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**A basin-wide strategy for underwater noise monitoring in the Mediterranean (EO 11)**

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UNEP/MAP
Athens, 2015

**ECOLOGICAL OBJECTIVE 11: ENERGY INCLUDING UNDERWATER NOISE**

**A basin-wide strategy for underwater noise monitoring in the Mediterranean**

*This document has been prepared, thanks to the financial support of* ***ACCOBAMS*** *and* ***UNEP/MAP – RAC/SPA****, by experts from the Joint ACCOBAMS/ASCOBANS/CMS Working Group on Noise (Alessio MAGLIO as coordinator, Manual CASTELLOTE and Gianni PAVAN).*

## EXECUTIVE SUMMARY

The Ecosystems Approach (EcAp) initiative, as implemented in the framework of the Barcelona Convention, is structured in 11 Ecological Objectives, where the eleventh is energy including underwater noise (EO11). In this context, the Agreement on the Conservation of Cetaceans in the Black Sea, the Mediterranean Sea and the contiguous Atlantic area (ACCOBAMS), in accordance with the Secretariat of the Mediterranean Action Plan of the United Nations Environment Program (UNEP/MAP), launched a study to develop a basin-wide strategy for underwater noise monitoring in the Mediterranean. Hence, the present technical guidance was developed by members of the Joint ACCOBAMS/ASCOBANS/CMS Noise Working Group (JNWG). This guidance outlines the indicators related to EO11, and provides the necessary information for stakeholders to secure a correct and straightforward implementation. The basis for developing such strategy was the Descriptor 11 of the Marine Strategy Framework Directive (MSFD) of the European Union and therefore two separate indicators are used for impulsive noise and continuous noise (indicator 11.1.1 and 11.1.2, respectively). Indicator 11.1.1 addresses space-time distribution of impulsive noise sources, while the 11.1.2 addresses levels of continuous noise through the use of measurements and models. The proposed strategy on noise monitoring recommends several adaptations for the Mediterranean case. Particularly, both indicators are more closely related to the acoustic biology of key marine mammal species of the Mediterranean which are known to be sensitive to noise, i.e. the fin whale, the sperm whale and the Cuvier's beaked whale. The proposed monitoring strategy, represents a further important progress towards an effective and widely agreed regulation of underwater noise at a regional scale.

### Indicator 11.1.1

*Proportion of days and geographical distribution where loud, low and mid-frequency impulsive sounds exceed levels that are likely to entail significant impact on marine animals*

GES related to indicator 11.1.1 is defined in terms of the space-time distribution of impulsive noise sources. However, in the above definition some terms and expressions need to be explained before defining GES: *proportion of days* is to be interpreted as the number of days over a calendar year; *geographical distribution* is defined as the number of grid cells over a 20 × 20 km grid covering the whole Mediterranean basin; i*mpulsive sounds* are to be interpreted as source levels of anthropogenic noise sources; *impact* is defined as severe and/or sustained and/or long-term avoidance of an area, and/or disruption of acoustic behaviour, i.e. stop calling and/or stop clicking. Further, we need to define what impulsive noise sources are to be taken into account. The JNWG recommends addressing all human activities using low frequency noise sources, regardless of their source level, thus accounting for fin whale sensitivity over very long ranges. Also, it is recommended to address

human activities using mid frequency noise provided their source levels exceeds a fixed threshold. Thresholds for mid frequency noise sources were set in order to account for Cuvier's beaked whale sensitivity to mid frequency sounds. So, in order to define GES related to indicator 11.1.1, it is recommended to establish a spatial threshold (i.e. a number of cells over a grid) and a time threshold (i.e. a number of days over a calendar year). Exceeding either of such thresholds in a given year means that GES is not attained for that year. Indicator 11.1.1 is presented in synthesis in table 1 below.

**Indicator 11.1.2**

*Levels of continuous low frequency sound with the use of models as appropriate*

GES related to indicator 11.1.2 is defined in terms of levels of continuous noise in specific frequency bands. These are third-octave bands centred at 20, 63, 125, 250, 500 and 2000 Hz. Frequency bands were selected where shipping noise is likely to be dominant compared to other sources according to Mediterranean data (63, 125, 250 and 500 Hz), but also where noise potentially masks fin whale calls and sperm whale clicks (20 Hz and 2000 Hz, respectively). Two metrics are recommended for monitoring: the annual arithmetic mean Sound Pressure Level (SPL), expressed in dB re 1µPa (rms); and the annual 33.3% Exceedance Level (or $L_{33.3}$), meaning the noise level exceeded 33.3 % of a calendar year. $L_{33.3}$ is aimed at accounting for possible increase in ambient noise levels due to recreational craft in summer. In fact, it is assumed that recreational craft can cause significant increase in ambient noise levels during the summer period, i.e. June to September, which represents a third (= 33.3%) of a year. So, in order to define GES related to indicator 11.1.2, it is recommended to establish a conservative noise threshold. If the annual arithmetic mean SPL is above the noise threshold, GES is not met that year for that region while if the mean is below, the $L_{33.3}$ is inspected to figure out if during summer the threshold was exceeded. If so, GES is not met again. Indicator 11.1.2 is presented in synthesis in table 2 below.

**Needs for GES assessment concerning Ecological Objective 11**

For GES assessment related to EO11, three thresholds need to be established: a spatial and a temporal threshold concerning indicator 11.1.1 and a noise threshold concerning indicator 11.1.2. The JNWG considers that at this stage conservative thresholds can be proposed for both indicators and hence the ACCOBAMS Secretariat is requested to carry out the following tasks with a view to find out the thresholds:

1. Reviewing what spatial and temporal thresholds have been selected by European Member States for implementing impulsive noise indicator of D11
2. Fulfilling action CA 2b1 of the 2014-2016 Work Plan ("Identifying Noise Hotpots for cetaceans in the ACCOBAMS area") in order to provide the necessary baseline information on space-time distribution of impulsive noise sources across the Mediterranean
3. Reviewing ambient noise data available for the Mediterranean Sea as a follow up of the present work in order to identify the threshold for continuous noise indicator 11.1.2.

