nevertheless one has to keep in mind that effects may not be related solely to ability to hear a sound.

For increased ambient sound it is may be useful to complement the existing indicator based on regional considerations with additional frequency bands (taking into account regional different species and sound sources of concern). The following issues were raised during the discussion:

- To set thresholds for individual seasons instead of yearly averages
- Identification of areas that may be affected by sound in other frequency bands; an example that was mentioned is the West coast of Scotland, where many seal scares (ADDs) are used, generating sound at 10 kHz that may be relevant for harbour porpoises.
- Identification high use areas and refuge areas, and identify biological important areas to be kept quiet (precautionary approach)
- Change from trends to averages thresholds might be considered
- Impacts of ambient sounds may occur at other frequencies than those being monitored (e.g. masking may be occurring at higher frequencies). It should be possible to model those higher frequencies, noting that in some seas, transmission properties may be such that the influence of higher frequency sources is wider than in other seas. At present though there is no evidence of major impact from increased ambient sound (see Section 4 below), so it will be difficult to establish GES against any indicator of impact. It would however be useful to understand the variation in anthropogenic ambient sound at finer scales of space and time than the current proposed trends. It would be then be easier to distinguish when and where impacts might be more likely to occur

Further considerations of the relationship between anthropogenic and natural ambient sounds were discussed:

- Averages can be dominated by natural sounds,
- Variation in natural sounds need to be better understood
- The signal to noise ratio is important
- Measurements need to be standardised, e.g. what kind of averaging times are relevant biologically
- The concept of “acoustic habitat” and its potential degradation needs further exploration and possible development as an indicator, e.g. to predict for temporal habitat loss
- Eventually, “habitat degradation” or, e.g., more precisely “%loss of acoustic habitat by species/area” might provide a way of combining the information from the two existing indicators 11.1 and 11.2 into a single impact indicator.

It was agreed that monitoring and modelling of ambient sound should be at the regional or sub-regional scale (depending on the size of the regions). Effects may occur at much smaller scales, but so the choice of an “impact indicator” needed to take account of both scales. It was noted that both the anthropogenic ambient sound and its possible biological consequences may vary through the year (or at shorter time scales) so this ideally needed to be taken into account in any assessment.
It was suggested to consider on a local scale the overlap of species hotspots especially for sensitive species with ambient noise sources and aggregate or scale that up in the GES assessment. The acoustic basin approach for determining soundscapes (pressure) was supported in the discussion (based on oceanographic features, e.g. bathymetry).

Session 4: Indicators of impacts of underwater noise on fish and invertebrate

This session discussed the following issues:

- evaluate knowledge to date on potential impacts (at population or ecosystem scale) of underwater noise on fish and invertebrates
- explore whether new indicators describing impact should address fish and invertebrates and the potential scales at which such indicators could be defined (EU wide, regional, sub-regional)

Chair: Michel André
Summary of presentation: **Indicators of impacts of underwater noise on fish and invertebrates**
By Frank Thomsen[2], Michel André[3]

Marine invertebrates and fish comprise a very wide array of taxa. There are approximately 35,000 extant fish species with more than 50 % marine, and invertebrates (marine and non-marine) number much more than a million species. Many fishes and invertebrates produce sound and at least for fish we know that acoustic signals are used in short-range communication during aggressive encounters, courtship and spawning. Fish species sensitive to sound comprise those that only receive particle motion (e.g. flatfish) and those that are also sensitive to pressure (e.g. herring). Invertebrates generally detect particle motion. Both fish and invertebrates are mainly sensitive to frequencies well below 1 kHz. Most human generated sounds have most energy below 1 kHz too. Injury and hearing loss have been documented for fish. However, behavioural- and masking effects could be more relevant for the Marine Strategy Framework Directive due to the suspected larger impact ranges. For fish, a few studies have indicated behavioural response to impulsive sounds and there is evidence for acoustic masking due shipping sound. However, population consequences of these disturbances are unknown. For invertebrates, we have less knowledge on effects of underwater noise than for fish but a few investigations have shown acoustic trauma in cephalopods from relatively low-level sounds. From the limited knowledge gained so far, we conclude that behavioural response in fish during important life stages, masking of fish communication in high noise areas and injury of some invertebrates to low levels noise might be topics for the development of further MSFD D11 criteria. Yet, it is clear that the already existing indicators are very relevant when defining GES for fish and invertebrates. It could be explored whether there is a need to consider particle motion values to address the specific hearing characteristics of both taxa. However, the current focus shall be on operationalising the two existing indicators in a way that they can be used in managing large-scale behavioural effects and masking.

Questions discussed in break-out groups:

1. *Assuming that we do not need (or will be able) to address all species groups, which species groups might be most promising to address first?*
2. *Are most concerns with ambient noise or with impulsive noise? Can we identify potential directions for indicators for these species groups?*
3. *If indicators for other groups would be defined, what is the most relevant scale for monitoring and assessment?*

[2] DHI, Agern Alle 5, DK-2970 Hørsholm, Denmark frth@dhigroup.com
[3] Laboratori d'Applications Bioacústiques (LAB), Technical University of Catalonya, BarcelonaTech (UPC), Rambla Exposició, 24, 08800 Vilanova i la Geltrú, Barcelona, Espanya, michel.andre@upc.edu

Key discussions outcomes:

There are effects known of underwater noise on fish and invertebrates, but it is not known whether these effects scale up to the population or wider area impacts.

