METHODOLOGICAL GUIDE:
GUIDANCE ON UNDERWATER NOISE MITIGATION MEASURES




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Guidance on underwater noise mitigation measures

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PRINCIPAUTÉ DE MONACO
Ministère d'État

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ACCOBAMS

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FOREWORD

Underwater noise is recognised as a threat for marine wildlife and the conservation of endangered species. The ACCOBAMS Agreement has addressed the impact of underwater noise on cetacean species through a varied range of actions:

- Resolution 2.16 (2004), 3.10 (2007), 4.17 (2010, repealed), 5.13 (2013), 6.17 (2016), 7. 13 (2019, which replaced 4.17), 8.17 (2022): juridical tools promoting the adoption and the dissemination of mitigation measures to stakeholders of each Contracting Party
- Recommendations from the Scientific Committee identifying scientific priorities as well as proposing science-based conservation measures
- Scientific studies aimed at increasing our understanding of the noise issue
- Establishment of long-term monitoring and assessment processes and associated tools.

This document is a guide to the implementation of operational measures to mitigate the impact of underwater noise generated by human activities at sea. It is intended to be used by industry, scientists, regulators, technicians and other stakeholders involved in the environmental management of such activities.

The first guide was released in 2013, and reviews were issued in 2016, 2019 and 2022. This new version include the following updates:

- A reorganisation of chapters dedicated to technologies and procedures related to impulsive and continuous noise
- Updates on such technologies and mitigation procedures
- The inclusion of a section regarding the link with other international regulation in the Mediterranean and Black Sea regions.

The global scheme for mitigating the impact of underwater noise (upstream considerations, mitigation during works, downstream tasks) appears to have consolidated in recent years and latest reviews present comparable protocols and procedures than presented here (see for example (HELCOM 2016, OSPAR 2020, JNCC 2023). It is foreseeable than future updates of this guide will mainly concern new available technologies, adjustments to mitigation procedures for impulsive noise emissions, and updates from ecosystem-based instruments such as the Marine Strategy Framework Directive of the EU and the Integrated Monitoring and Assessment Program of UNEP/MAP.

Conscious that the measures contained in this document may represent operational constraints, these should not limit their use and solutions should be found to meet cetacean protection targets.

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1. BACKGROUND

For the purpose of this guide, *noise* can be defined as sound that causes negative effects. Recalling also the work carried out for the implementation of the Marine Strategy Framework Directive of the European Union, noise can be classified in two impulsive and continuous noise:

- Impulsive noise, defined as a sound emitted by a point source comprising one or more pulses of short duration and with long gaps between these pulses[1]

According to the European Commission, sources of impulsive underwater noise of major concern are the following:

  - Seismic surveys (airguns)
  - Offshore construction (pile driving)
  - Military Sonar
  - Use or disposal of explosives

- Continuous noise, meaning sound generated continuously by some anthropogenic source. In this case, shipping is considered the main contributor to the rising of ocean ambient noise.

This version of the guide addresses both continuous and impulsive noise sources as these are equally concerning with regards to marine life.

The guide is thought to outline practices and technologies that should be used during, instead, or in addition to conventional techniques producing underwater noise, with the aim of reducing the acoustic impact of human activities at sea. References are also included for those technologies which are deemed likely to become increasingly used (and market available) in the next future.

Also, this guide links to guidelines addressing the impact assessment phase established by the CMS as well as to rules related to ecosystem-based management of underwater noise pollution defined by EU and UNEP/MAP.

Finally, this guide reviews information on areas where spatial mitigation measures should be applied in the Mediterranean and Black Seas, i.e. areas where activities having an acoustic impact on cetaceans should be avoided as far as possible.

[1] A deeper insight of how an impulsive sound is defined, and especially what is considered to be a *short pulse* and a *long gap*, is given in the report of the TSG Noise (Van der Graaf et al. 2012b)

2. IMPACT OF IMPULSIVE UNDERWATER NOISE

Impulsive noise may cause negative effects of different magnitude, according to the characteristics of the noise emissions. The following table gives an indicative view about the impacts caused in both individuals/groups and populations. It has been derived from the work done within the Convention of Biological Diversity (CBD 2012), the *Service Hydrographique et Océanographique de la Marine* (Stéphan et al. 2012) and early work of TG Noise (Van der Graaf et al. 2012).

However, this table represent an important simplification of a highly more complex situation. Reaction of marine mammals to noise depends on such factors as species, individual, age, sex, prior experience with noise and behavioural state. Observed reactions to noise in marine mammals could theoretically result in impacts such as decreased foraging efficiency, higher energetic demands, less group cohesion, higher predation, decreased reproduction, and thus seriously impact the population. Moreover, repeated exposures to impulsive noise may lead animals to abandon an area, an effect considered as habitat loss due to acoustic disturbance (Thompson et al. 2013, Brandt et al. 2018, Graham et al. 2019) which may correspond to a reduction in the carrying capacity of an environment and hence a decline in the population size in the long term (Tougaard et al. 2013, Borsani et al. 2023, Sigray et al. 2023). On the other hand, injuries or deaths of animals may not have an impact on the population if these are few with respect to the size of the population (Weilgart 2007).

EFFECT TYPE	IMPACT ON INDIVIDUALS AND GROUPS	POTENTIAL IMPACT ON POPULATIONS
NONE	Perturbation under ambient noise level or under detection threshold of species	None
	Perturbations are detected but individuals/groups show no reactions	None
BEHAVIOURAL	Perturbations are detected and animals show slight response	Low
	Individuals modify their behaviour but normal activities are not affected	Low
	Individuals modify their behaviour and stop their normal activities	Medium
PHYSIOLOGICAL	Hearing is temporarily altered	Medium/High
	Hearing is permanently damaged	High
	Tissue damages, haemorrhages	Very high
	Injuries leading directly to animal death	Very high

3. IMPACT OF CONTINUOUS UNDERWATER NOISE

A significant portion of the continuous underwater noise generated by human activity is produced by commercial shipping (Hildebrand 2009, Hildebrand & Jesus 2021). The IMO recognizes that underwater-radiated noise from commercial ships may have both short and long-term negative consequences on marine life, especially marine mammals (IMO 2014, 2023). As shown in the example hereafter (Figure 1), multiple continuous noise sources (ships) create sound fields propagating for tens to hundreds of km, overlapping each other, and finally resulting in diffused increase of ambient noise levels. This increase represents a modification of the natural acoustic conditions of cetacean habitats.

It is worth noting that for a broad range of marine mammals, masking effects (on communication, navigation, prey/predator detection etc.), caused by rising continuous noise levels are likely to have an increasingly prevalent impact on a longer term (Pavan 2010). In the worst cases, the predicted decreased communication range for baleen whales is in the order of hundreds to thousands of km, owing to increases in ambient noise due to shipping (Okeanos Foundation 2008).

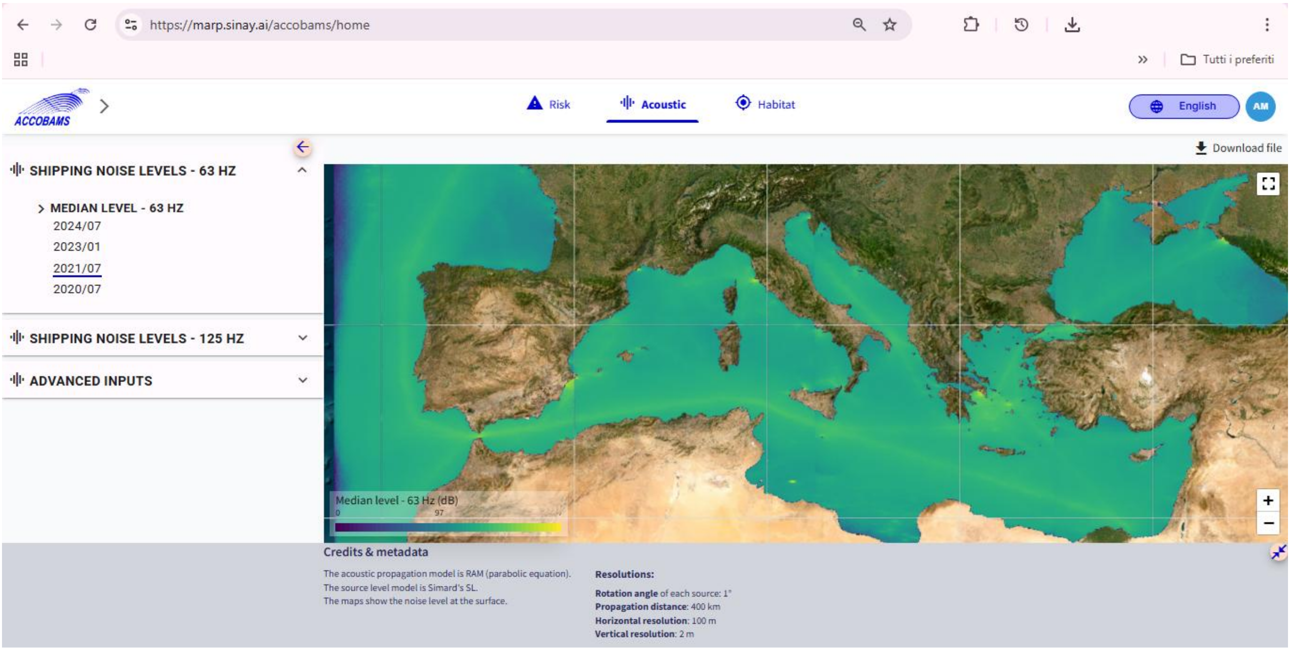

Figure 1. Shipping noise in the Black Sea, the Mediterranean Sea and the contiguous Atlantic area. Map available in the NETCCOBAMS platform.

4. CITED LITERATURE

Brandt MJ, Dragon AC, Diederichs A, Bellmann MA, Wahl V, Piper W, Nabe-Nielsen J, Nehls G (2018) Disturbance of harbour porpoises during construction of the first seven offshore wind farms in Germany. Mar Ecol Prog Ser 596:213–232.

CBD (2012) Scientific synthesis on the impacts of underwater noise on marine and coastal biodiversity and habitats. Montreal, Canada.

Van der Graaf S, Ainslie MA, André M, Brensing K, Dalen J, Dekeling R, Robinson S, Tasker ML, Thomsen F, Werner S (2012) European Marine Strategy Framework Directive Good Environmental Status (MSFD-GES): Report of the Technical Subgroup on Underwater noise and other forms of energy.

Graham IM, Merchant ND, Farcas A, Barton TR, Cheney B, Bono S, Thompson PM (2019) Harbour porpoise responses to pile-driving diminish over time. R Soc Open Sci 6.

HELCOM (2016) Underwater noise mitigation measures. In: *3rd Meeting of the Working Group on Reduction of Pressures from the Baltic Sea Catchment Area*. Gothenburg, Sweden, p 10

Hildebrand JA (2009) Anthropogenic and natural sources of ambient noise in the ocean. Mar Ecol Prog Ser 395:5–20.

Hildebrand JA, Jesus SM (2021) Trends in inputs of anthropogenic noise into the marine environment. The Second World Ocean Assessment:860–883.