**Table 1.** Key concepts concerning indicator 11.1.1 (impulsive noise).

| Impulsive Noise indicator in synthesis | | | | |
|---|---|---|---|---|
| Description | Tools | Variables of the indicators | Thresholds | GES assessment |
| **Number of days over a year and number of cells over a grid** in which activities using loud source levels occur | A register of activities using impulsive noise sources | All activities using low-frequency sources are included in the register<br><br>Activities using mid-frequency sources are included in the Register provided the source level exceeds a noise thresholds : 176 dB re 1µPa rms for sonar, deterrent devices and other non-pulse sounds; 186 dB re 1µPa$^2$s m$^2$ for other pulse sounds[1]<br><br>Activities included in the register are mapped through cartographic software on a gridded space. Grid size is 20 x 20 km throughout the Mediterranean.<br><br>The number of days in which impulsive sound occur is computed by grid cell | Two thresholds are to be set, these are site-specific:<br><br>Spatial threshold = maximum acceptable number of grid cells in which impulsive noise occurs<br><br>Temporal threshold = maximum acceptable number of days over a year in which impulsive noise occurs | GES is not met for a given year if either the spatial or temporal threshold is exceeded |

[1] Definition of *pulse* and *non-pulse* sounds are given by Southall et al. (2007). TSG Noise uses such definition in addressing the impulsive noise indicator (Van der Graaf al. 2012)

**Table 2.** Key concepts concerning indicator 11.1.2 (continuous noise).

| **Ambient Noise indicator in synthesis** | | | | |
|---|---|---|---|---|
| Description | Tools | Variables of the indicators | Thresholds | GES assessment |
| **Arithmetic mean SPL over a year** (dB re 1μPa rms)<br><br>and<br><br>**$L_{33.3}$, i.e. 33% exceedance level**[2] **(**dB re 1μPa rms**)** | Existing monitoring networks for measurements (EMSO/INFN Network)<br><br>Acoustic Modelling and Mapping software | Frequencies to be monitored are third-octave bands centred at (with justification):<br><br>- 20 Hz (fin whale biological significance)<br>- 63 Hz (shipping noise sound energy content)<br>- 125 Hz (shipping noise sound energy content)<br>- 250 Hz (shipping noise sound energy content in the Med)<br>- 500 Hz (shipping noise sound energy content in the Med)<br>- 2000 Hz (sperm-whale biological significance ) | Threshold = ambient noise level in dB re 1μPa rms | Both the annual arithmetic mean and $L_{33.3}$ are inspected.<br><br>The $L_{33.3}$ index can capture seasonal increase due to recreational craft during summer<br><br>If $L_{33.3}$ exceeds the threshold, than GES is not met |

[2] In the present report, the *L* notation for Exceedance Levels (e.g $L_{33.3}$, $L_{10}$, $L_{90}$ etc.) means *unweighted sound pressure level for continuous sound that is exceeded for N% of the time interval considered* (de Jong *et al.*, 2011)

# INDEX

## 1. Introduction

Anthropogenic energy introduced by human activities into the marine environment includes sound, light and other electromagnetic fields, heat and radioactive energy. Among these, the most widespread and pervasive is underwater sound (Dekeling *et al.*, 2013a). Sound energy input can occur at varying spatial and temporal scales. Anthropogenic sounds may be of short duration (i.e. impulsive) or be long lasting (i.e. continuous). Sound transmission in the marine environment is very variable. Lower frequency sounds can travel far (tens to thousands of kilometres), whereas higher frequency sounds transmit less well in the marine environment (hundreds of meters to few kilometres (Urick, 1996). Sources of marine noise pollution include ship traffic, geophysical exploration and oil and gas exploitation, military sonar use and underwater detonations, telemetry devices and acoustic modems, scientific research involving the use of active acoustic sources, and finally offshore and inshore industrial construction works. Such activities are growing throughout the Mediterranean Sea (e.g.De Micco; OWEMES, 2012; US Energy Information administration, 2013).

Marine organisms can be adversely affected both on short and long timescales (and include acute or chronic impact and temporary or permanent effects (Richardson et al, 1995). Adverse effects can be subtle (e.g. temporary reduction in hearing sensitivity, stress effects causing reduced immunity, reproduction success or survival), or more obvious (e.g. injury, death). The former may be difficult to observe and evaluate while the latter may in some circumstances be related to acute short-range noise exposures. Management concern is primarily associated to the negative effects of noise on sensitive protected species, such as some species of marine mammals, though there is growing awareness that an ecosystem-wide approach also needs to be considered.

In the framework of the Mediterranean Action Plan of the United Nations Environment Program (UNEP/MAP), the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) defines pollution as follows: “*Pollution” means the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results, or is likely to result, in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of seawater and reduction of amenities* (article 2-a). With regard to assessment and monitoring purposes, underwater noise is concretely being considered by the Contracting Parties to the Barcelona Convention for the first time under the ongoing implementation of the Ecosystems Approach process (**Decision 17/6**). Eleven Ecological Objectives (EO), and respective operational objectives and indicators have been agreed for the Mediterranean through **Decision 20/4** during the 17$^{th}$ Meeting of Contracting Parties (COP 17). Indeed, following the definition contained in the Decision 20/4, the EO11 is achieved when **noise from human activities causes no significant impact on marine and coastal ecosystems**. However, during the last Meeting of Contracting Parties (COP 18, Istanbul, 2013), **Decision 21/3** provided a specific list of descriptions of good environmental status and targets for the other EOs, contrary to EO11, considered not yet sufficiently understood to allow a proper definition of good environmental status.