There is much less knowledge of effects on other species compared with marine mammals. Invertebrates and fish have other vulnerabilities than mammals – they are often benthic or demersal and stay close to the seabed or they react by going deeper after exposure (marine mammals can surface and to an extent mitigate the effect of the sound exposure). If there are impacts on fish or certain invertebrates, then there may be commercial considerations, and in addition there may be food chain effects.

In technical terms, issues related with sound particle vibration and seabed vibration are relevant, but there is not enough knowledge of their consequences and more research is required. Seabed vibration tends to be local (relatively short range) and is therefore not likely to be useful to develop as an MSFD indicator; sound particle motion is also an issue but in general can be predicted from sound pressure in the acoustic far-field.

Presently, indicators could possibly be defined for fish and these may be able to be implemented at a sub-regional scale for the larger regions. However, further studies on a few suitable fish species are needed. Additional criteria to consider are as follows:

1. Which species are more sensitive/vulnerable to noise exposure?
2. What are umbrella / canary species that may represent wider effects?
3. Which potential indicator species do we have a good evidence base for? Or good *potential* evidence base (e.g. ease of study)

The following points were made:

- Existing evidence base may have biases for particular species/groups, Need to regularly review evidence base, which is developing rapidly
- Link to other descriptors, e.g. in fisheries management
- Precautionary approach would take most sensitive species as indicator species (caveat is variation in species sensitivity to different frequencies/aspects of sound)
- Need to be aware of interactions with other species (e.g. prey/predators: ecosystem-based management)
- It is important that indicator can be expressed as a pressure (sound) so that thresholds can be defined.

The principles needed to select relevant species for setting up a biological indicator are as follows:

- There must be evidence for impact from sound on that species
- The species must be a relevant species for the ecosystem
- The species must be widely distributed
- Information on the distribution of these species and the possible impact on these species should already have been collected
- The species should not be impacted by many other strong pressures, in order to distinguish the impact of sound from other pressures.

In terms of interpretation of ambient sound versus impulsive noise as masking versus displacement the following has been concluded.

Displacement of species is one of the main concerns. Displacement probably occurs mainly from impulsive sounds. There is anecdotal evidence from fishermen available and scientific studies from Norwegian scientists, but these have been disputed. For pile driving several studies carried out in the UK indicate that herring is a sensitive species (in the UK no seismic surveys are allowed on herring spawning grounds during the spawning season). In some studies (mostly laboratory studies) also aversion and increased swim speed have been observed, but it is not clear whether and how those results can be translated to the marine environment (where laboratory studies have been shown to be very useful to assess direct physiological effects like hearing damage or injury).

Masking by continuous sound may be important for fish by a possible influence on communication and even navigation (acoustic cues are sometimes used). Several studies (Italian study, UK studies (Bristol University)) have shown links between sound and mortality.

For invertebrates there is a potential for masking where invertebrates can be shown to use sound (possible for larval stages) (shipping). Injury from impulsive sound might be one of main concerns for invertebrates.

However it is not yet feasible to define a suitable impact indicator for invertebrates and fish, due to a lack of knowledge, especially for invertebrates. Potentially in the future, further research may support the development of such an indicator. Long term comparative studies in loud and quiet areas, identification of representative species (sensitive species), species interaction (masking) and critical ratios and masking thresholds (masking) should be examined.

It is also relevant to consider different regional issues: the scenarios might include deep sea (e.g. Atlantic Ocean) - coastal shelf – estuarine - archipelago – reefs.

LIST OF ANNEXES:

Annex 1: Criteria for a good (state) indicator

Criterion	Specification
Sensitivity	Does the indicator allow detection of any type of change against background variation or noise?
Accuracy	Is the indicator measured with a low error rate?
Specificity	Does the indicator respond primarily to a particular human pressure, with low responsiveness to other causes of change?
Simplicity	Is the indicator easily measured?
Responsiveness	Is the indicator able to act as an early warning signal?
Spatial applicability	Is the indicator measurable over a large proportion of the geographical to which it is to apply e.g. if the indicator is used at a UK level, is it possible to measure the required parameter(s) across this entire range or is it localised to one small scale area?
Management link	Is the indicator tightly linked to an activity which can be managed to reduce its negative effects on the indicator i.e. are the quantitative trends in cause and effect of change well known?
Validity	Is the indicator based on an existing body or time series of data (either continuous or interrupted) to allow a realistic setting of objectives?
Communication	Is the indicator relatively easy to understand by non-scientists and those who will decide on their use?

Annex 2: Workshop Programme (document attached)

Annex 3: Speakers Presentations (documents attached)

Annex 4: List of Participants (document attached)

Annex 5: List of references

TG Noise Publications and other main references:

- 2012, Van des Graaf AJ and al., *European Marine Strategy Framework Directive - Good environmental status (MSFD GES): Report of the technical subgroup on Underwater noise and other forms of energy*. http://ec.europa.eu/environment/marine/pdf/MSFD_reportTSG_Noise.pdf

- 2014, JRC Scientific and Policy reports. *Technical guidance on monitoring for the Marine Strategy Directive* http://publications.jrc.ec.europa.eu/repository/bitstream/JRC88073/lb-na-26499-en-n.pdf.pdf

- 2014, JRC Scientific and policy reports, Monitoring guidance for underwater noise in European Seas. Part I Part II: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/monitoring-guidance-underwater-noise-european-seas-part-ii-monitoring-guidance

- 2015 CEFAS, Impacts of noise & use of propagation models to predict the recipient side of noise. Final Report. http://mcc.jrc.ec.europa.eu/documents/201605065206.pdf

JRC MSFD – Competence Centre
http://mcc.jrc.ec.europa.eu/