IMO (2014) Guidelines for the reduction of Underwater Noise from Commercial Shipping to address adverse impacts on Marine Life. London.

IMO (2023) Revised Guidelines for the reduction of Underwater Radiated Noise from Shipping to address adverse impacts on Marine Life. London.

JNCC (2023) JNCC guidance for the use of Passive Acoustic Monitoring in UK waters for minimising the risk of injury to marine mammals from offshore activities.

Okeanos Foundation (2008) Shipping Noise and Marine Mammals. Hamburg, Germany.

OSPAR (2020) Inventory of measures to mitigate the emission and environmental impact of underwater noise.

Pavan G (2010) The shipping noise issue.

Stéphan Y, Boutonnier J-M, Pistre C (2012) Bilan des activites anthropiques génératrices de bruit sous marin et de leur récente évolution en france metropolitaine.

Thompson PM, Hastie GD, Nedwell J, Barham R, Brookes KL, Cordes LS, Bailey H, McLean N (2013) Framework for assessing impacts of pile-driving noise from offshore wind farm construction on a harbour seal population. Environ Impact Assess Rev 43:73–85.

Tougaard J, Buckland S, Robinson S, Southall B (2013) An analysis of potential broad-scale impacts on harbour porpoise from proposed pile driving activities in the North Sea Report of an expert group convened under the Habitats and Wild Birds Directives – Marine Evidence Group.

Weilgart L (2007) A Brief Review of Known Effects of Noise on Marine Mammals. Int J Comp Psychol 20:159–168.

5. TERMS & DEFINITIONS

ACCOBAMS	Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and the contiguous Atlantic area
ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas
AMD	Acoustic Mitigation Devices. This terminology is employed to include all devices which use acoustics as a means of mitigating interactions between cetaceans and human activities. Usually AMDs encompass Acoustic Deterrent Devices (ADD), developed for cetaceans, and Acoustic Harassment Devices (AHD), conceived for seals.
EIA	Environmental Impact Assessment.
EZ	The Exclusion Zone is defined as the area within which no animals must be present during noise emissions. An individual or a group entering this zone trigger the application of mitigation procedures/practices. The extent of the EZ should be determined on the basis of a scientific approach, i.e. by means of sound propagation modelling verified in the field. The limit of the EZ should be set following existing science on safe/harmful exposure criteria. However, such criteria are controversial and hence a precautionary approach should can be employed.
IMO	International Maritime Organization
IMAP	Integrated Monitoring and Assessment Programme of UNEP/MAP
LFAS/MFAS	Low- and Mid-Frequency Active Sonar employed during military exercises
MMO	Marine Mammal Observers are experienced observers employed to visually detect the presence of marine mammals within a defined zone. Animals can be spotted by the naked eye or by means of appropriate binoculars
MSFD	Marine Strategy Framework Directive of the European Union
PAM	Passive Acoustic Monitoring signifies the activity of recording continuous underwater sound by means of hydrophones. Several configurations exist to set up a PAM system. Marine mammal detection by means of towed PAM systems (as used by PAM operators during seismic exploration) is only one of the possible ways of PAM monitoring.
TG-Noise	Technical Groupe on Underwater Noise of the European Commission. This group addresses the implementation of the Descriptor 11 of the MSFD

6. MAIN HUMAN ACTIVITIES GENERATING UNDERWATER NOISE

Human maritime activities produce a wide range of underwater sounds that vary greatly in frequency, intensity, duration, and directivity. Understanding these characteristics is essential for assessing potential impacts on marine fauna and for applying appropriate mitigation measures described in the following chapter.

The present section summarises the principal sources of anthropogenic underwater noise relevant to the ACCOBAMS area and provides indicative acoustic parameters for each category. Values shown are representative of typical operations and should be considered as approximate ranges that may vary with equipment type, operating conditions, and environmental context.

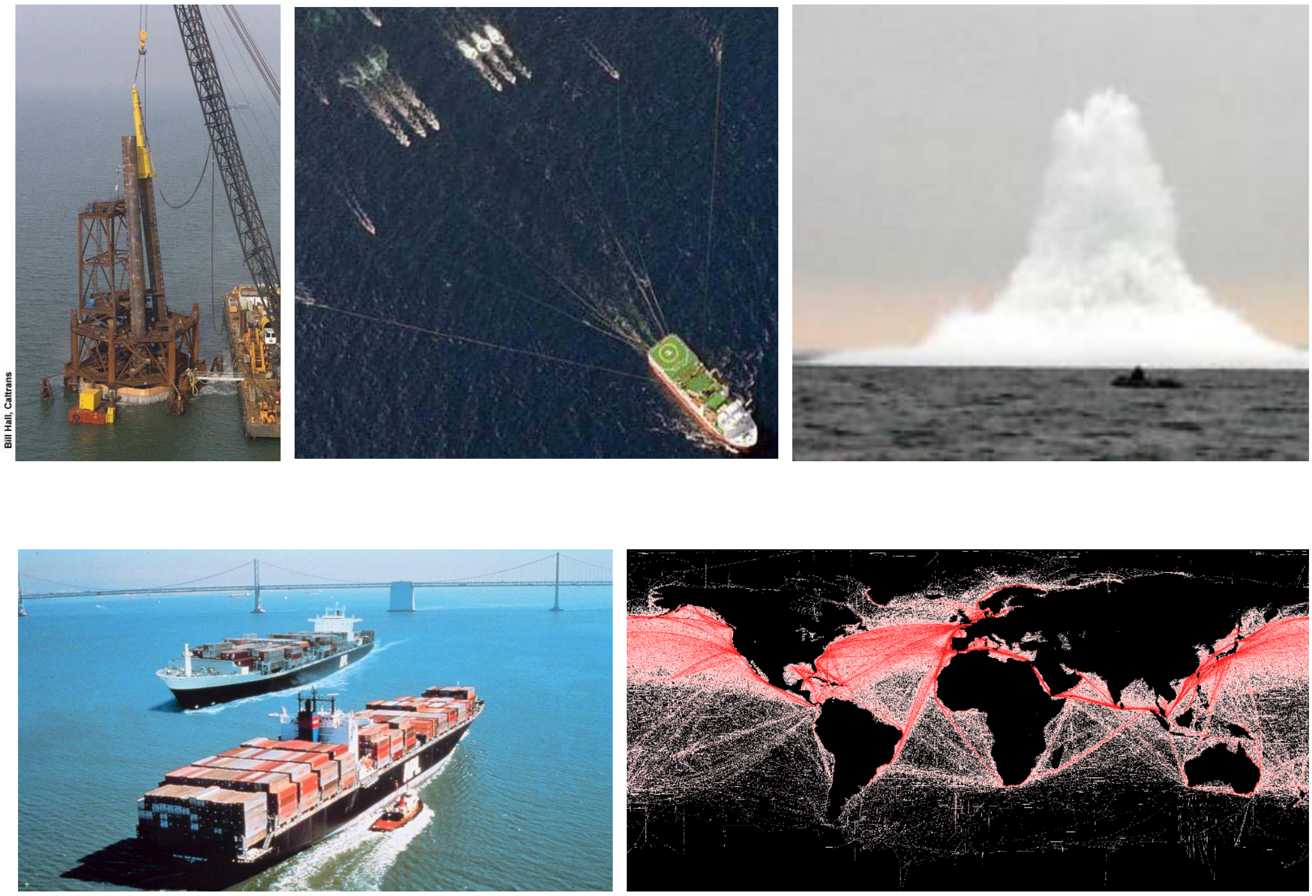

Figure 2. From left to right and top to down: the installation of a cofferdam before a pile driving, a seismic survey, an underwater explosion in shallow waters, cargo ships, global marine traffic routes.

6.1. Pile Driving, Drilling and Dredging

Pile driving is one of the most intense sources of impulsive underwater noise, commonly associated with offshore wind, port, and coastal infrastructure construction. Impact hammers generate short, high-intensity pressure pulses as piles are driven into the seabed. Vibratory and rotary drilling techniques produce lower-level, quasi-continuous sounds. Dredging generates broadband, low-frequency noise arising from mechanical excavation and sediment transport Sound propagation is typically omnidirectional in shallow water and can extend several kilometres depending on substrate and water depth.

6.2. Seismic Surveys

Seismic exploration uses arrays of compressed-air guns that release short, high-pressure pulses to image subsurface structures. Airgun arrays produce very high source levels, dominated by low-frequency energy (below 300 Hz) and repeated at regular intervals (every 8–15 seconds). Alternative techniques such as marine vibroseis, sparkers, and boomers generate lower peak pressures but may have broader frequency content. The cumulative acoustic footprint of seismic operations can cover extensive areas, especially in deep-water basins.

6.3. Use or Disposal of Explosives

Underwater detonations are used for clearance of unexploded ordnance, rock fragmentation during construction or other demolition works. They are the loudest anthropogenic sound sources in the marine environment and produce extremely short, omnidirectional shock waves with very high peak pressures. The acoustic energy released can cause physical injury to nearby fauna and may propagate over long distances in low-frequency bands.

6.4. Sonar Systems

Sonars transmit acoustic signals to detect, map, or classify underwater objects. They vary widely in frequency and intensity depending on purpose:

- **Military active sonars (LFAS/MFAS)** usually operate between 100 Hz and 8 kHz with very high source levels and focused horizontal beams.
- **Scientific and industrial sonars**, such as multibeam echosounders and sub-bottom profilers, operate at higher frequencies (tens to hundreds of kHz) and produce narrower beams and shorter pulses.

6.5. Shipping and Continuous Sources

Commercial shipping, fishing vessels, and offshore industrial installations generate continuous underwater noise dominated by low frequencies (< 1 kHz). Main contributors regarding shipping are propeller cavitation, engine vibration, and flow noise along the hull. This type of sound increases the ambient noise level across wide areas and contributes to long-term changes in acoustic habitats.

6.6. Typical Acoustic Characteristics of Main Anthropogenic Sources

Activity / Source Type	Typical Source Level (dB re 1 µPa @ 1 m)	Bandwidth (Hz–kHz)	Dominant Frequency Range (Hz)	Pulse Type / Duration	Directionality
Impact pile driving	230–255 (Peak); 190–220 SEL	20 Hz – 20 kHz	100 – 500	Impulsive, 10–100 ms	Mostly omnidirectional
Vibratory piling / drilling	160–190 RMS	50 Hz – 2 kHz	100 – 800	Quasi-continuous	Omnidirectional
Dredging	160–180 RMS	20 Hz – 2 kHz	100 – 500	Continuous	Omnidirectional
Seismic airgun array	230–260 P-P	5 Hz – 100 kHz	10 – 300	Impulsive, 10–100 ms, repetitive	Downward-directed
Marine vibroseis (prototype)	200–215 RMS	6 Hz – 100 Hz	10 – 80	Continuous, sweep 5–20 s	Directional (downward)
Underwater explosion (0.5–50 kg TNT eq.)	270–290 Peak	2 Hz – 1 kHz	6 – 100	Impulsive, < 10 ms	Omnidirectional
Naval LFAS / MFAS sonar	220–240 RMS	100 Hz – 8 kHz	300 – 3 500	Pulsed / variable	Directional (horizontal)
Multibeam / echosounder sonar	200–240 RMS	10 kHz – 400 kHz	30 – 300 kHz	Short pulses (0.1–1 ms)	Narrow beam
Shipping (commercial vessels)	150–190 RMS	6 Hz – 30 kHz	10 – 1 000	Continuous	Omnidirectional
Offshore industrial operations	150–195 RMS	10 Hz – 10 kHz	50 – 500	Continuous	Omnidirectional

The values and descriptions presented here provide a general overview for environmental assessment and planning purposes. Actual measurements should always be obtained during site-specific studies, taking into account equipment specifications, operational settings, bathymetry, and propagation conditions Mitigation and monitoring practices corresponding to these activities are detailed in the following chapters.

