ACCOBAMS

Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area, concluded under the auspices of the Convention on the Conservation of Migratory Species of Wild Animals (CMS)

Accord sur la Conservation des Cétacés de la Mer Noire, de la Méditerranée et de la zone Atlantique adjacente, conclu sous l'égide de la Convention sur la Conservation des Espèces Migratrices appartenant à la Faune Sauvage (CMS)

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ANTHROPOGENIC NOISE AND MARINE MAMMALS: REVIEW OF THE EFFORT IN ADDRESSING THE IMPACT OF ANTHROPOGENIC UNDERWATER NOISE IN THE ACCOBAMS AND ASCOBANS AREAS

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Note of the Secretariat

During the last Meeting of the Parties, the Resolution 4.17 (Guidelines to address the impact of anthropogenic noise on Cetaceans in the ACCOBAMS area) was adopted with the task for the Working Group to go ahead with this issue. The composition of the Working Group was approved by the Seventh Meeting of the ACCOBAMS Scientific Committee and Yanis Souami was designated as coordinator.

The main role of the Working Group was to simplify and clarify Guidelines to facilitate their implementation by the Parties and shipping operators, in particular by providing information about mitigation technologies and management measures as well as their effectiveness and cost.

The year 2011 was dedicated to contact numerous Organisations and make them aware about the Guidelines.

A joint Working Group with ASCOBANS was created accordingly to the ACCOBAMS Scientific Committee recommendation and on the occasion of the 19th ASCOBANS Advisory Committee Meeting (19-23 March 2012).

After collecting opinion from different actors (industries, states, scientists, NGOs and others), a working platform was created in 2012 to exchange documents on noise with the view of preparing a synthesis.

The "Cluster Maritime Français", was approached by the Coordinator of the Working Group. Its view is only exposed in Document 23.

During the Eighth Meeting of the Scientific Committee, it was decided to appoint a consultant for providing a bibliographic synthesis (*ACCOBAMS-MOP5/2013/Doc22: Anthropogenic noise and marine mammals: review of the effort in addressing the impact of anthropogenic underwater noise in the ACCOBAMS and ASCOBANS areas*) and consulting of noise-producers (*ACCOBAMS-MOP5/2013/Doc23: Implementation of underwater noise mitigation measures by industries: Operational and economical constraints*).

According to the decision of the Parties a Methodological guide (*ACCOBAMS-MOP5/2013/Doc24: Methodological guide: Guidance on Underwater Noise Mitigation Measures*) was prepared, thanks to a Voluntary Contribution of Monaco, by the coordinator of the Working Group. It aims to improve and facilitate the use of the Guidelines to Address the Impact of Anthropogenic Noise on Cetaceans in the ACCOBAMS Area.

The Parties will be invited to comment and take note of the document

Anthropogenic noise and marine mammals. Review of the effort in addressing the impact of anthropogenic underwater noise in the ACCOBAMS and ASCOBANS areas

Joint ACCOBAMS-ASCOBANS Noise Working Group

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Index

List of Figures and Tables

List of Acronyms (1)

ACCOBAMS	Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area
ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas
BARCELONA CONVENTION	Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean
BERN CONVENTION	Convention on the Conservation of European Wildlife and Natural Habitats
CBD	Convention on Biological Diversity
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMS	Convention on the Conservation of Migratory Species of Wild Animals
EC	European Commission
ECS	European Cetacean Society
EU	European Union
FOEI	Friends of the Earth International
HELCOM	Convention on the Protection of the Marine Environment of the Baltic Sea area, 1992 (Helsinki Convention)
HESS	High Energy Seismic Survey Team (US)
ICES	International Council for the Exploration of the Sea
IFAW	International Fund for Animal Welfare
IUCN	International Union for the Conservation of Nature
IMO	International Maritime Organisation
IWC	International Whaling Commission
JNCC	Joint Nature Conservation Committee (UK)
MEDDE	Ministère de l'Ecologie, du Développement Durable et de l'Energie (FR)
MEPC	Marine Environmental Protection Committee
MSFD	Marine Strategy Framework Directive
NAMMCO	North-Atlantic Marine Mammal Commission
NERI	National Environmental Research Institute (DK)
NMFS	National Marine Fisheries Service (U.S.)
NOAA	National Oceanic and Atmospheric Administration (U.S.)
OSPAR	Convention for the protection of the marine environment of the North-East Atlantic
UNCLOS	United Nations Convention on the Law of the Sea

List of Acronyms (2)

ADD	Acoustic Deterrent Devices
AHD	Acoustic Harassment Devices
AMD	Acoustic Mitigation Devices
EBSA	Ecologically and Biologically Significant Zone
EIA	Environmental Impact Assessment
EZ	Exclusion Zone
MMO	Marine Mammal Observer
MPA	Marine Protected Area
NPA	Noise Protection Area
PAM	Passive Acoustic Monitoring
PTS	Permanent Threshold Shift
SIA	Strategic Impact Assessment
TTS	Temporary Threshold Shift

Summary

Underwater anthropogenic noise is considered a major threat in the conservation of marine wildlife. Since concern and evidence of the negative effects of noise on the marine environment arose, a wide variety of scientific, political and technical effort has been undertaken. This review is focused on the political and technical effort that has been carried out to date to understand and mitigate the known and potential impacts of anthropogenic noise on marine mammals.