In this context, the Agreement on the Conservation of Cetaceans in the Black Sea, the Mediterranean Sea and the contiguous Atlantic area (ACCOBAMS), in accordance with the Secretariat of the UNEP/MAP, launched a study to develop a basin-wide strategy for underwater noise monitoring in the Mediterranean. Hence, the present technical guidance was developed by members of the Joint ACCOBAMS/ASCOBANS/CMS Noise Working Group (JNWG). This document outlines the importance of assessing and monitoring underwater noise in the Mediterranean Sea, and discusses the issues related to the choice of indicators currently proposed for the implementation of Descriptor 11 of the Marine Strategy Framework Directive (MSFD), with a view to propose adaptations to the

Mediterranean case, whenever possible. The monitoring strategy here proposed brings forward the work carried out so far by UNEP/MAP, in coherence with other international legal frameworks operating in the area (such as ACCOBAMS and the European Union Directives).

### 1.1. Underwater noise in the Mediterranean Sea

The Mediterranean basin is an almost enclosed sea area highly exploited by humans, where all the aforementioned noise-producing human activities take place on a regular basis. Some features belonging specifically to the Mediterranean region need to be taken into account while addressing underwater noise impacts:

- The presence of highly sensitive and/or endangered species
- The heavy human development of the coastal region
- The high concentration of cumulative pressures in many areas

It has been demonstrated that naval exercises involving the use of mid-frequency active sonars caused several mass stranding events of Cuvier's beaked whales along the coasts of the Mediterranean Sea and in other sea areas at least during the last 20 years (e.g. Frantzis, 1998; Fernandez *et al.*, 2004; Martin *et al.*, 2004; Agardy *et al.*, 2007; Filadelfo *et al.*, 2009). Such correlation has not been identified with any other anthropogenic noise source, although this cannot be ruled out for the case of geophysical surveys (e.g. Southall *et al*., 2013; Castellote and Llorens 2013). There is concern that such anthropogenic noise sources may play a role in increasing stress on marine fauna (Rolland et al., 2012). It should be remembered as well that the Mediterranean harbours one of the most critically endangered mammal populations in the world, i.e. the Mediterranean Monk Seal. Furthermore, based on recent IUCN assessments, several cetacean species are experiencing a decreasing population trend, e.g. the bottlenose dolphin and the sperm whale (Notarbartolo di Sciara et al,. 2012; Bearzi et al,. 2012).

Several international legal frameworks addressing environmental protection and conservation recognise noise as a pressure factor that need to be assessed, monitored and where necessary mitigated. In this context, the ACCOBAMS Agreement is concretely working toward a wide adoption of operational measures aimed at mitigating the impacts of anthropogenic noise on marine mammals. The main tools already developed include:

- ACCOBAMS Resolution 4.17 (*Guidelines to address the impact of anthropogenic noise on cetaceans in the ACCOBAMS area*, adopted by Parties in 2010), in which operational measures and procedures are outlined for each noise-producing human activity;
- *Guidance on underwater noise mitigation measures* (ACCOBAMS, 2013), a practical document aimed at guiding industrial companies in the implementation of procedures to reduce the risk of inducing acoustic impacts.

## 2. The choice of indicators for monitoring and assessing anthropogenic underwater noise

Underwater noise can be classified as impulsive or continuous in terms of its effects on marine life. It is well known that high powered impulsive noise may cause direct acute effects such as hearing loss, tissue damages and death to individuals of sensitive species such as cetaceans. It may also cause permanent effects, such as when animals are displaced permanently from an important feeding area. Continuous noise entails a chronic exposure mainly associated with stress and behavioural changes

potentially leading to negative effects at the population level over time. Hence **relevant indicators should be developed in order to consider, and appropriately manage, these two categories of noise**. Other than the impulsive or continuous nature of noise, its frequency spectrum is relevant for designating indicators, because sound propagation is frequency dependent. Also, marine species sensitivity to sound is frequency dependent. Therefore, on one hand, the **frequency nature of noise should be considered as a determining factor**, on the other hand key species (sensitive, emblematic, etc.) of the Mediterranean Sea should be considered while addressing monitoring guidance. The JNWG proposes considering the potential impact of noise on the fin whale (*Balaenoptera physalus*), the Cuvier's beaked whale (*Ziphius cavirostris*) and the sperm whale (*Physeter macrocephalus*), three sensitive and emblematic species of the Mediterranean region.

In order to be in coherence with the Marine Strategy Framework Directive of the European Union (MSFD) and to harmonise measures, it is proposed that the base for developing an assessment strategy (and thus indicators) for the Mediterranean Sea be the guidance for implementing the Descriptor 11 (D11) of the MSFD (Dekeling *et al.*, 2013). This guidance, developed by the Technical Sub-Group on Underwater Noise (TSG Noise) of the European Commission, will soon be adopted in part of the Mediterranean region (EU countries bordering the area). The MSFD explicitly gives instructions to Member States on how to apply an ecosystem-based approach to the management of anthropogenic noise in order to attain the Good Environmental Status (GES). With the Commission Decision 2010/477/EU, two indicators are retained addressing **low and mid frequency impulsive noise** and **low frequency continuous noise**.