7. NOISE MITIGATION TECHNOLOGIES RELATED TO IMPULSIVE NOISE

The following section presents technologies and approaches designed to reduce the acoustic impact of impulsive underwater noise generated by human activities such as pile driving, drilling, dredging, or controlled detonations. These techniques primarily apply to shallow-water construction, although some are now being adapted for deeper environments. The technologies are grouped into three main categories consistent with the classification proposed by the *Journal of Ocean Technology* (2019):

1. **Path interruption** – reducing sound transmission between the source and the environment (e.g., bubble curtains, cofferdams, noise screens).
2. **Near-source absorption/resonance systems** – using physical or acoustic resonators to dissipate or absorb sound energy.
3. **Source modification** – reducing the emitted noise at its origin (e.g., softer hammers, variable-energy drivers).

7.1. Bubble Curtain Systems

Bubble curtains remain one of the most effective and widely used mitigation measures. They consist of perforated hoses releasing compressed air to form a screen of bubbles that scatter and absorb acoustic energy.

- **Single bubble curtains (SBCs)** typically achieve 10–15 dB reduction (SEL) in shallow-water monopile operations.
- **Double bubble curtains (DBBCs)** or **encapsulated bubble curtains (EBCs)**, where two or more concentric hoses or flexible sleeves are used, have shown up to ≈ 20 dB SEL attenuation under controlled field conditions. Recent hydrodynamic and acoustic modelling demonstrates that splitting air flow into two concentric layers improves efficiency by up to ≈ 11 dB insertion loss compared to single curtains (Peng et al., 2024; Beelen et al, 2025).

These systems are particularly effective for **pile driving**, **drilling**, and **dredging** in shallow-to-moderate depths (< 50 m), provided sufficient air supply and ring geometry are maintained. In deeper waters, maintaining uniform bubble distribution requires pressure-compensated compressors or modular ring systems deployed by ROVs (Peng et al., 2021).

Figure 3. Big Bubble curtain around a construction site (link).

7.2. Cofferdams, Noise Screens, and Encapsulation Systems

Rigid or semi-rigid structures, such as **cofferdams** or **IHC Noise Mitigation Systems (NMS)**, surround the source and isolate it from open water. These can achieve 10–22 dB SEL reduction when properly sealed. Encapsulation efficiency depends strongly on geometry, air content, and seal integrity.

Emerging encapsulated systems use polymer membranes or double-layer screens to enhance attenuation at mid-to-high frequencies while being easier to deploy.

Figure 4. NMS (left) and Cofferdam (right). Sources: OSPAR (2020), Verfuß and Julich (2012)

7.3. Hydro Sound Dampers and Hybrid Systems

Hydro Sound Dampers (HSDs) consist of nets or sleeves carrying small air- or foam-filled elements that oscillate at resonant frequencies. They can be combined with bubble curtains or rigid frames, forming hybrid systems that improve performance, particularly in the low-frequency range (100–500 Hz).

Offshore-suitable HSD systems achieve a broadband insertion loss of approximately 10–12 dB (SEL) during impact pile-driving operations in shallow waters.

HSD system has been effectively deployed for pile diameters up to 9.5 m and in water depths up to 45 m, confirming its applicability for a broad range of foundation types in offshore construction.

Source: OffNoise Solution GmbH (link)

7.4. Other Resonator-based systems

Resonator systems use arrays of Helmholtz-type cavities tuned to specific frequencies to absorb and dissipate acoustic energy. Laboratory studies (Peng, 2023) showed 15–25 dB attenuation at resonance and up to 10–15 dB broadband reduction with multi-frequency arrays. These passive, compact devices can function at greater depths than air-based systems. Field demonstrations in Europe reported ≈ 8 dB SEL reduction alone and 14–15 dB when combined with a bubble curtain under realistic pile-driving conditions (Wochner, 2018). Results confirm feasibility but also variability depending on frequency and environment.

7.5 Summary of Current Performance Ranges

TECHNOLOGY	TYPICAL NOISE REDUCTION (SEL)
SINGLE BUBBLE CURTAIN	10–15 dB
COFFERDAM, NOISE SCREEN, DOUBLE OR ENCAPSULATED BUBBLE CURTAIN	10–22 dB
HYDRO SOUND DAMPER / HYBRID HSD + BUBBLE CURTAIN	10–20 dB
RESONATOR SYSTEMS (OTHER THAN HSD)	8 – 20 dB

7.6. Source Modification: Low-Noise Construction Techniques

The following construction methods represent alternatives or complements to conventional impact pile driving, designed to reduce the generation of impulsive underwater noise during offshore and coastal developments. They are increasingly adopted in European offshore projects and are suitable for adaptation in the Mediterranean and Black Sea regions.

- **Vibro-piling and Vibro-drilling**

Vibro-piling uses high-frequency vertical vibration rather than impact energy to penetrate the seabed. Typical source levels are substantially lower than those of conventional impact piling, with a quasi-continuous sound signature and limited low-frequency content, potentially reducing the impact on marine fauna. Vibro-drilling, combining vibration and rotary cutting, yields similar acoustic characteristics and has been successfully demonstrated for large-diameter piles in moderate water depths. Source levels are reported between 160 and 190 dB re 1µPa m in scientific literature.

- **Drilled and Bored Monopiles**

Rotary drilling or down-the-hole hammer systems can install monopiles in hard or compact sediments with markedly lower acoustic output than impact hammers. Field measurements indicate a reduction of several tens of decibels in sound exposure level for comparable pile sizes. These systems are particularly suited for areas with rocky or consolidated seabeds typical of many Mediterranean coasts.

- **Suction-Bucket Foundations**

Suction buckets are steel cylinders installed by pumping water out of the interior cavity, generating suction that embeds the bucket into the seabed. Installation produces only low-level flow noise with minimal impulsive components (120 – 140 dB re 1µPa). This method provides an low-noise alternative for jacket and monopile foundations in shallow water, but also for installation of the anchoring systems for floating turbines.

- **Concrete-Gravity and Floating Foundations**

Gravity-based and semi-floating foundations are placed or ballasted onto prepared seabeds without pile driving. Associated acoustic emissions occur only during towing, dynamic positioning, and ballast operations and remain lower compared with percussive techniques. These options are particularly relevant for floating wind and hybrid energy platforms expected to expand in the Mediterranean.

- **Marine Vibroseis (MV)**

Marine vibroseis systems generate controlled, low-amplitude continuous signals as a non-impulsive alternative to seismic airguns. Modern prototypes produce signals within a low-frequency band suitable for geophysical surveys while eliminating the sharp pressure peaks characteristic of airguns. Available information reports typical peaks are in the 170-180 range. The absence of high-pressure transients substantially reduces the potential for physiological and behavioural impacts on marine fauna while maintaining sufficient data quality for subsurface imaging.

7.7. Performance Verification and Reporting

Noise-reduction values should be expressed in **Sound Exposure Level (SEL)** and **Peak Sound Pressure Level (Lpeak)** and validated through in-situ pre- and post-mitigation acoustic measurements. Verification ensures transparency between predicted and measured effects and may support reporting under MSFD Descriptor 11 and IMAP Ecological Objective 11 (e.g. through reporting data to the ACCOBAMS Noise Register).

7.8. References and further reading

Peng, Y., Jarquin Laguna, A., & Tsouvalas, A. (**2023**). A multi-physics approach for modelling noise mitigation using an air-bubble curtain in impact pile driving. Frontiers in Marine Science, 10, Article 1134776. https://doi.org/10.3389/fmars.2023.1134776

Simon Beelen, Marten Nijhof, Christ de Jong, Leen van Wijngaarden, Dominik Krug; Bubble curtains for noise mitigation: One vs two. *J. Acoust. Soc. Am.* 1 February **2025**; 157 (2): 1336–1355. https://doi.org/10.1121/10.0035817

Peng, Y.; Tsouvalas, A.; Stampoultzoglou, T.; Metrikine, A. Study of the Sound Escape with the Use of an Air Bubble Curtain in Offshore Pile Driving. *J. Mar. Sci. Eng.* **2021**, *9*, 232. https://doi.org/10.3390/jmse9020232

Bellmann M. A., Brinkmann J., May A., Wendt T., Gerlach S. & Remmers P. (2020) Underwater noise during the impulse pile-driving procedure: Influencing factors on pile-driving noise and technical possibilities to comply with noise mitigation values. Supported by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU)), FKZ UM16 881500. Commissioned and managed by the Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie (BSH)), Order No. 10036866. Edited by the itap GmbH.

OSPAR (2020). *OSPAR Inventory of Noise Mitigation Measures*. Report prepared by Thomas Merck, Stephanie Werner, Sven Koschinski and Karin Lüdemann.

CEFAS (2021). Review of the Effectiveness of Noise Abatement Systems during Offshore Piling. JNCC Report No. 677, Peterborough, UK.

Federal Maritime and Hydrographic Agency (BSH) *“Hydro-Sound-Damper (HSD) – Offshore-suitable Noise Abatement System … broadband insertion loss ΔSEL ≈ 10–12 dB”*. https://www.bsh.de/EN/TOPICS/Offshore/Environmental_assessments/Underwater_sound/_Module/Karussell/_documents/Artikel_Hydro-Sound-Damper.html

Peng, Y. (2023). Underwater Noise Reduction Using Acoustic Metamaterials. PhD Dissertation, Delft University of Technology, The Netherlands. https://pure.tudelft.nl/ws/portalfiles/portal/239404886/Yaxi_Peng_final_dissertation.pdf

Wochner, M. (2018). Noise Mitigation System – Demonstration Results Report. Austin, TX. https://adbmtech.com/wp-content/uploads/2020/08/AdBm-2018-Demonstration-Public-Release-Final-edit.pdf

Tsouvalas, A. (2020). Underwater noise emission due to offshore pile installation: A review. *Energies, 13*(12), 3037. https://doi.org/10.3390/en13123037

Tsouvalas, A., & Metrikine, A. V. (2016). Structure-borne wave radiation by impact and vibratory piling in offshore installations. *Journal of Marine Science and Engineering, 4*(3), 44. https://doi.org/10.3390/jmse4030044

Nedwell, J., Langworthy, J., & Howell, D. (2003). Measurements of underwater noise during piling at the Red Funnel Terminal, Southampton. *Subacoustech Report 558R0207.*

Guan, S., & Miner, R. (2020). Underwater noise characterization of down-the-hole pile driving activities off Biorka Island, Alaska. *Marine Pollution Bulletin, 154*, 111056. https://doi.org/10.1016/j.marpolbul.2020.111056

Tsouvalas, A. (2020). Underwater noise emission due to offshore pile installation: A review. *Energies, 13*(12), 3037. https://doi.org/10.3390/en13123037

Bellmann, M. A., et al. (2020). Underwater noise during percussive pile driving: Influencing factors and technical mitigation. ERA Report. https://www.itap.de/media/experience_report_underwater_era-report.pdf

Tsouvalas, A. (2020). Underwater noise emission due to offshore pile installation: A review. *Energies, 13*(12), 3037. https://doi.org/10.3390/en13123037

Nedwell, J., & Howell, D. (2004). A review of offshore windfarm related underwater noise sources. *Subacoustech Report 544R0308*.