Several international bodies have responsibilities for the protection of the marine environment, including from the negative effects of anthropogenic noise. These bodies include treaties, conventions and agreements as well as intergovernmental organisations and agencies. Some organisations (e.g. OSPAR and the Barcelona Convention) work to phase out pollution in all its forms, whilst others (e.g. ACCOBAMS and ASCOBANS) directly act for the conservation of cetaceans and deal with noise and other threats. Finally, the European Union is responsible for implementation of the HABITATS Directive (92/43/EEC, 1992) and the Marine Strategy Framework Directive (2008/56/EC, 2008), both of which are transposed by member states at a national level.

In recent years, while the scientific community provided early recommendations on noise exposure limits for marine mammals, international fora formulated guidelines aiming to mitigate the negative effects of human activities commonly identified as the main source of underwater noise: the use of high powered active sonar during military or civil operations; seismic surveys for oil and gas exploration and geophysical research; marine traffic (shipping, recreational craft, fishing etc.), and coastal and offshore industrial development (oil and gas, wind farms and other marine renewable energies, port and harbour extensions, etc.). These guidelines recommend the use of a set of procedures and practices that are thought to reduce the negative effects of noise, for example by carefully assessing the risk through acoustic modelling, by siting activities in lower-risk areas or excluding activities from areas of higher risk, by gradually increasing source levels in the hope that animals will escape dangerous areas, by monitoring specific zones both visually and acoustically, etc. Further, some available guidelines recommend the use of best technical solutions aiming to reduce the emission of noise. Such technologies may reduce the source levels (e.g. different foundation techniques instead of piling for wind farms) or the received levels (e.g. noise-reducing techniques such as different types of sound dampers). Software and other informatics tools are employed during the planning phase of some maritime activities (usually to carry out risk assessments), and during real-time mitigation procedures (mainly for passive acoustic monitoring) alerting observers to the presence of individuals enabling mitigation to prevent injuries.

At a national level, Member States of the European Union have implemented some of these international recommendations by developing mitigation frameworks. Although few countries as yet have dedicated laws that regulate noise-inducing activities, more general domestic and EU environmental law (such as the Habitats Directive) apply to many of these activities and the EU's new MSFD expressly requires countries to achieve "good environmental status" for underwater noise. In practice, whether or not mitigation measures are applied has depended on the environmental policy of private companies or competent authorities (military or civil). From publicly available information, it appears that navies from different countries have mitigation frameworks including a wide range of procedures, though it is not clear how these procedures are put in practice and hence their effectiveness remain doubtful. Also, seismic exploration and coastal and offshore industrial development seem to apply a large number of mitigation procedures. At present, few mitigation measures (mainly vessel speed limits for some Marine Protected Areas or Sanctuaries) are employed for marine traffic noise. A range of practical solutions, including route and speed management, need to be evaluated and quieting technologies seem to be especially promising for the design of future vessels. Good ship maintenance and husbandry also often prevent additional noise.