Concerning low and mid frequency impulsive noise, it should be clear that this indicator, according to the basic principle of the MSFD, addresses the ecosystem rather than individual animals or species, and the cumulative impact of activities, rather than that of individual projects or programmes. Such concepts can be applied to the objectives of the UNEP/MAP and in the framework of the EcAp process. Hence, impulsive noise can be monitored by setting up a **register of anthropogenic activities** which use loud noise sources. By knowing the date and location of such activities, **the proportion of days within a given period, and over a given geographical scale, in which activities generating impulsive sounds take place** can be computed, monitored and managed. Nonetheless, not all noise sources impact the marine environment, thus not all noise-producing activities need to be taken into account. TSG Noise proposes to use a threshold system as a condition to include human activities in the register. In other words, activities are taken up in the register if they use low and mid-frequency impulsive noise sources exceeding a certain source level threshold. With regards to the MSFD, thresholds are mainly based on studies focussing on the onset of behavioural disruption in harbour porpoise (*Phocoena phocoena*), a very common species in the North Sea, but absent in the Mediterranean Sea. In the present document, the JNWG describe adaptations of the impulsive noise indicator to Mediterranean species.

With regards to the indicator for ambient noise, TSG Noise state that the primary objective thereof should be to detect a trend in sound levels over a given temporal scale, considering a consistent range of frequencies. Simple averaging methods of sampling units are recommended for calculating noise levels over a year in the frequency bands where shipping is likely to be dominant compared to other continuous noise sources, i.e. 63 and 125 Hz third-octave frequency bands. However, for the UNEP/MAP needs, further options could be proposed. First, detecting a trend in sound levels could not be the best option if we are aiming at taking into account the potential negative effects of noise to marine wildlife, and particularly to cetaceans. In fact, even a decreasing trend, which satisfies the definition of GES *sensu* TSG Noise, could stay above biologically relevant thresholds, i.e. levels causing negative effects, during a long time (several years). In this regard, **the establishment of a noise threshold for ambient noise should be considered**. Further, baleen whales may be covered by reporting energy up to 1 kHz, and ships are known to produce noise in a wider band than the two octaves indicated for the MSFD. Additionally, if we are concerned about GES for sensitive and

vulnerable toothed whales, it could be relevant to include higher frequency bands. Therefore, the main difference between the ambient noise indicator of D11 and **the ambient noise indicator proposed for the EO11** is that the former only focus on the frequency content of noise from shipping regardless of its potential impact on marine wildlife, while the latter **wants to take into account also the potential impact on key cetacean species**. This can be achieved by selecting biologically relevant frequency bands for monitoring. Finally, as a seasonal component exists in levels of some human activities (e.g. recreational craft) throughout the Mediterranean Sea, and given that these aspects have never been deeply studied, a finer temporal scale for averaging could be proposed (e.g. seasonal or monthly). Such issues are discussed in sections 3.2.

## 3. Monitoring Strategy

The monitoring strategy depends on several factors, including the types of noise sources to be monitored, the choice among in-situ measurements or models and mapping or a combination, the spatial and temporal scales, the frequency and location of sampling sites, the definition of baseline values and thresholds, the sound metrics to compute results and the summary statistics to show such results. Such variability is reflected in different monitoring strategies addressed in the following paragraphs.

### 3.1. Impulsive noise indicator (11.1.1)

Taking the UNEP/MAP COP17 definition (2012), the indicator for impulsive noise is defined as follows: *Proportion of days and geographical distribution where loud, low and mid-frequency impulsive sounds exceed levels that are likely to entail significant impact on marine animals*.

In order to be in coherence with the definition from TSG Noise, impulsive sounds are to be interpreted as **source levels of anthropogenic sound sources**. As stated previously, implementing this indicator can be achieved through the establishment by Contracting Parties of a register of maritime activities using impulsive noise sources. Recommendations related thereto are discussed in the following sections.

#### 3.1.1. Noise sources

There is general agreement on what human activities use impulsive noise sources which should be included in the register. These are naval exercises involving the use of low and mid-frequency sonars, geophysical surveys, underwater detonation, pile driving and the use of acoustic deterrent devices. For the purpose of the UNEP/MAP, the JNWG proposes that whether or not a given human activity is taken up in the register depend on the significant impact caused to key cetacean species found in the Mediterranean Sea, namely the fin whale, the sperm whale and the Cuvier's beaked whale. Therefore, the meaning of significant impact needs to be defined. The JNWG proposes to adapt the definition used by TSG Noise, that is: **severe and/or sustained and/or long-term avoidance of an area, and/or disruption of acoustic behaviour, i.e. stop calling or stop clicking**.

Thus, based on the available knowledge on the acoustic biology/ecology of fin whales and Cuvier's beaked whales, the JNWG proposes to include two different lists of human activities at sea, one for **low-frequency** impulsive noise sources, and one for **mid-frequency** impulsive noise sources. The former addresses the sensitivity range of the fin whale, and lists activities that need to be included in the register regardless to the source level, i.e. all activities using low frequency impulsive noise sources should be included in the register. The latter addresses the sensitivity range of sperm whales

and Cuvier's beaked whales and is based on a threshold system as a condition for inclusion in the register. This proposal is based on the fact that displacement and/or acoustic behavioural disruption may occur for Mediterranean fin whales in response to low frequency impulsive noise at very long ranges, reaching more than 200 km (Borsani *et al.*, 2008; Castellote *et al.*, 2012). Setting a minimum source level threshold for inclusion in the register of low-frequency sources would be useless as all activities would be very likely to be included. On the other hand, sperm whales and beaked whales have been identified to be highly sensitive to mid-frequencies (e.g. Aguilar de Soto *et al*., 2006; Weir, 2008). Power contained in mid-frequency bands is normally related to power contained in low frequency bands, and travels less far than low frequencies. Using a threshold system for inclusion of human activities in the register appears consistent because it simplifies methodology, and reduces cost for monitoring.