Shonberg, A., Koopmann, M., & Reinhardt, J. (2017). Suction bucket jackets for offshore wind turbines: Applications from in-situ observations. *Conference Presentation*. https://www.researchgate.net/publication/327572904

Reach, I., Smith, D., & Kennedy, D. (2014). Marine environmental considerations for concrete gravity base foundations in offshore wind. *ICE Proceedings: Civil Engineering, 167*(CE1), 35–42. https://doi.org/10.1680/fsts.59757.035

Fried, S., Li, Y., & Alonso, M. (2022). Low-carbon, nature-inclusive concrete gravity-based foundations. *Tufts* University.

Koekkoek, R. (2015). Gravity base foundations for offshore wind turbines. *TU Delft Repository*. https://repository.tudelft.nl/

Amaral, J., Amaral, D., McCauley, R., & Parsons, M. (2020). The underwater sound from offshore wind farms. Acoustics, 2(3), 510–536.

Matthews, M. N. R., Nowacek, D. P., & Thode, A. M. (2020). A modeling comparison of the potential effects on marine mammals from sounds produced by marine vibroseis and air gun seismic sources. Journal of Marine Science and Engineering, 9(1), 12. https://doi.org/10.3390/jmse9010012

Duncan, A. J., Weilgart, L., Leaper, R., & Jasny, M. (2017). A modelling comparison between received sound levels produced by a marine vibroseis array and those from an airgun array. Marine Pollution Bulletin, 119(1), 277–288. https://doi.org/10.1016/j.marpolbul.2017.04.001

Ruppel, C. D., Spence, G. D., & Talling, P. J. (2022). Categorizing active marine acoustic sources based on their potential to affect marine animals. Journal of Marine Science and Engineering, 10(9), 1278. https://doi.org/10.3390/jmse10091278

8. MITIGATION DURING IMPULSIVE NOISE EMISSIONS

The following procedures outline the operational measures to be implemented when activities generating impulsive underwater noise are carried out. They aim to minimise disturbance, injury, and displacement of marine mammals and other sensitive species. These procedures should be integrated into the project's environmental management plan and applied by qualified personnel.

8.1. General provisions

- **Use of Acoustic Mitigation Devices (AMD)**

Before any sound source is activated, acoustic deterrent devices may be employed to gently displace marine mammals from the exclusion zone. Only devices whose characteristics and deployment methods have been approved by the relevant national or regional authorities should be used. The activation period should be long enough to ensure that animals have time to leave the area before the start of noise emissions.

- **Soft-Start or Ramp-Up Procedure**

Noise emissions must begin gradually to allow marine fauna to vacate the vicinity. The soft-start consists of a stepwise increase in source power from the lowest practicable level to full operational output. Its duration should not be less than fifteen minutes and must be repeated whenever the source has been inactive long enough for animals to re-enter the exclusion zone. During this time, visual and acoustic monitoring should confirm that no animals are present within the zone.

Specific rules for deep seismic exploration are recommended:

- The soft start procedure should be of 15 min duration at least and 20 minutes minimum for airgun arrays of more than 8 airguns.
- Single airgun testing and surveys do not require a soft start

- Soft start steps should be as much as possible in equal increases of sound pressure (6dB is a doubling of sound pressure). This can be achieved by doubling the number of sound sources (airguns) on each step. Therefore 1 to 2 to 4 to 8 airguns and so on until the entire array is active. This follows the basic principles of sound sources giving approximately 6dB sound pressure increases.
- Once soft start is complete, data acquisition (first good shot point) should occur within a maximum of 20 minutes.

- **Visual and Acoustic Monitoring**

Dedicated Marine Mammal Observers (MMOs) and Passive Acoustic Monitoring (PAM) operators shall monitor the exclusion zone before, during, and after operations.

- **Pre-start monitoring:** The area must be visually and acoustically surveyed for at least 30 minutes before the soft-start. If marine mammals are detected, the start must be delayed until the area is clear.
- **During operations:** Continuous monitoring is required. If animals approach or enter the exclusion zone, the activity must be reduced or stopped until they leave.
- **Post-operation monitoring:** Observations should continue for at least 30 minutes after the last sound emission to ensure that no delayed reactions or strandings occur.

- **Night-time and Poor-Visibility Conditions**

When visual monitoring is not possible, acoustic monitoring becomes the primary tool. Operations should only continue if PAM equipment is fully functional and detection capability has been demonstrated. In case of PAM failure, activities must be suspended until monitoring is restored. When possible, infrared or thermal imaging systems may complement acoustic detection.

- **Exclusion and Buffer Zones**

The exclusion zone (EZ) defines the minimum radius around the source within which no animals should be present during sound emissions. Its extent should be determined through site-specific modelling and verified in the field. A larger buffer zone may be applied around the EZ to allow for early detection and response.

- **Power-Down and Shut-Down Procedures**

If marine mammals enter the exclusion zone, the sound source should be immediately reduced to the lowest possible power level (power-down). A complete shut-down is required if animals remain within or re-enter the zone. Operations may only resume after a new pre-start observation period confirms that the area is clear.

- **Contingency and Equipment Reliability**

Redundant systems and spare components should be available for critical monitoring equipment. Any failure in MMO, PAM, or deterrent systems must be reported and rectified without delay. A record of all interruptions, responses, and corrective actions should be maintained.

- **Documentation and Reporting**

All mitigation actions, observation data, and any incidents of non-compliance should be recorded using standardised forms (See Annexes 1 and 2). Reports must include dates, times, environmental conditions, details of the operations, mitigation measures applied, and outcomes. These records form the basis for post-activity assessment and future improvement of mitigation procedures.

8.2. Provisions for Marine Mammal Observers

MMOs are responsible for detecting marine mammals, advising when to start, delay, or suspend operations, in accordance with the approved mitigation plan.

  - MMO personnel should have completed a training under the ACCOBAMS *Highly Qualified MMO/PAM Certification*[2] and being experienced in the identification of species living in the ACCOBAMS Area.
  - The number of MMOs employed in mitigation should be adequate to the specific conditions of the operation:
    - For seismic surveys, at least three MMOs should be aboard seismic vessels, observing the survey zone continuously. Shifts should never exceed 2 hours and MMOs must be able to rest between shifts.
    - For operations requiring the use of explosives, pile driving, and other activities generating loud impulsive noise signals underwater, the Risk Assessment and/or Impact Assessment documents are consulted to adjust the number of MMOs to the sensitivity of the area and species. When such documents are incomplete or not sufficiently developed, the same rules than for seismic surveys apply with regards to the number of MMOs to be employed.
- MMOs should be equipped with reticule binoculars (with compass bearing and rangefinder) and a standard “Cetacean Sighting Form" made available by ACCOBAMS (Annexed to this document)
- Night-time work may require the use of thermal or infrared cameras to supplement visual effort

Core tasks:

- Maintain continuous visual watch of the exclusion and buffer zones before, during, and after noise-generating operations.
- Record all sightings with date, time, species (if known), distance, and behaviour.
- Advise the vessel master or site manager when mitigation actions are required (soft-start initiation, power-down, shut-down).
- Document any interruptions, technical issues, or environmental factors affecting visibility.
- Compile and submit complete observation logs at the end of the project.

8.3. Provisions for Passive Acoustic Monitoring operators

PAM operators are responsible for detecting, classifying, and tracking vocalising marine mammals using underwater acoustic sensors. They also advise operators when to start, delay, or suspend operations, in accordance with the approved mitigation plan.

[2] https://accobams.org/main-activites/mmo-certificate-school/

Their data complement visual observations and enable mitigation during poor visibility or night-time operations.

- PAM personnel should have completed a training under the ACCOBAMS *Highly Qualified MMO/PAM Certification*[2] and be experienced bio-acousticians, familiar with the vocalisations of cetaceans of the ACCOBAMS Area.
- At least 1 operator should be in the PAM position during night and bad weather conditions. Likewise, MMOs and operators in the PAM position should be able to shift every two hours. This may require either dedicated PAM operators or MMOs with double skills.
- PAM equipment should detect and localise cetaceans. The capability of transmitting in real-time the recordings is also a crucial need. Market-available instruments can meet these needs, and the list is continuously evolving due to fast technological developments. No specific guidance about hardware is given as any recommendation may quickly become obsolete.
- With regards to software, PAMGuard is a proven software that is suggested here because it is an industry standard tool which is open source and easily downloadable for free[3]. Also, it is foreseeable that PAMGuard will remain a widely used and supported software in the coming years. Further PAM software exists although more complex to obtain and use. Such software can be obviously used provided the performance is demonstrated (e.g. when supported by scientific publications).

8.4. Complementary equipment: Infrared Cameras

Thermal infrared (IR) imaging is a promising solution for the real-time detection of marine mammals, particularly whales. The system functions by capturing heat signatures from whale blows, which appear as transient thermal anomalies at the sea surface. These are automatically detected using algorithms that analyse spatiotemporal contrast patterns over short durations.

Field validation across polar, temperate, and tropical regions showed detection ranges up to 3 km for whale blows and even greater for surface behaviours like breaches. The system outperforms human observers (MMOs) during nighttime, fog, and fatigue conditions, and complements them effectively when used together.

Although IR detection cannot identify species, thermal IR systems can enhance marine mammal detection and mitigation strategies, especially when integrated with conventional visual and acoustic methods. and is therefore recommended as a supporting tool within mitigation procedures.