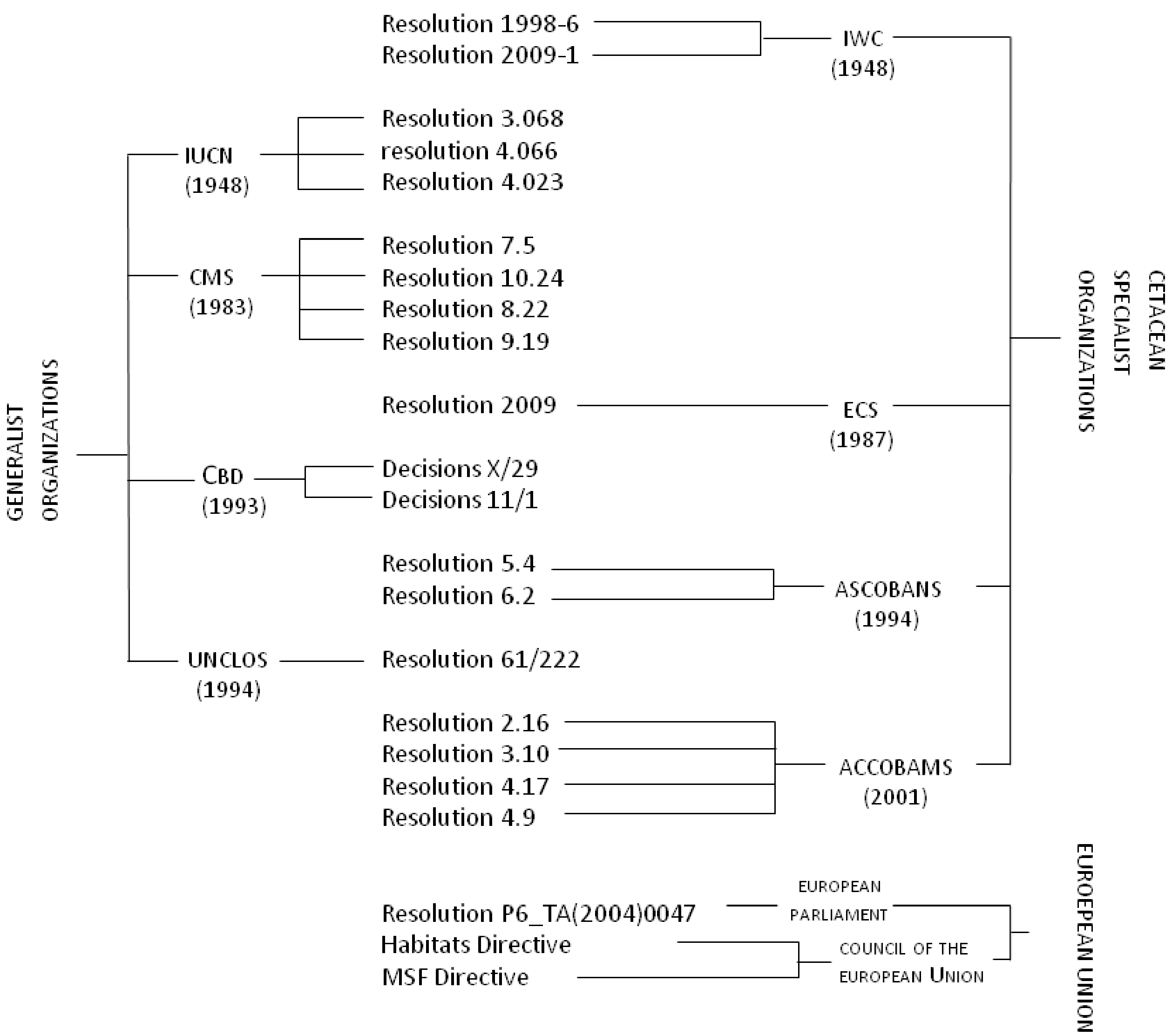

Figure 1. Synthesis of recent relevant international law texts addressing the issues of noise and of conservation of marine wildlife. In brackets the year in which the international bodies were established (IUCN and ECS) or entered into force (all other bodies)

Underwater noise mitigation is increasingly focused on measures that can reduce cumulative, chronic, sub-lethal noise exposures and impacts, rather than only on those that address acute impacts close to a noise source. For this reason, several intergovernmental guidelines and reports, and most recently the International Whaling Commission's Scientific Committee, have emphasised use of such measures as habitat planning, time-area closures, and development and use of best available quieting technologies as critical means of reducing cumulative effects. Mitigation frameworks might be improved (and their use spread) by gathering more baseline information on the distribution, abundance, seasonality and the acoustic ecology of cetaceans, and expanding our understanding of the range of effects sound has on these species. Subsequently, thresholds for safe/harmful exposure levels could be proposed, if possible, though this is a complicated task, as there is much variation between species, individuals, behavioural context, etc. Further, consulting the private sector would help in the dissemination and comprehension of mitigation measures as well as to determine the costs of particular measures and the most appropriate solutions to ensure protection of wildlife. In addition, some existing solutions (best practices and best available technologies) need to be tested and progressed urgently in order to confirm (or reject) their effectiveness; and agencies should accelerate development and use of noise-quieting technologies through incentives and regulations. Finally, we observe that more effort needs to be made in order to simplify and/or clarify guidelines from ACCOBAMS and ASCOBANS, to enhance their comprehension by all relevant stakeholders. Measures to ensure monitoring and reporting of mitigation are required across the noise producing sector.