In summary, **activities using low frequency impulsive noise sources with no threshold** for inclusion in the register are the following:

- Low frequency military sonar (LFA)
- Geophysical surveys (both commercial or scientific, using any source like airguns, sparkers, subbottom profilers, etc.)
- At sea or shore based detonations
- Pile driving (only for "assisted press-in systems" which include all types of piston-based hammers)

The **activities with a minimum threshold** for inclusion in the register, include the following mid frequency noise sources:

- Mid frequency military sonar: SL > 176 dB re 1 µPa m
- Mid frequency acoustic deterrent: SL > 176 dB re 1 µPa m
- Other non-pulse sound source: SL > 176 dB re 1 µPa m
- Other pulse sound source SLE > 186 dB re 1 µPa² m² s

Such thresholds follow the recommendations given by TSG Noise (Dekeling *et al.*, 2013) and presented hereafter. First, received noise levels eliciting behavioural reactions are identified through a literature review. Then, it is assumed that significant impact occurs when such noise levels reach a range of 1000 m from the noise source, meaning that sources producing levels that cause behavioural reaction at 1000 m from the source are included in the register. Finally, noise levels eliciting behavioural reaction at 1000 m are back calculated to find the **source level (SL) used as threshold for inclusion in the register**, indicated in the list above. Considering non-pulse sound sources (mid-frequency military sonar, acoustic deterrent devices and other non-pulse sources), thresholds are based on beaked whale reaction to mid-frequency military sonar. A study focussing on Blainville's beaked whale (*Mesoplodon densirostris*) suggests 140 dB re 1µPa (rms) as the thresholds for the onset of behavioural reaction due to mid-frequency sonars (Tyack *et al.*, 2011). After back calculation (see Dekeling et al., 2013 Part III for details), the source level threshold is 176 dB re 1µPa. However, it is worth recalling a recent study from DeRuiter *et al.* (2013) focussing on Cuvier's beaked whale behavioural reaction to simulated mid-frequency sonar. This work suggests lower levels, i.e. levels ranging from 89 to 127 dB re 1µPa (rms), for triggering behavioural reactions in Cuvier's beaked whale. Such reactions include ceasing normal fluking and echolocation, changing swim pattern and extending both dive duration and subsequent non-foraging interval (DeRuiter et al., 2013). Of course this latter study is more coherent for the Mediterranean case, but the range of noise levels triggering a response, as suggested, appear too large. Furthermore, the same study shows that distant sonar exercises incidentally exposing a tagged whale to comparable received levels (78 – 106 dB re 1µPa rms) did not elicit such responses. Hence, the JNWG proposes as interim criterion to use the noise level recommended by TSG Noise based on Tyack et al. (2011), i.e. 176 dB, as a threshold for mid-frequency non-pulse noise sources. Updating this threshold will be necessary

once deeper knowledge will be available. For *other pulse sound source*s, the JNWG advices to adopt as interim criterion the threshold used in the technical guidance for implementation of D11. Such threshold is based on the onset of behavioral disruption for the harbor porpoise at 1000 m, which is the marine mammal with lowest TTS thresholds known to date (Lucke *et al.*, 2009). Finally, in order to establish the register, for each of the above activities, the basic information required to derive the number of days in which activities using impulsive sources occur in an area, is:

- Position data (geographic position: lat/long)
- Period of operation (start – end)
- Source Level dB re 1µPa rms at 1m
- Number of hours of activity per day
- Duty cycle (ON/OFF ratio) or % of time ON
- Frequency range
- Source level (for mid-frequency sources)

### 3.1.2. Temporal and Spatial scales

Concerning temporal scales, the JNWG recommend using 1 year for the impulsive noise indicator, in coherence with D11. Hence, the indicator addresses the number of days within 1 year in which activities generating impulsive sounds take place. With regards to spatial scales, the geographical distribution of impulsive sound sources can be easily represented under the form of cartography by means of a spatial grid. Such a grid could be used for the following tasks:

- Collecting and storing data
- Presenting cartographic data
- Assessment purposes
- Other management actions

Thus, grid cell size needs to be defined. Options considered by the TSG Noise are based either on administrative or biological reasoning. For instance, in the UK, data concerning seismic surveys are registered in standard hydrocarbon licensing blocks that are 10 minutes latitude by 12 minutes longitude. A different option could be to base the grid on estimated impact. Based on studies carried out in the North Sea, the reported range of displacement effects for harbour porpoises from pile driving has been of the order of 20 km (Tougaard *et al*, 2012; Dähne *et al.*, 2013). Hence, taking a 20 km radius, this means an area of about 1250 km². This implies that in a grid cell of about the same surface over which a pile driver is active, it can be assumed that porpoises are absent in that cell, and hence the potential habitat loss can be estimated. The problem with this is that harbour porpoises, which presently represent the best reference about displacement effects, are absent in the Mediterranean Sea. Instead, after consultation with the ACCOBAMS Scientific Committee, it seems practicable to use a grid size based on biological reasoning, particularly on the grid size used for studying ecological features of cetacean populations in the Mediterranean Sea. A study from Azzellino *et al.* (2011) assessed the feasibility of using models of beaked whale distribution developed in an area to another area (a model developed in the Ligurian Sea to the Alboran Sea, considering that study), in order to formulate (early) recommendations on conservation measures in non surveyed areas. The main result of this study suggests that applying "uncertainty buffers" of 20 km radius around the centroid of predicted presence cells may guarantee that the prediction process is appropriately conservative and robust. Following Azzellino *et al.* (2011), a grid size of 20 x 20 km is proposed. This grid size would enable to assess the potential habitat loss for beaked whales. This also would help meeting the need of adapting TSG Noise recommendations to the Mediterranean case.