[3] http://www.pamguard.org/

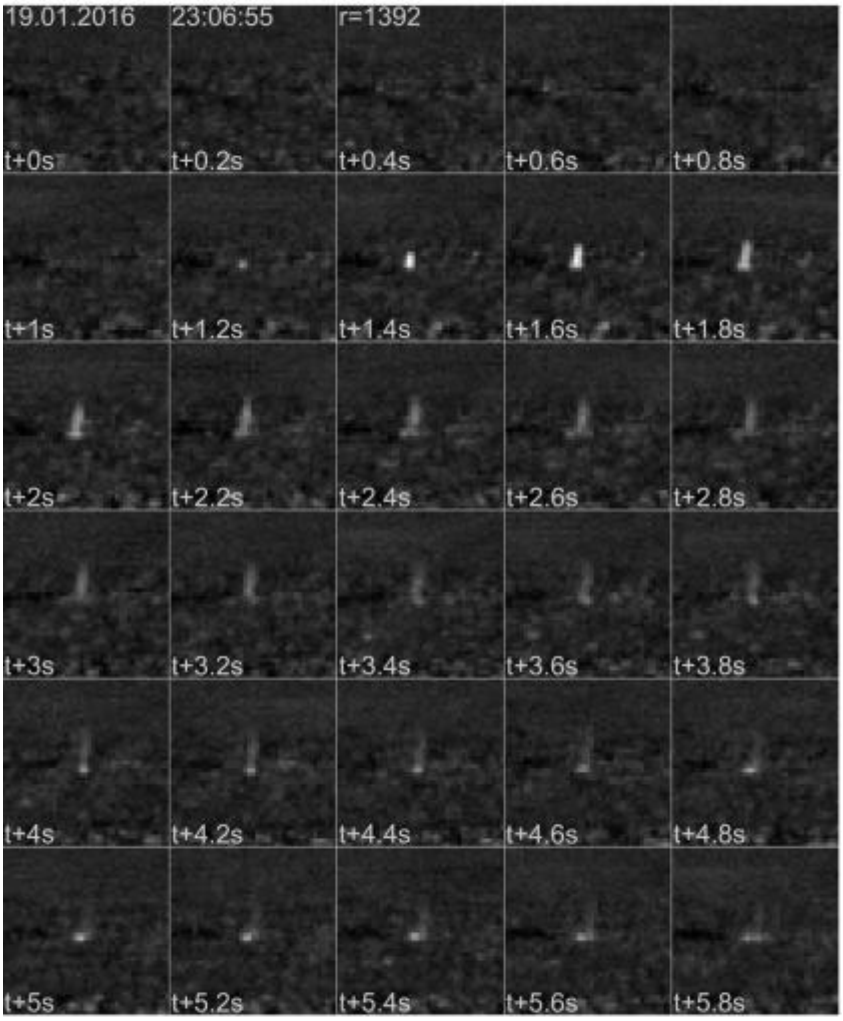

Figure 5. Example of the use of the infrared camera for cetacean monitoring (Source: Zitterbart et al, 2020)

8.5. References and further reading

ACCOBAMS Resolution 7.13 (2022). Anthropogenic Noise.

ACCOBAMS Resolution 6.8 (2019). Implementation of an ACCOBAMS Certification for Highly Qualified Marine Mammals Observers

DFO (Canada) 2020. Workshop report: review of near-real-time whale detection technologies

Joint Nature Conservation Committee (JNCC) Guidance for the use of Passive Acoustic Monitoring in UK waters (2023).

Pavan, G. (2006) Guidelines to address the issue of the impact of anthropogenic noise on marine mammals in the ACCOBAMS area

Smith HR, Zitterbart DP, Norris TF, Flau M, Ferguson EL, Jones CG, Boebel O, Moulton VD (2020) A field comparison of marine mammal detections via visual, acoustic, and infrared (IR) imaging methods offshore Atlantic Canada. Mar Pollut Bull 154.

Rodofili, E. N., Lecours, V., & LaRue, M. A. (2022). *Remote sensing techniques for automated marine mammals detection*. *PeerJ*, 10, e13540. https://doi.org/10.7717/peerj.13540

Zitterbart, D. P., Smith, H. R., Flau, M., Richter, S., Burkhardt, E., Beland, J., Bennett, L., Cammareri, A., Davis, A., Holst, M., Lanfredi, C., Michel, H., Noad, M., Owen, K., Pacini, A., & Boebel, O. (2020). *Scaling the laws of thermal imaging–based whale detection*. Journal of Atmospheric and Oceanic Technology, 37(5), 807–824. https://doi.org/10.1175/JTECH-D-19-0054.1

9. MITIGATION TECHNOLOGIES RELATED TO CONTINUOUS NOISE SOURCES (SHIPPING)

Continuous underwater noise, primarily generated by commercial shipping and offshore industrial activities, represents the most widespread anthropogenic sound input in the marine environment. This chapter presents the principal technological approaches that can reduce noise emissions at the design, construction, and retrofitting stages of vessels and offshore installations. The focus is on structural, propeller, and machinery solutions that decrease the generation or transmission of underwater-radiated noise. Operational measures implemented during service are described separately in Chapter 10.

9.1 Structural and Hull-Integrated Solutions

- **Hull Form Optimisation**

Optimising the hull shape improves hydrodynamic flow and reduces turbulence, thereby limiting cavitation at the propeller. Design tools based on computational fluid dynamics allow designers to identify zones of high flow separation and adjust geometry accordingly. A smoother wake field not only enhances propulsion efficiency but also lowers broadband noise, particularly in the low-frequency range below 1 kHz.

- **Structural Damping and Isolation**

Vibration from machinery propagates through the hull and radiates into surrounding water. Integrating damping layers, viscoelastic coatings, or floating decks can reduce resonance amplitudes. Engine foundations should be resiliently mounted and major structural members isolated from machinery to prevent re-radiation of mechanical noise.

- **Lightweight and Composite Materials**

Composite and hybrid structures provide inherent damping and lower stiffness compared with steel, thus reducing vibration transmission. These materials are increasingly used in small and medium-sized vessels and may gradually be extended to larger designs as regulatory experience grows.

9.2 Propeller-Related Technologies

- **Low-Noise Propeller Design**

Propeller geometry determines both efficiency and noise emission. Skewed or highly skewed blades, variable-pitch mechanisms, and tip-optimised profiles delay cavitation inception. Additional blades distribute thrust more evenly, reducing tonal peaks associated with blade-passing frequencies.

- **Propeller Boss Cap Fins and Energy-Saving Devices**

Hub-mounted fins or rotating caps reduce hub-vortex cavitation. Devices such as Mewis or Schneekluth ducts straighten and accelerate the inflow to the propeller, improving efficiency and reducing pressure fluctuations. These systems can be installed on newbuilds or retrofitted during regular dry-dock maintenance.

- **Air-Lubrication and Micro-Bubble Systems**

By injecting micro-bubbles along the hull, these systems reduce boundary-layer resistance and alter acoustic impedance, decreasing the transmission of noise generated by the propeller and hull vibration. While primarily introduced for energy savings, measurable reductions in underwater noise have also been observed.

9.3 Machinery and Powertrain Modifications

- **Quiet Propulsion Systems**

Hybrid-electric, fully electric, or podded propulsion systems generate smoother torque and fewer mechanical vibrations than conventional shaft lines. They also allow machinery to be positioned farther from the hull, reducing radiated noise. When combined with flexible couplings and active control systems, these configurations achieve substantial vibration reduction.

- **Machinery Arrangement and Enclosure**

Noise-producing machinery should be located centrally and mounted on resilient foundations. Insulated enclosures around engines, generators, compressors, and pumps prevent transmission to the hull. Careful routing of piping and cabling also minimises secondary vibration paths.

9.4 Summary of Main Noise-Reduction Approaches for Shipping and Industrial Vessels

Category	Technology / Measure	Typical Effect on Noise	Implementation Stage
Hull & structure	Hull optimisation, damping coatings, composite materials	5–10 dB reduction (broadband)	Design / retrofit
Propeller design	Skewed blades, multi-blade or variable-pitch propellers	3–6 dB reduction (tonal)	Design / retrofit
Energy-saving devices	Mewis or Schneekluth duct, PBCF, hub cap	2–5 dB reduction	Retrofit
Air-lubrication systems	Micro-bubble / air-film lubrication	Up to 5 dB (low frequencies)	Newbuild / retrofit
Electric / hybrid propulsion	Pod drives, diesel-electric systems	5–10 dB (mechanical)	Design stage
Machinery isolation	Flexible mounts, insulation, resilient couplings	3–8 dB	Retrofit

9.5 References and further reading

Tom A. Smith, Jake Rigby, 2022. Underwater radiated noise from marine vessels: A review of noise reduction methods and technology. Ocean Engineering, Volume 266, Part 1.ISSN 0029-8018. https://doi.org/10.1016/j.oceaneng.2022.112863.

IMO MEPC. *Revised Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life* (MEPC.1/Circ.906/Rev.1).

Galanis, K. (2002). *Hull construction with composite materials for ships over 100 m in length*. MIT.

Mendoza Vassallo, P.N. (2017). *Vibration and noise damping in marine panels using viscoelastic layers*. University of Naples.

Ianniello, S., Muscari, R., & Di Mascio, A. (2014). *Ship underwater noise assessment by acoustic analogy*. *Journal of Marine Science and Technology*, 19(3), 280–295.

Haron, M.H., Taib, I., & Saragasan, S. (2024). *Analysis on the turbulence flow on propeller with varying blade counts*. *Semarak Journal of Transportation and Fluid Engineering*.

Sun, Y., Zhang, X., & Zhang, J. (2020). *Study of PBCF impact on propeller noise*. *Journal of Naval Architecture and Ocean Engineering*.

Musinguzi, B. (2024). *Underwater noise and energy-saving devices (Mewis duct, PBCF)*. World Maritime University Dissertation.

Truong, T. (2001). *Bubble layer applications for underwater noise reduction*. DTIC Technical Report.

Chillemi, G. et al. (2024). *Review on air lubrication in ships*. *Applied Sciences*, 14(13), 5888.

Geertsma, R.D., Negenborn, R.R., Visser, K., & Hopman, J.J. (2017). *Review of hybrid propulsion for marine vessels*. *Applied Energy*, 194, 30–54.

Parsons, M.J. et al. (2020). *Underwater noise from a solar-electric ferry*. *JASA*, 147(5), 3575.

Fragasso, M., & Moro, L. (2022). *Marine diesel engine mounting design for vibration and noise control*. *Ocean Engineering*, 258, 111770.

Moro, L. (2015). *Structure-borne noise isolation in ships using resilient mounts*. PhD Thesis, University of Trieste.

Guo, H. et al. (2021). *Wake equalizing ducts and propeller noise performance*. *Physics of Fluids*, 33(6), 065123.

Lin, J. et al. (2020). *CFD analysis of inflow duct-assisted propeller noise*. *Applied Ocean Research*, 98, 102099.

Yousefi, R. & Takinoue, M. (2023). *Noise reduction using stator grids and pre-ducts in marine propellers*. *Journal of Marine Science and Engineering*, 11(3), 626.

10. OPERATIONAL AND MAINTENANCE MEASURES FOR NOISE REDUCTION

Even when vessels or installations have been designed with noise-reduction features, operational practices and maintenance routines remain essential to keeping emissions low throughout the service life of the ship. This chapter summarises the key measures that can be implemented during normal operation and maintenance to minimise underwater noise from shipping and other continuous sources. They complement the technological solutions presented in Chapter 9.

10.1 Propeller and Hull Maintenance

- **Regular Propeller Polishing**

Surface roughness and fouling on propeller blades increase cavitation inception and tonal noise. Routine polishing, typically every 6 to 12 months depending on operational area and biofouling rate, maintains a smooth blade surface and can restore both acoustic and fuel-efficiency performance.

- **Hull Cleaning and Coatings**

Biofouling on the hull increases flow turbulence and vibration. Periodic underwater cleaning or the use of advanced anti-fouling coatings reduces drag and associated noise. Cleaning schedules should be optimised to balance environmental regulations on biofouling removal with acoustic and fuel-saving benefits.

10.2 Speed Management

- **Relationship Between Speed and Noise**

Underwater-radiated noise from propeller cavitation increases sharply with vessel speed. Reducing speed by a modest amount (for instance 10–20 %) can yield several decibels of reduction in broadband noise while lowering fuel consumption.