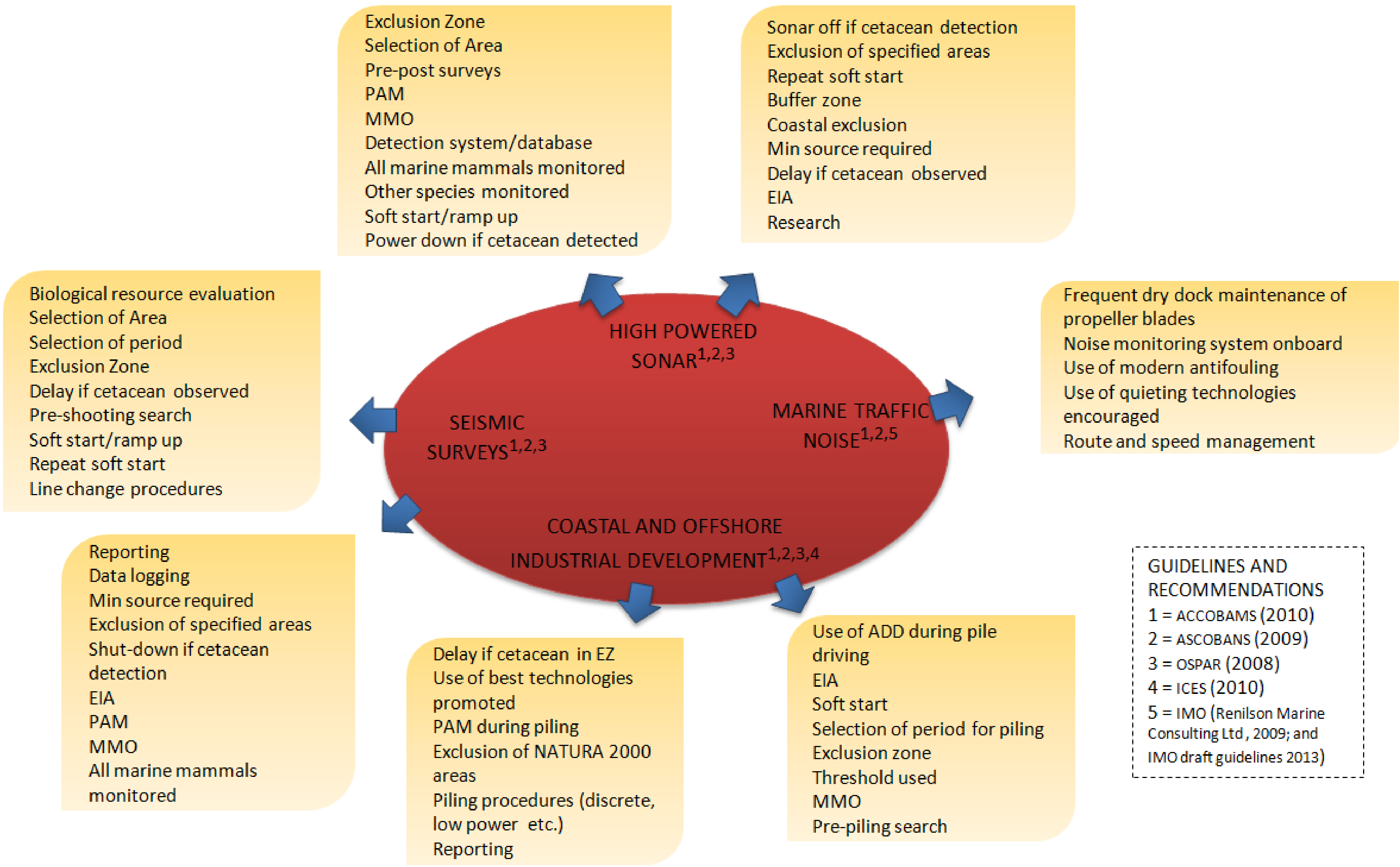

Figure 2. Synthesis of measures aiming to mitigate the negative effects of noise-inducing human activities, as recommended by international fora such as ACCOBAMS, ASCOBANS, OSPAR and ICES. In 2009, the IMO took note of the contents of a report, prepared by Renilson Marine Consulting and submitted by the IFAW and FOEI, which presents advice for mitigating the impact of shipping noise. Additionally, in March 2013 the Drafting Group on Underwater Noise of the Sub-committee on Ship Design and Equipment of the IMO agreed to the draft MEPC circular on Guidelines for the Reduction of Underwater Noise from Commercial Shipping, for submission to MEPC 65 (2014) with a view to approval

1. Underwater Noise and Marine Mammals under International Conventions and Agreements

In has been now widely accepted that marine wildlife is threatened by the unregulated and wide-scale development of human activities. Several international organizations take part in the process of building a sustainable way of development in the marine environment. The activities of these organisations span over a wide range of fields with different levels of priority accorded to the issues of underwater noise and conservation of marine mammals. Among these bodies we distinguish International Treaties, Conventions, and Agreements as well as Agencies, Commissions and Associations. Thus, current progress in managing marine noise pollution is the result of the work undertaken by all these bodies.

Underwater noise is recognised as a form of pollution. Hence, this issue is mentioned in the statutes of the international conventions dealing *inter alia* with the large topic of pollution such as the United Nations Convention on the Law of the Sea (UNCLOS), the Convention on the Protection of the Marine Environment of the North-East Atlantic (OSPAR), the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) and the Convention on the Protection of the Marine Environment of the Baltic Sea Area (HELCOM). Each convention states that pollution means “the introduction by man, directly or indirectly, of substances or energy” into the environment (1–4).