### 3.2. Ambient noise indicator (11.1.2)

UNEP/MAP COP17 (2012) define the indicator for ambient noise as follows: Trends in continuous low frequency sounds with the use of models as appropriate. As stated in section 2, a threshold could be a better option for the objectives of the UNEP/MAP with respect to monitoring trends. Therefore, the JNWG propose to simplify the definition of the ambient noise indicator as follows: *Levels of continuous low frequency sound with the use of models as appropriate*. Issues related to the implementation of a monitoring of ambient noise are discussed in the following sections.

#### 3.2.1. In-situ measurements, models and noise mapping

The use of in-situ acoustic measurements is essential for:

- Gathering fundamental field data to establish information on the ambient noise in a given location
- Reducing uncertainty on source levels to be used as the input for modelling
- Increasing evidence base to improve management decisions

The use of models is essential for:

- Reducing the time required to establish a trend (the expected trend in shipping noise, based on observations in deep water, is of the order of 0.1 dB/year; and therefore it takes many years, possibly decades, to reveal such small trends without the help of spatial averaging)
- Reducing the number of stations required to establish a trend over a fixed amount of time (similar reasoning to above), therefore reducing the cost of monitoring
- Helping with the choice of monitoring positions and equipment (selecting locations where the shipping noise is dominant as opposed to explosions or seismic surveys being dominant).
- Producing noise maps, which are a valuable tool to quickly understand the ensonification levels over large areas, and a fundamental tool to calculate the extent of potentially impacted (non-GES) areas
- Predicting future scenarios and therefore testing different noise reduction strategies, e.g. by answering simple questions such as what happens if we reduce by XX dB the noise of 1% (or 20% etc.) of the circulating ships? Will this be a significant reduction?

#### 3.2.2. Location of sampling sites

Recommendations for the placement of measurement devices are listed as follows:

- Monitoring in both high traffic and low traffic areas, also searching and including spots where the noise is supposed to be the lowest
- Monitoring may be more cost effective if existing oceanographic stations (e.g. EMSO/INFN networks, (Favali *et al.*, 2013)) included noise monitoring along with the other oceanographic variables already being monitored;

- Consider local topography and bathymetry effects e.g. where there are pronounced coastal landscapes or islands/archipelagos it may be appropriate to place hydrophones on both sides of the feature;
- As far as possible avoid locations close to other sound producing sources that might interfere with measurements e.g. oil and gas exploration or offshore construction activities. Areas of particularly high tidal currents may also affect the quality of the measurement.
- Monitoring station should be primarily located in important cetacean habitat, as identified by ACCOBAMS (see Fig. 1).
- Whenever possible use deep monitoring stations, either autonomous or cabled, to limit the influence of surface and sub-surface noise.

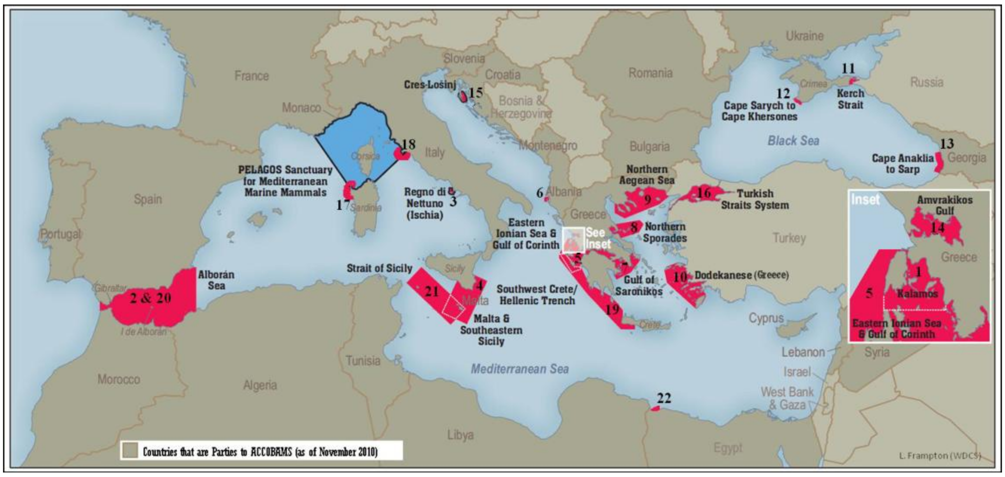


**Figure 1.** Areas of special importance for cetaceans in the ACCOBAMS area (ACCOBAMS Resolution 4.15, 2010)

### 3.2.3. Frequency range issues

MSFD indicator 11.2.1 specifies narrow frequency bands where noise from shipping is most likely to dominate over other sources, i.e. they are chosen to be most representative of the environmental pressure from shipping noise. These are the third-octave band centred at 63 Hz and 125 Hz. For the purposes of the UNEP/MAP, an approach considering a wider range of frequencies is proposed, considering the potential masking effect of anthropogenic noise on biological signal used by fin whales and sperm whales.