- **Smart Steaming**

"Smart steaming" integrates voyage planning, cargo schedules, and weather routing to determine optimal speeds that minimise fuel use and acoustic output without compromising delivery efficiency. Such adaptive speed management can be applied voluntarily or under regional environmental programmes.

- **Speed Limits in Sensitive Areas**

Where feasible, temporary or permanent speed restrictions can be applied in areas of high ecological value such as marine protected areas or cetacean corridors. These measures are most effective when accompanied by stakeholder awareness and clear charting.

10.3 Routing and Spatial Planning

- **Re-Routing Traffic**

Relocating shipping lanes away from key biodiversity zones can significantly reduce cumulative acoustic exposure. Spatial planning tools, including dynamic management systems and automatic identification system (AIS) data analyses, help identify zones where re-routing provides the greatest environmental benefit.

- **Temporal Management**

Adjusting traffic intensity during sensitive biological periods, such as breeding or migration, can complement spatial management. This approach requires coordination among authorities and industry to maintain navigational safety while achieving acoustic mitigation objectives.

10.4 Crew Awareness and Training

Operational noise mitigation is most effective when crews understand how their actions influence underwater-radiated noise. Training programmes should include:

- Basic principles of underwater noise generation and its ecological relevance.
- Recommended operational practices (speed, machinery settings, maintenance checks).

Integrating noise-awareness modules into safety and environmental management systems fosters consistent long-term application of best practices.

10.5. References and further reading

Borelli, D., Gaggero, T., Rizzuto, E., & Schenone, C. (2016). *Holistic control of ship noise emissions*. Noise Mapping, 3(1), 107–119. https://doi.org/10.1515/noise-2016-0010

Leaper, R. (2019). *The role of slower vessel speeds in reducing underwater noise*. Frontiers in Marine Science, 6, 505. https://doi.org/10.3389/fmars.2019.00505

Leaper, R., Renilson, M., & Ryan, C. (2014). *Reducing underwater noise from large commercial ships: Current status and future directions*. Journal of Ocean Technology, 9(1), 70–81.

11. COMPLIANCE WITH OTHER INTERNATIONAL REGULATION IN THE MEDITERRANEAN AND BLACK SEA REGIONS

The implementation of existing international instruments provides a coherent legal and operational foundation for reducing underwater noise impacts in the Mediterranean and Black Seas. Adhering to these frameworks ensures consistency across jurisdictions and facilitates harmonised monitoring, reporting, and mitigation of anthropogenic underwater noise in line with ACCOBAMS conservation goals.

11.1 Environmental Impact Assessment (EIA)

In the Mediterranean and Black Sea regions, EIAs are mandated under national and international legal frameworks**.** The Convention on Migratory Species (CMS) **Family Guidelines on Environmental Impact Assessment for Marine Noise** provide detailed recommendations for assessing the effects of underwater noise on marine mammals and other species. These guidelines describe the steps for baseline noise evaluation, prediction of sound propagation, assessment of exposure and potential effects, and development of mitigation and monitoring plans.

Project proponents should use CMS Family Guidelines to ensure full compliance with the conservation objectives of the ACCOBAMS Agreement.

References:

Annex to UNEP/CMS/Resolution 12.14. CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities. Convention on Migratory Species of Wild Animals, Bonn.

Prideaux G, 2017, ‘Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities’, Convention on Migratory Species of Wild Animals, Bonn.

Prideaux, G. 2019. *Advisory Note: Further Guidance on Independent, Scientific Modelling of Noise Propagation.* UNEP/CMS/COP13/Inf.8. Convention on Migratory Species, Bonn, Germany, 4 pp.

11.2 Ecosystem-based rules established under EU and UNEP/MAP

Under the Marine Strategy Framework Directive (MSFD; 2008/56/EC) and the Integrated Monitoring and Assessment Program of UNEP/MAP (Decision IG.22/7), Countries must achieve Good Environmental Status (GES) with respect to underwater noise. This includes two main criteria:

- **Impulsive noise:** spatial and temporal distribution of impulsive sound events.

- **Continuous noise:** Continuous low frequency underwater noise levels

According to targets initially established by the European Union Task Group on Underwater Noise (TG-Noise), no more than 10% of the habitat of sensitive species should be affected by impulsive noise averaged over one year, and no more than 20% of their habitat monthly by continuous noise. These thresholds are objectives intended to guide national environmental authorities in planning and reporting activities that may contribute to cumulative acoustic pressures.

In this respect, Industry should contribute in the following ways:

- Regarding impulsive noise: report impulsive noise events (Cf Sections 6.1 to 6.4) to the national noise registers established under the MSFD and IMAP frameworks. Alternatively, information on the occurrence of such noise events should be provided to the national authorities responsible for underwater noise management. The appropriate reporting method depends on the rules established at the national level.
- Regarding Continuous noise: ship owners should apply noise mitigation measures outlined in Chapters 9 and 10 of this guide which are related to technologies and operational measures for reducing ship-radiated underwater noise, respectively.

From a regional perspective, ACCOBAMS has established an Impulsive Noise Register and a Continuous Noise monitoring tool covering the whole Agreement. Both are available from the NETCCOBAMS platform[4] and may be consulted upon request addressed to the ACCOBAMS Secretariat. Outputs of such monitoring tools are meant to serve for periodical assessments of noise pollution in the Mediterranean and Black Seam, guide the development and implementation of adapted ecosystem-based management measures.

References:

ACCOBAMS Resolution 7.13. Anthropogenic Noise

ACCOBAMS Resolution 8.17. Anthropogenic Noise

Borsani, J. F., Andersson, M., André, M., Azzellino, A., Bou, M., Castellote, M., Ceyrac, L., Dellong, D., Folegot, T., Hedgeland, D., Juretzek, C., Klauson, A., Leaper, R., LE Courtois, F., Liebschner, A., Maglio, A., Mueller, A., Norro, A., Novellino, A., … Weilgart, L. (2023). *Setting EU Threshold Values for continuous underwater sound.* Technical Group on Underwater Noise (TG NOISE) MSFD Common Implementation Strategy. (J.-N. Druon, G. Hanke, & M. Casier, Eds.). Publications Office of the European Union. https://doi.org/10.2760/690123

Sigray, P., Andresson, M., André, M., Azzellino, A., Borsani, J. F., Bou, M., Castellote, M., Ceyrac, L., Dellong, D., Folegot, T., Hedgeland, D., Klauson, C., Leaper, R., LE Courtois, F., Liebschner, A., Maglio, A., Mueller, A., Norro, A., Novellino, A., … Weilgart, L. (2023). *Setting EU Threshold Values for impulsive underwater sound.* Technical Group on Underwater Noise (TG NOISE) MSFD Common Implementation Strategy (J.-N. Druon, G. Hanke, & M. Casier, Eds.). Publication Office of the European Union. https://doi.org/10.2760/60215

[4] hub.sinay.ai/accobams/

11.3 IMO – North-Western Mediterranean Sea Particularly Sensitive Sea Area (NW MED PSSA)

The North-Western Mediterranean Sea was established as Particularly Sensitive Sea Area (NW MED PSSA) under the International Maritime Organization (IMO) through a joint proposal by Spain, France, Monaco, and Italy. This PSSA aims primarily to reduce the risk of ship strikes with large cetaceans such as the fin whale (*Balaenoptera physalus*) and Sperm whale (*Physeter macrocephalus*).

Among the approved protective measures, voluntary speed reduction is identified as the most effective to lower both strike risk and underwater radiated noise from shipping. By slowing vessel speeds, cavitation and engine-related noise are significantly reduced, resulting in direct acoustic benefits.

In this area, it is recommended to reduce ship speed in the range of 10 to 13 knots.

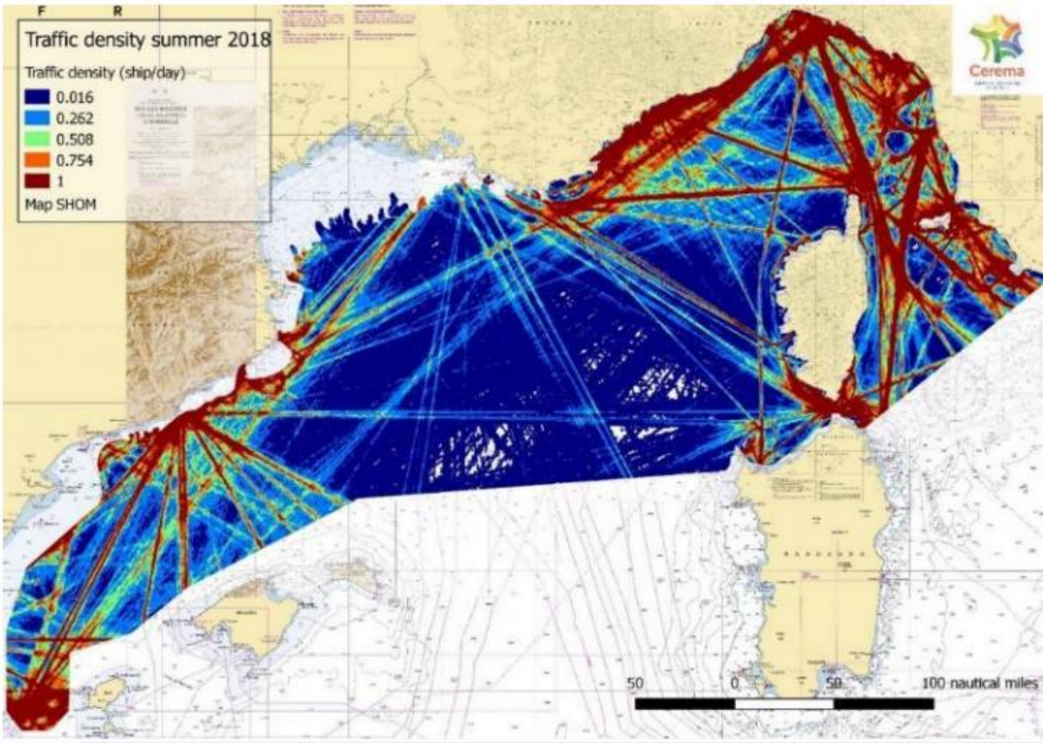

Figure 6. NW MED PSSA and representation of ship traffic within its boundaries (source: MEPC 80/17/Add.1)

References:

IMO. MEPC 80/17/Add.1. RESOLUTION MEPC.380(80). Designation of the north-western mediterranean sea as a particularly sensitive sea area.

12. SPATIAL MANAGEMENT TOOLS FOR MARITIME ACTIVITIES

Following maps are examples of existing spatial management tools which should be used to manage human activities at sea.

9.1 Areas of special concern for Beaked whales

The map hereafter is based on a modelling exercise to estimate favourable habitat areas for Cuvier's beaked whale and on the analysis of stranding data.