Marine mammals are emblematic marine species that are protected by several international conventions. According to different priorities in the objectives of each convention, marine mammals benefit from different levels of protection and are classified as having different conservation statuses. The Convention on International Trade in Endangered Species (CITES) list 24 taxa of cetaceans and two of pinnipeds in Appendix I (species threatened with extinction whose trade needs strict regulation) and all other taxa of cetaceans and the species of the *Monachus* genus in Appendix II (species that benefit from regulation of trade of specimens) (5). Further, under the Convention for the Conservation of Migratory Species of Wild Animals (CMS), 15 species of cetaceans and one pinniped are defined as endangered in Appendix I. Moreover, 36 species of cetaceans and two species of pinnipeds are considered as having unfavourable status and listed in Appendix II of the same convention (6). Concerning the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention), 30 species of cetaceans and 3 species of pinnipeds are mentioned in Appendix I (strictly protected species) while Appendix II (protected species) of the same convention lists all other species of cetaceans and 6 more species of pinnipeds (7).

All species of cetaceans are protected in the Black Sea, Mediterranean Sea and Portuguese and Spanish Atlantic under the ACCOBAMS agreement (8) while ASCOBANS gives protection status to all toothed whales except the sperm whale (*Physeter macrocephalus*) (9).

In **Table 1** we give an overview of the portion of protected species which are mentioned in the annexes to the texts of conventions and found in European Union waters as regular, occasional or accidental (definition taken from the ANNEX 1 to the ACCOBAMS Agreement (8)). The range of species was consulted on the following public web platforms: OBIS SEAMAP, http://seamap.env.duke.edu/; The IUCN Red List platform http://www.iucnredlist.org/; as well as on the Atlas of Cetacean Distribution in North-west European Waters (10) and the 2010 ACCOBAMS status report *Conserving Whales, Dolphins and Porpoises in the Mediterranean and Black Seas* (11).

In parallel, the conservation of marine mammal populations lies among the objectives of the Convention on Biological Diversity (CBD) (12) and of the International Union for the Conservation of Nature and Natural Resources (IUCN) (13). Finally, issues concerning whaling and sustainable use of whales and pinnipeds by mankind worldwide are addressed by the Convention for the Regulation of Whaling, through the International Whaling Commission (IWC) (14), and by the North Atlantic Marine Mammal Commission (NAMMCO) (15), limited to its area of intervention. However, while the IWC has been contributing to manage the issue of underwater noise since the 1990s, the NAMMCO Commission has not to date taken specific actions.

Table 1. The table lists the portion of marine mammal protected species, mentioned in the annexes to the texts of conventions, which are found in European waters as regular, occasional or accidental. Species are listed in order of concern received by international fora: T. Truncatus is mentioned in eight annexes while D. Delphis and M. Monachus in seven and so on. * ANNEXES II and IV to the Habitats Directive are shown with the purpose of highlighting how the European Union has implemented international fora recommendations. More details about the Habitat Directive are given in paragraph 1.2.

	CITES		CMS		Bern		ACCOBAMS	ASCOBANS	H Directive*	
ANNEXES	I	II	I	II	II	III	I		II	IV
Tursiops truncatus		x	x	x	x		x	x	x	x
Delphinus delphis		x	x	x	x		x	x		x
Monachus monachus	x	x	x	x	x				x	x
Phocoena phocoena		x		x	x		x	x	x	x
Balaenoptera borealis	x		x	x	x		x			x
Grampus griseus		x		x	x		x	x		x
Physeter macrocephalus	x		x	x	x		x			x
Balaenoptera physalus	x		x	x	x		x			x
Eubalaena glacialis	x		x		x		x			x
Globicephala melas		x			x		x	x		x
Kogia simus		x			x		x	x		x
Lagenorhynchus acutus		x		x	x			x		x
Lagenorhynchus albirostris		x		x	x			x		x
Megaptera novaeangliae	x		x		x		x			x
Mesoplodon densirostris		x			x		x	x		x
Orcinus orca		x			x		x	x		x
Pagophilus groenlandicus		x	x	x		x				x
Phoca vitulina		x		x		x			x	x
Pseudorca crassidens		x			x		x	x		x
Stenella coeruleoalba		x			x		x	x		x
Steno bredanensis		x			x		x	x		x
Balaenoptera acutorstrata	x				x		x			x
Balaenoptera musculus	x		x		x					x
Globicephala macrorhynchus		x			x			x		x
Halichoerus grypus		x		x		x			x	
Hyperoodon ampullatus	x					x		x		x
Kogia breviceps		x			x			x		x
Mesoplodon bidens		x			x			x		x
Mesoplodon mirus		x			x			x		x
Phoca hispida		x				x			x	x
Stenella frontalis		x			x			x		x
Ziphius cavirostris					x		x	x		x
Balaenoptera edeni	x				x					x
Erignathus barbatus		x				x				x

1.1. Decisions, Resolutions, Recommendations

Following the identification of underwater noise as a source of disturbance, stress, injury and death in the marine environment, a variety of international law texts have been produced with the aim of regulating noise-generating human activities and abating the negative effects of acoustic pollution. Recent effort towards the achievement of these objectives is presented hereinafter:

- The Resolution 1998-5 and the Resolution 1998-6 of the International Whaling Commission were adopted during the 50th annual meeting in **1998** and identify underwater noise as an argument for future work. In particular, the commission urges the scientific committee to examine environmental changes and human factors other than direct hunting in the study of whale dynamics. Thus, **noise impact is identified** by the SWGEC (Standing Working Group on Environmental Concern) **as a priority topic for future research** (16). Since that time, the SWGEC has convened four symposia on ocean noise, on recent developments in the noise literature, on seismic surveys, on masking impacts, and on the impacts (including noise) of offshore renewable; and every year addresses developments in the field for the IWC Scientific Committee's annual report.