The JNWG advices to include the two third-octave bands recommended by TSG-Noise (63 and 125 Hz) and also 250 Hz and 500 Hz, in order to expand the coverage for shipping noise. This is justified by the results obtained in the Mediterranean (e.g. Castellote, 2010; Pulvirenti *et al.*, 2014) where shipping noise spectrum typically peaked at higher bands than the ones proposed by TSG-Noise. Also, two more third-octave bands are proposed, focussing on key frequencies for fin whale and the sperm whale communication. The band centered at 20 Hz for fin whales, and the band centered at 2000 Hz for sperm whales. These two bands are selected based on the peak frequency of the vocalizations of both species (fin whale: Watkins 1981, sperm whale: Madsen *et al.*, 2002 ; Watkins et al. 1980). Even if sperm whale click peak frequency has been identified in 5000 Hz, its lower peak frequency limit has been defined in 2000 Hz. It seems more relevant to use the lower peak frequency limit because it is more likely to be affected by anthropogenic noise and it requires lower sampling rates to be recorded, reducing the cost of monitoring equipment and data archiving volume. Therefore third-octave bands proposed by the JNWG are:

- **20 Hz**, based fin whale biological significance

- **63 Hz**, based on the frequency bands where noise from shipping is most likely to dominate over other sources according to Tasker et al. (2010)
- **125 Hz**, based on frequency bands where noise from shipping is most likely to dominate over other sources according to Tasker et al. (2010)
- **250 Hz**, based on frequency bands where noise from shipping is most likely to dominate over other sources according to Mediterranean data (Pulvirenti *et al*. 2014)
- **500 Hz**, based on frequency bands where noise from shipping is most likely to dominate over other sources according to Mediterranean data (Pulvirenti *et al*. 2014)
- **2000 Hz**, based sperm whale biological significance

### 3.2.4. What metrics and summary statistics?

The metric recommended for calculating ambient noise levels for the D11 is the annual average of the squared sound pressure in third octave bands expressed as a level in decibels, in units of dB re 1 µPa. Such a metric can be adopted for the ambient noise indicator of the EO11.

With regards to summary statistics, PART III of the last available report from TSG Noise (Dekeling et al., 2013) widely discusses the relevance of different averaging methods for calculating the value in decibels of the squared sound pressure over a period (1 year for the MSFD objectives). TSG Noise supports the use of the arithmetic mean of the sample units, as this is robust to changes or differences in sample duration while sensitive to significant increments in noise levels. In addition the JNWG consider that values in percentile appear very useful to convey information about how much time noise levels are maintained (e.g. Merchant *et al.*, 2013). **Figure 2** shows an example of 3 years of measurements in the 63 Hz third octave band made at the CTBTO Cape Leeuwin station (Dekeling et al, 2013).

In order to account with biological significance of ambient noise monitoring, a biologically relevant threshold in decibel for GES assessment has to be defined. Further, we should define how much time we can accept levels above that threshold. As stated above, information about how much time noise levels are maintained is given by levels in percentile. In aerial acoustics, a noise level exceeded N% of time is commonly written $L_N$, e.g. $L_{10}$ means the noise level exceeded 10% of sampled time; $L_{50}$ means the noise level exceeded 50% of time and so on. This is in accordance with the International Standard for aerial environmental noise ISO 1996-1:2003(E) (*Acoustics – Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures*). The same notation is used in this report[3]. Therefore, while the annual arithmetic mean could be within GES, a certain percentile (e.g. $L_{10}$) could exceed the GES level. This would mean that a proportion (e.g. 10%) of the sampled time GES would not be met, even if the annual arithmetic mean is within GES. Hence, one could argue whether this is acceptable or not. In conclusion, both statistics (annual arithmetic mean and percentile values) should be employed to evaluate whether an area is within GES or not.

[3] Standard ISO 1996-1:2003(E) requires using subscripts specifying whether the percent exceedance level is weighted, and what weighting function is used, e.g. for aerial acoustics $L_{A10}$ means A-weighted 10% Exceedance Level. In the present document weighting functions are not used and hence all levels, including percent exceedance levels, are unweighted.

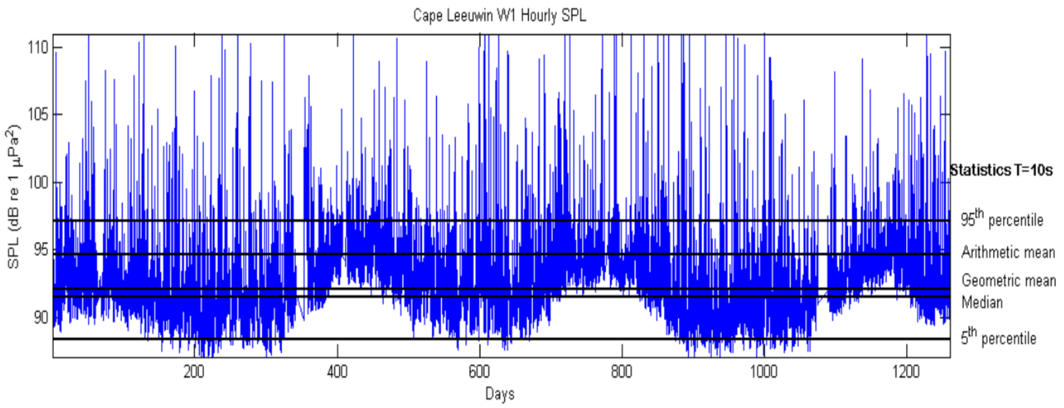


**Figure 2**. Monitoring noise in the 63 Hz third-octave band with different summary statistics over three year measurements in cape Leuween (taken from Dekeling et al, 2013). **N.B.**: in this figure, 95th percentile means $L_5$ and 5th percentile means $L_{95}$.

From a general point of view, if the only purpose of the indicator is monitoring the trend over time (years) for shipping noise as is requested by the MSFD, the annual mean SPL and variance could be sufficient. However, the ACCOBAMS reasoning for monitoring ambient noise is driven by the potential negative effect in sensitive cetaceans. Therefore, a finer temporal resolution is needed to better monitor seasonal departure from GES and hence the use of percent exceedance levels is necessary. In practice, if the annual arithmetic mean is above the noise threshold, GES is not met that year for that region while if the mean is below, then percentiles need to be inspected to figure out how much time the threshold was exceeded that year. If the percent used is proportional of the duration of the season of concern then this accounts with acute increases during specific seasons. Assuming that the strongest seasonal effect on ambient noise during a year is recreational craft occurring from June to September (4 out of 12 months), we should consider the $L_{33.3}$ index. In conclusion, in a situation where the annual arithmetic mean is below the threshold, the $L_{33.3}$ is inspected, and whether is higher than the threshold, therefore GES is not met that year.