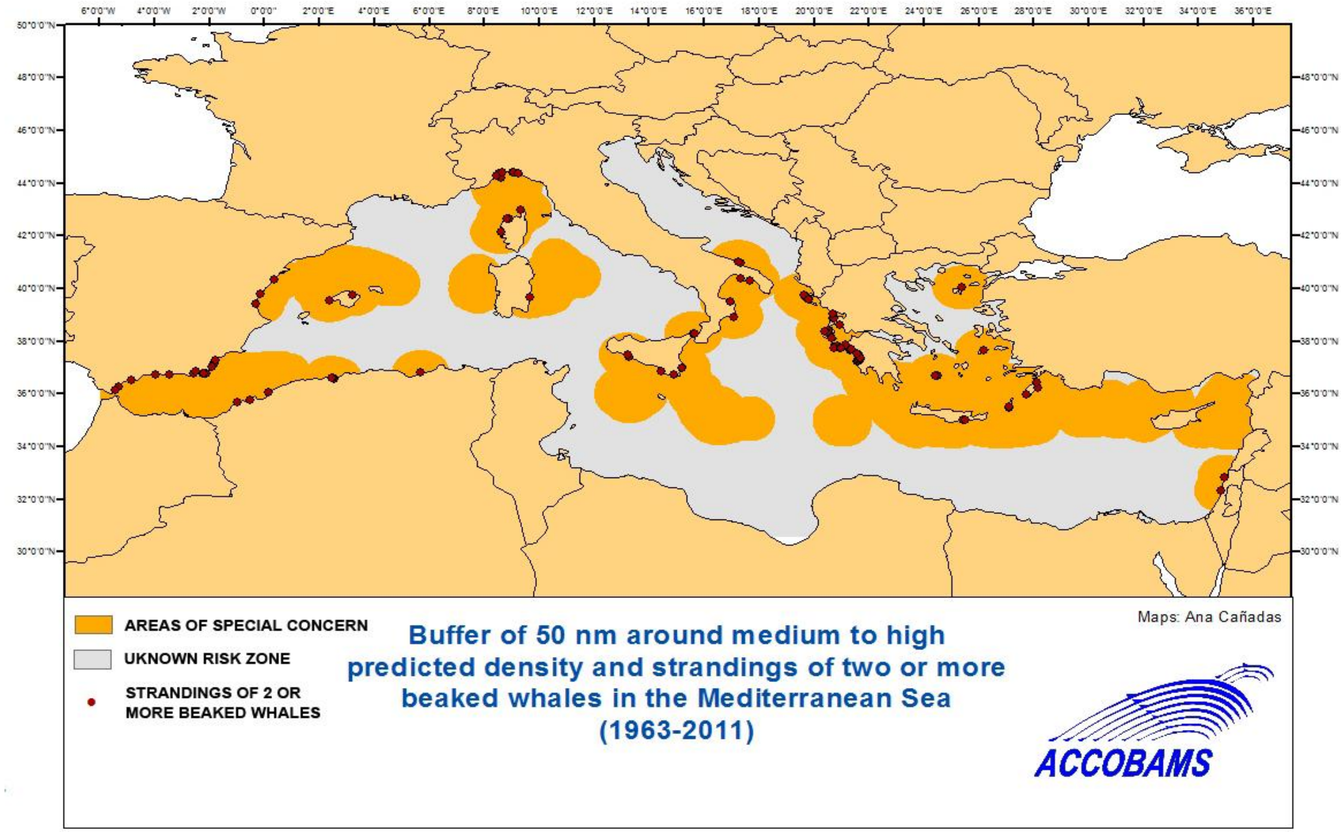

Figure 7. Areas of special concern for Beaked whales as approved by the ACCOBAMS Scientific Committee. Source: Cañadas et al. (2010).

12.2 Marine Protected Areas in the Mediterranean as available from MAPAMED

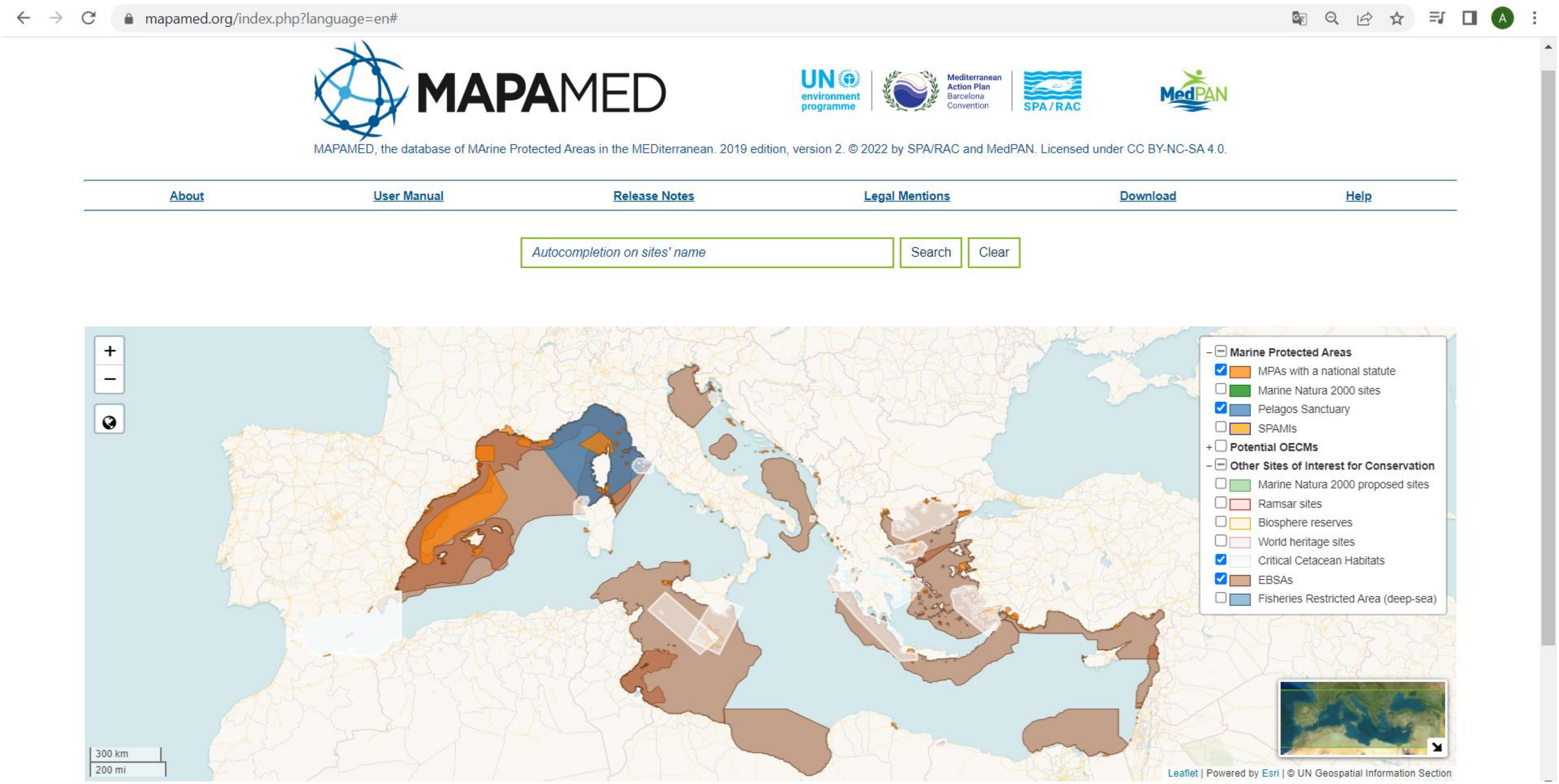

Figure 8 ; Atlas of Marine Protected Areas in the Mediterranean Sea (accessed 24/10/2022). The designations employed and the presentation of the information on this document do not imply the expression of any opinion whatsoever on the part of ACCOBAMS concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

12.3 Overview of the noise hotspots in the ACCOBAMS Area

Main outputs of the two Noise Hotspots reports ("Overview of the Noise Hotspots in the ACCOBAMS Area", 1st and 2nd edition, 2016 and 2022, respectively),are shown hereafter. Maps are intended to show the cumulative spatial coverage of impulsive noise sources in the ACCOBAMS area. However, temporal aspects are equally important to assess the risk for cetaceans but are not visible in this map. Impulsive noise sources are used indeed during works that may last a few days to several months and hence the areas shown in the map are not continuously exposed to impulsive noise.

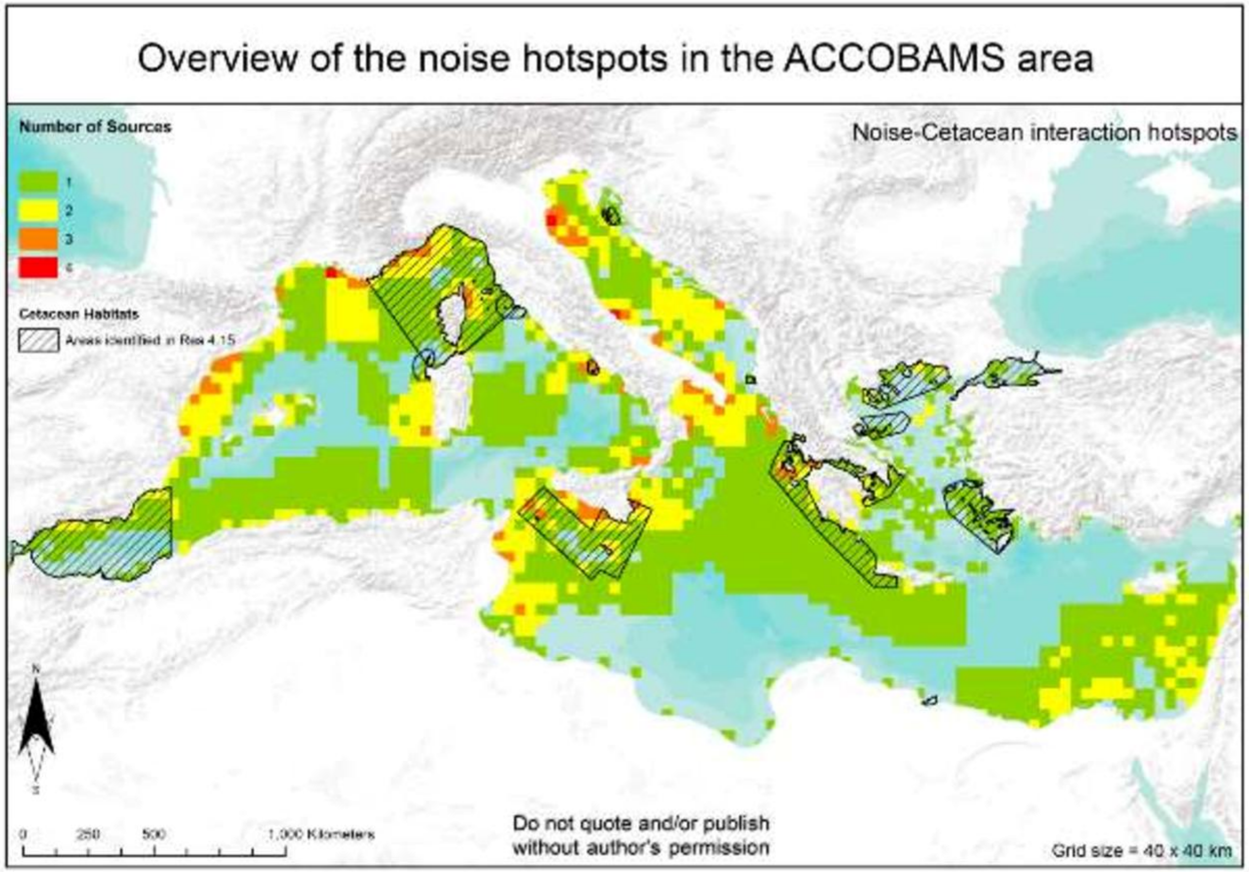

Figure 9. Overview of the noise hotspot areas and overlap with some important habitat of cetaceans: noise sources include seismic surveys, harbour activities, offshore energy sites, naval exercises (data incomplete in some areas). Period of data collection (2005 – 2015). Source : Maglio et al. 2016.