- Resolution 7.5 of the CMS, **2002**, addresses the impact of wind turbines on migratory species. This Resolution calls the contracting parties to realize a full environmental impact assessment, **including noise among the factors needed to be studied**, prior to deciding upon the localization of construction sites and prior to permission granting. Further, this Resolution promotes the development of **specific guidelines** for the establishment of such installations (17).

- The European Parliament adopted the Resolution P6_TA(2004)0047 in **2004.** It deals with environmental effects of high intensity active naval sonar. The Parliament calls on the European Union and its Member States to adopt moratoriums aiming to restrict the use of high-intensity active naval sonar until a **global assessment of their cumulative environmental impac**t on marine mammals, fish and other marine life has been completed. Moreover, the European Parliament calls to develop **alternative technologies** and to **study the impact of noise** in European waters. Finally, it calls to investigate mass stranding events related to the use of naval sonar (18).

- The Resolution 3.068 of the IUCN, adopted in the **2004** World Conservation Congress, allowed notable progress in considering noise as a parameter related to the conservation status of a species. Besides promoting **new research** on underwater noise, the Resolution recommends the application of best scientific results to **establish guidelines** in order to address the impact of noise on marine wildlife. Furthermore, this Resolution requests the Species Survival Commission (SSC) **to evaluate the status of conservation** of marine species **in light of noise pollution** and calls the World Commission on Protected Areas (WCPA) to consider anthropogenic noise in all its work related to marine protected areas (19).

- The ACCOBAMS Agreement recognises man-made noise as a form of pollution in the Resolution 2.16 (**2004**) and urges the Parties to limit noise generating activities in priority habitats of protected species, in particular Cuvier's beaked whale, *Ziphius cavirostris*. Furthermore it urges Parties to consult groups conducting activities that produce underwater noise in order to **recommend that "extreme caution be exercised in the ACCOBAMS area"** and that, ideally, the most harmful of these activities should not be conducted in the area until satisfactory guidelines are developed. Moreover, this Resolution calls the Parties to provide the scientific committee with protocols and guidelines employed by military authorities during maritime operations and encourages **the development of guidelines** to be employed during operations that might cause negative effects on cetaceans (20).

- The Resolution 8.22 adopted by the CMS Conference of the Parties in **2005** recognizes the need to better coordinate the international effort for the conservation of cetaceans. In particular, this Conference requests and encourages the Secretariat and Scientific Council of CMS to **closely cooperate with other international fora and organisations**, such as the CBD, the OSPAR Convention, the UNCLOS as well as the IWC and the IMO, in order to **promote**, through collaborations and synergies between all these bodies, a **more efficient** way to address the issue of conservation of cetaceans. Additionally, the Conference expresses the need to evaluate the actions carried out by CMS, ACCOBAMS and ASCOBANS to abate anthropogenic impacts and, finally, to prioritise the impacts and regions requiring the most urgent attention (21).

- The ASCOBANS Resolution No. 4 of the 5th meeting of the Parties, adopted in **2006**, promotes the development of efficient mitigation measures, calls for new research on underwater noise impacts and on the effectiveness of acoustic deterrent devices. Furthermore, it **requests** the Parties and Range States to **introduce guidelines** on mitigation measures **for seismic surveys**. This resolution addresses as well other sources of underwater noise, **requesting** to establish **guidelines**, and procedures for evaluating these guidelines, for the human activities concerned (**shipping, offshore activities, military** etc.) (22).

- The **2007** UN Resolution 61/222, in its article X, encourages the Parties to use the available tools in order to conserve and manage vulnerable marine ecosystems. In the same paragraph, the **establishment of marine protected areas** is mentioned. Further, it encourages new studies and research effort on acoustic impacts and request the Division **to realize a synthesis of existing results** and findings (23).

- The ACCOBAMS Resolution 3.10 (**2007**) invites Parties to consider underwater noise **as a threat** for cetaceans and especially for beaked whales. Parties are also invited to characterise noise sources, to define potentially dangerous exposure doses, to map the noise exposure of marine mammals and to include underwater noise in the environmental impact assessments. Finally, Parties are invited to consider noise as a **quality descriptor** for the marine protected areas. Further, this Resolution promotes coordination of the effort with the actions undertaken by the Barcelona Convention concerning the Protocol for Specially Protected Areas and Biological Diversity in the Mediterranean area. Lastly, this Resolution establishes the working group dedicated to addressing the issue of anthropogenic noise in the ACCOBAMS area (24).