### 3.3. Approaches for the achievement and maintenance of GES

For both indicators (impulsive and ambient noise), three different approaches can be implemented for GES determination:

- Setting thresholds
- Setting a downward trend in indicator values
- Using both thresholds and trends

Taking into account the basic concepts for developing the present monitoring strategy, the best option seems to be the use of thresholds for both indicators. Considering the impulsive noise indicator, two thresholds are required, i.e. number of days over a year and number of cells over a grid. The exceedance of either of the two threshold means that GES is not met. However, the temporal and spatial coverage at which the use of loud impulsive noise sources occurs across a sea area is unknown in the Mediterranean region. Also, it is unknown to us what values of this indicator, considering both the spatial and temporal component, could be considered as threshold values for GES achievement. In order to face such lack of knowledge, a preliminary task could be to review what thresholds have been selected by EU Countries for implementing D11 and evaluate if these are

appropriate to be proposed for the whole Mediterranean region. Further, dedicated research projects should be carried out to provide new baseline information on both the temporal and spatial coverage, i.e. number of days over a year and number of cells over a grid respectively, at which activities using impulsive noise sources occur.

On the other hand, baseline knowledge about ambient noise levels throughout the Mediterranean is limited, and the effects of noise are not sufficiently known to robustly determine whether existing levels are too high, or if GES is being achieved. Therefore, the JNWG propose to identify a conservative SPL threshold, and define that the arithmetic annual mean and the $L_{33.3}$ index must be below that threshold in order to meet GES. Subsequently, a thorough review of available literature on ambient noise in the Mediterranean Sea is needed to identify the threshold for ambient noise.

It is noteworthy that during the period 2014-2016 ACCOBAMS has planned to carry out a considerable work to provide the necessary baseline information. The achievement of noise-related tasks contained in the 2014-2016 Work Plan will enable the full implementation of both impulsive and ambient noise indicator.

**Table 3.** List of tasks to be carried out to enable the implementation of the Mediterranean Strategy on Noise Monitoring.

| Issue | Objective | TASK |
| --- | --- | --- |
| Impulsive noise | Define thresholds for **number of days over a year** and **number of cell over a grid**. | Review what thresholds have been selected by EU Countries for implementing D11<br><br>Request ACCOBAMS to accomplish with action CA 2b1 of 2014-2016 Work Plan ("Identifying Noise Hotpots for cetaceans in the ACCOBAMS area") |
| Ambient noise | Define a threshold for ambient noise in **dB re 1µPa (rms)** | Request ACCOBAMS to review the ambient noise data available for the Mediterranean Sea as a follow up of the present work in order to identify the threshold. |

## 4. Further issues

### 4.1. Requirements for research in acoustics of interest for ambient noise monitoring

For research purposes, and with a view to robustly support the implementation of mitigation policies, it is recommended to increase time resolution to describe fine scale temporal variations of noise levels to be possibly correlated with human activities (e.g. ship traffic). For example, the following data appear necessary to understand in depth ambient noise patterns over a give area:

- Monthly mean SPL and variance to possibly reveal seasonal patterns
- Additional percent exceedance levels: $L_{95}$, $L_{90}$, $L_{75}$, $L_{66.6}$, $L_{50}$, $L_{33.3}$, $L_{25}$, $L_{10}$, $L_5$, for each third-octave band, calculated monthly and annually

### 4.2. Acoustic comfort

By analogy with human environments, the "acoustic comfort" is a useful concept that can be recalled with a view to attain the good environmental status. Research effort aimed at defining acoustic comfort for marine mammals are very likely to help in defining and/or updating thresholds needed for implementing the ambient noise indicator.

# ANNEX I

**Data sheets for Ecological Objective 11:** ***Energy including underwater noise***

**ECOLOGICAL OBJECTIVE 11**: **noise from human activities causes no significant impact on marine and coastal ecosystems.**

| Indicator N° | Description (Decision COP17) | Operational objective (Decision COP17) | State/Pressure | Parameter description | GES assessment | Guidelines | Recommendations/ Needs |
|---|---|---|---|---|---|---|---|
| 11.1.1 | Proportion of days and geographical distribution where loud, low and mid-frequency impulsive sounds exceed levels that are likely to entail significant impact on marine animals | 11.1 Energy inputs into the marine environment, especially noise from human activities is minimized | Pressure | **Number of days over a year and number of cells over a grid** in which activities using loud source levels occur | GES is not achieved or maintained if either the temporal or spatial thresholds are exceeded | Monitoring Guidance for Underwater Noise in European Seas (Dekeling et al, 2013) | Outlined in the Task List (page 11, Section 4, Tab. 1) |
| 11.1.2 | Continuous low frequency sounds levels with the use of models as appropriate | | | **Arithmetic mean SPL over a year** (dB re 1µPa rms)<br>and<br>**$L_{33.3}$, i.e. 33% exceedance level (**dB re 1µPa rms**)**<br>in the 1/3 octave bands centred at:<br>20, 63, 125, 250, 500 and 2000 Hz | GES is not achieved or maintained if the $L_{33.3}$ index, calculated over a year, is above the threshold | Monitoring Guidance for Underwater Noise in European Seas (Dekeling et al, 2013) | Outlined in the Task List (page 11, Section 4, Tab. 1) |

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