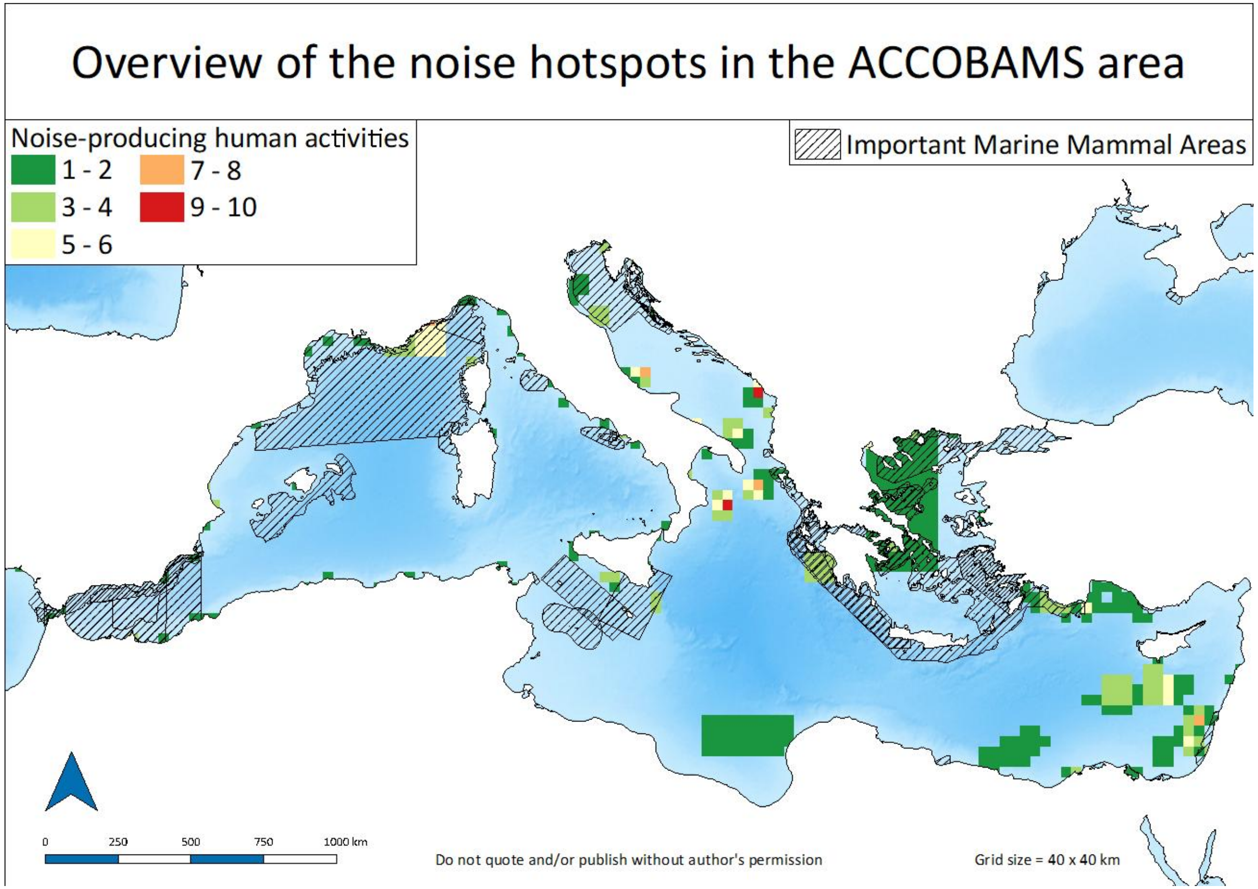

Figure 10. Overview of the noise hotspot areas and overlap with some important habitat of cetaceans: noise sources include seismic surveys and harbour activities (data incomplete in some areas). Period of data collection (2016 – 2022).

12.4 Important Marine Mammal Areas (IMMAs)

Important Marine Mammal Areas (IMMAs) are deisgnated through a process set up by a dedicated task force supported by several international bodies[5]. IMMAs consist of areas that may merit place-based protection and/or monitoring. IMMAs could be considered also by industry for the implementation of mitigation measures related to their activities.

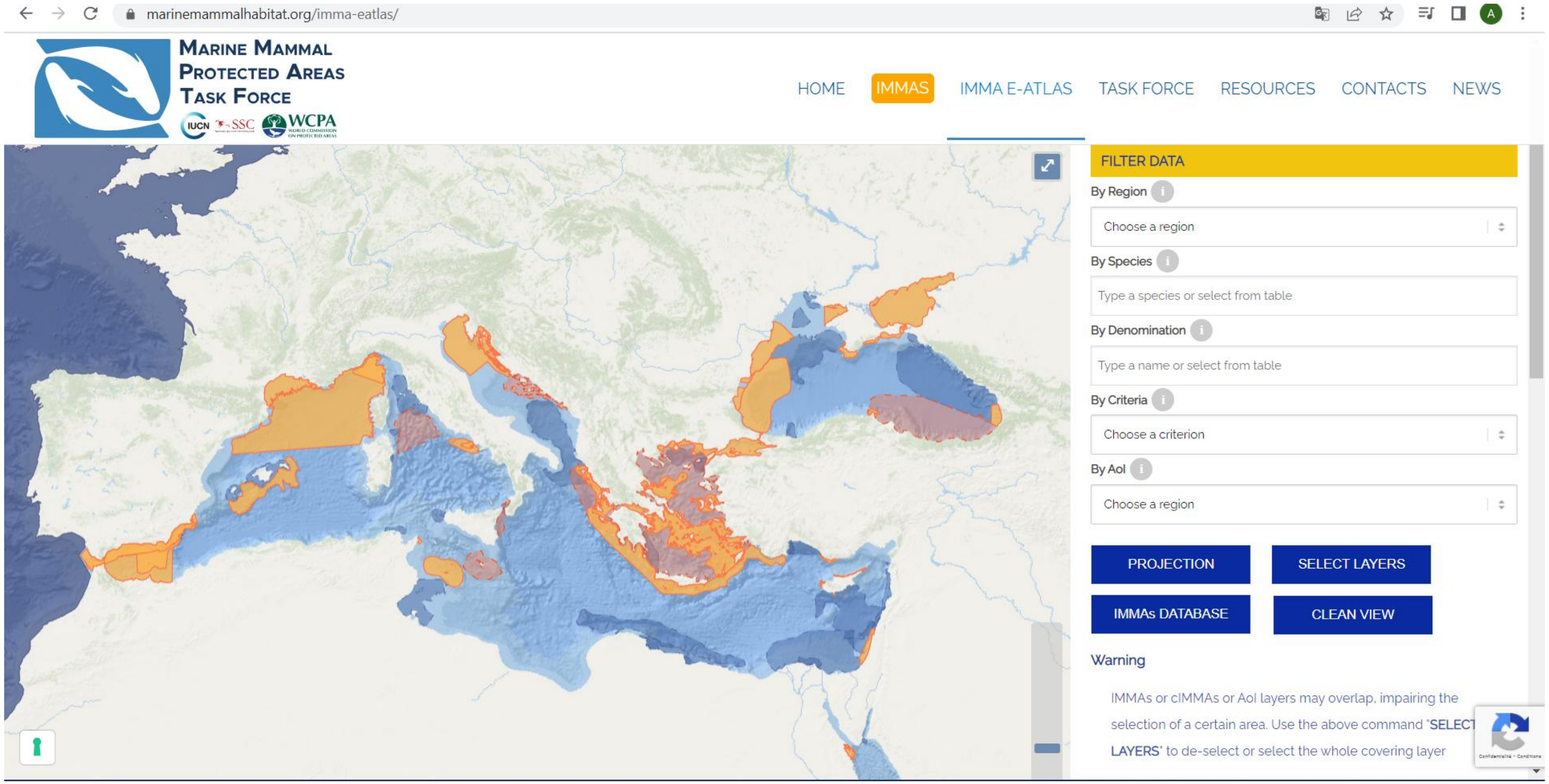

Figure 11. Important Marine Mammals Areas as displayed on the website marinemammalhabitat.org (accessed 24/10/2022).

[5] The International Committee on Marine Mammal Protected Areas (ICMMPA), the International Union for Conservation of Nature's (IUCN) World Commission on Protected Areas (WCPA) and members of the IUCN Species Survival Commission (SSC).

13. Annexe 1: Template for reporting MMO and PAM operations

MMO/PAM REPORT FOR THE ACCOBAMS AREA

(To be sent within one month after the completion of the operation)

Contact details: Name; email; phone number

Content:

- Area and characteristics of the survey
  - Date and location (including mapping*) of survey
  - Objectives of the survey
  - Number and types of vessels involved in the survey
  - Contact details of all MMO and PAM operators aboard the vessel(s)
  - Material and method used as MMO/PAM
  - Total number and volume of the airguns used
  - Nature of airgun array discharge frequency (in Hz), intensity (in dB re. 1µPa or bar meters) and firing interval (seconds), and / or details of any other acoustic energy used
- Records
  - A record of all occasions when the airguns were used (copy of the forms*)
  - A record of the watches made for marine mammals, including details of any sightings and the seismic activity during the watches (copy of the forms and/or excel filled if possible*)
- Details of any problem encountered during the seismic survey including instances of non-compliance with the ACCOBAMS guidelines

Annexes*:
The excel file filled* (example ACCOBAMS Marine Mammal Recording Forms adapted from JNCC forms) – Guidance, Cover page, Operations, Effort and Sightings. Please read the Guide to Using ACCOBAMS Marine Mammal Recording Forms prior to use (Annexed to this document).

Support:

- email to the Executive Secretariat of ACCOBAMS (secretariat@accobams.net)
- or paper send to the following address:

  ACCOBAMS
  Secrétariat Permanent
  Jardin de l'UNESCO
  Terrasses de Fontvieille
  98000 Monaco

Date

Signature

** : in case of data confidentiality, please send a copy of the paragraph specifying the terms of confidentiality and the delay, and send the data after the period of confidentiality.*

14. Annexe 2: Standard Cetacean Sighting Forms

Three standard files should be used during MMO and PAM operations:

- Deckforms (PDF), intended for recording hand-written observations during visual monitoring.
- Recording forms (Excel spreadsheet), intended for transcription of recordings from the Deckforms.
- Guide for Marine mammal recording forms (PDF), a user guide of the Recording forms.

These files are available upon request to the Secretariat of ACCOBAMS.