- The IUCN adopts in **2008** two resolutions concerning the ACCOBAMS area. Resolution 4.066 promotes development of an informal consultation process, in the form of a **permanent consultation forum**, facilitating the exchange of information, exchanges of perspectives **between States bordering the Mediterranean**, so as to achieve better governance in the area. In addition, the congress calls its members to improve the collaboration between the different bodies like the Mediterranean Action Plan (MAP), the General Fisheries Commission for the Mediterranean (GFCM) and ACCOBAMS. Besides, Resolution 4.023 strongly urges members to concretely apply conservation and recovery measures to the critically endangered **monk seal** (*Monachus monachus*) (25).

- Resolution 9.19 of the CMS (**2008**) calls the Parties to **adopt mitigation measures** for cetaceans related to high intensity active naval sonar use, **especially** in areas known or suspected to be **important habitat** to species particularly sensitive to active sonars (e.g. beaked whales). The conference urges the **consultation of stakeholders** conducting noise generating activities, in order to promote the best implementation of risk mitigation measures. Further, the Conference proposes to evaluate the potential benefits of establishing **noise protection areas** (26).

- The **2009** ASCOBANS Resolution No 2 of the 6th Meeting of the Parties sets up a range of recommendations applying to offshore construction activities for renewable energy production. The parties are encouraged to implement **environmental impact assessments** prior to construction, and to use a strategic approach to the siting of marine renewable energy developments. Then, the introduction of specific guidelines addressing the problem of noise is strongly recommended. Finally, the Meeting of the Parties invites the continuation of the **development of effective mitigation measures, guidelines and technological adaptations**, including acoustic deterrent devices, as well as furthering the understanding of noise effects on cetaceans and of the effectiveness of measures adopted (27).

- The European Cetacean Society resolution adopted during the 23th Conference (**2009**), requests to urgently adopt and **enforce regulations for effective mitigation** of active sonar use. This Resolution particularly urges competent authorities to take into account the conservation status and the potential and known effects of sonar on **beaked whales** (28).

- The Resolution 2009-1 on Climate and Other Environmental Changes and Cetaceans of the International Whaling Commission (**2009**), expresses the need to promote research efforts for the understanding of environmental changes on cetaceans,; noise impact is part of the priority research topics identified by the IWC in 1998 (29).

- The Decision X/29 (**2010)** adopted during the meeting of the Conference of the Parties to the Convention on Biological Diversity, requests the Executive Secretary to **compile and synthesise scientific knowledge** on impacts of anthropogenic noise on marine biodiversity. It urges as well the adoption of concrete measures for environmental risk management and mitigation of noise impacts. The key tools cited in this Resolution are Environmental Impact Assessments (EIA) and Strategic Impact Assessments (SIA) as well as the actions carried out in the framework of marine protected areas management. The scientific synthesis of available knowledge about noise impacts on marine wildlife has been completed and presented at the sixteenth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA), held in Montreal, 30 April-5 May 2012. Based on this work, the last meeting of the Conference of the Parties to the Convention on Biological Diversity, in October 2012, formulated relevant Decisions discussed later in this text (30).

- The Resolution 4.17 from the Meeting of the Parties to the ACCOBAMS Agreement (**2010**) establishes guidelines to address the impact of anthropogenic noise on cetaceans in the ACCOBAMS area (31). This Resolution encourages the use of these guidelines for noise producing human activities and invites the Parties to integrate the issue of anthropogenic noise in marine environmental management (EIAs, marine protected areas etc.). Further, the use of the precautionary principle is strongly requested along with the need to provide scientific review of impacts and mitigation measures. An important issue of this resolution is the establishment of a **common working group** on anthropogenic noise between the ACCOBAMS and ASCOBANS agreements.

- The ACCOBAMS Resolution 4.9 of **2010**, though specific to cetacean-related fishery management, gives some recommendations about the adoption of acoustic devices for mitigating cetacean-fishery conflicts. In particular, this resolution states that **great care** must be given to undertaking and evaluating **acoustic devices** using limited controlled in situ tests of effectiveness, in conjunction with the ACCOBAMS Scientific Committee, before widespread implementation is approved. The ANNEX to this Resolution gives the technical specifications and conditions of use of acoustic deterrent devices in the ACCOBAMS area (32).

- The **2011** Resolution 10.24 of the CMS affirms, again, the **need for further research** on acoustic impacts and migratory cycles of cetaceans and other migratory species. It promotes the development of **guidelines** to mitigate impacts and urges to use **best practices and technologies** already available. It proposes **to integrate noise** in EIAs **in order to achieve a holistic ecological approach** at a planning stage. Further, the Conference proposes to take into account the levels of acoustic pollution in developing action plans for MPAs. Finally, the private sector is invited to take part in the development of new technologies and practices that could improve the abatement of noise pollution in the marine environment (33).

- Finally, following the presentation of the scientific synthesis of the available knowledge on the impact of underwater noise (UNEP/CBD/SBSTTA/16/INF/12) (34), the CBD (**2012**), adopt relevant Decisions. In the item 10.2 of the text, the need for **more research** is expressed with a view to further improving the understanding of the issue. Then, it is stated that **indicators** should be developed and frameworks for the **monitoring of underwater noise be explored** for the conservation and the sustainable use of marine biodiversity (35).

In ANNEX I to the present work, Table **I** summarizes the main issues addressed by international laws while Table **II** lists the actions promoted relating thereto.

1.2. The role of the European Union

Due to its special nature, the European Union has a key role in the achievement of the objectives of international fora. Indeed, laws from the Council of the European Union bind Member States to implement them. This can be achieved through Council Regulations or Council Directives. In the former case, Member States directly apply the statements of the regulations whilst, in the latter case, directives need to be transposed into national laws. The most prominent European Union laws concerning marine mammal conservation in the last two decades are the following:

- the DIRECTIVE 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (*Habitats Directive*) (36)

- the DIRECTIVE 2008/56/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (*Marine Strategy Framework Directive*)(37)

The *Habitats Directive* defines the measures to be adopted by Member States in order to safeguard natural habitats and wildlife of the European Union. In practice, it instructs the creation of the network named NATURA 2000 of Special Areas of Conservation. The ANNEXES to this Directive list the natural habitats, in ANNEX I, and the species of fauna and flora, in ANNEX II, whose conservation requires the creation of such a kind of areas. Concerning marine mammals, the following species are listed in the ANNEX II:

- Bottlenose dolphin (*Tursiops truncatus*)
- Harbour porpoise (*Phocoena phocoena*)
- Monk seal (*Monachus monachus*)
- Grey seal (*Halichoerus grypus*)
- Ring seal (*Pusa hispida botnica* and *Pusa hispida saimensis*)
- Harbour seal (*Phoca vitulina*)

ANNEX IV lists the species in need of strict protection. All species of cetaceans are listed in this ANNEX as well as the monk seal (*Monachus monachus)* and the subspecies of Ring seal *Phoca hispida saimensis* among Pinnipeds.

The *Marine Strategy Framework Directive* (MSFD) establishes a framework within which Member States take the necessary measures to achieve or maintain good environmental status in the marine environment. This Directive has set 2020 as a deadline for Member States for the achievement of its objectives. It is an ambitious framework that aims to protect and prevent the marine environment from adverse impacts as well as restore deteriorated ecosystems and reduce human inputs, phasing out pollution. In the definition of “environmental status”, **acoustic conditions** are mentioned as **one of the features** to take into account in the **assessment** of the overall **status** of a given marine region. **Underwater noise** is explicitly mentioned as a form of human-induced pollution in need of regulation. Particularly, underwater noise is one of the eleven **descriptors** by which the “good environmental status” is assessed. Implementing this directive means that qualitative descriptors are “translated” into quantitative criteria and indicators. This can be viewed as a major success of the efforts in understanding addressing underwater noise at a large scale. However, identifying sound levels and thresholds related to such criteria and indicators is the ongoing work undertaken by the scientific groups that currently assist in the implementation of the MSFD. Further discussion on this issue is given in section **2.4.**

2. Existing guidelines review

Following recommendations from international bodies, several texts have been produced outlining guidance on how maritime operations should be carried out and what sound levels should not be exceeded. In this section we first identify noise sources and their levels of emission as identified by OSPAR and CEDA (Central Dredging Association). Then, we review current recommendations on noise exposure limits and on existing practices concerning management and mitigation purposes. Finally, we present how EU Member States implement mitigation measures, based on publicly available information.

2.1. Overview of sound levels by human activity

An overview of anthropogenic sound levels produced by maritime activities is given in the following table, adapted from the OSPAR report on impacts of the underwater noise on marine wildlife (38) and the CEDA review on noise emitted by dredging activities (39).

Table 2. Overview of the acoustic properties of some anthropogenic sounds. * Nominal source, ** Higher source levels from drill ships use of bow thrusters, * Projection based on literature data levels back-calculated at 1 m. CSD = Cutter Suction Dredger; TSHD = Trailing Suction Hopper Dredger.**

Activity	Source	Source level (dB re 1µPa m)*	Bandwidth (Hz)	Major amplitude (Hz)	Duration (ms)	Directionality
Sonar	Military sonar low frequency	235 Peak	100 – 500		6000 – 100,000	Horizontally focused
	Military sonar mid frequency	223 – 236 rms	2800 – 8200	3500	500 – 2000	Horizontally focused
	Echosounders	235 Peak	Variable	Variable 1500 – 36000	5 – 10 ms	Vertically focused
Seismic	Airgun array	260 – 262 P-to-P	10 – 100 000	10 – 120	30- 60	Vertically focused
Coastal and offshore works	TNT (0.5 – 50 kg)	272 – 287 Peak	2 – 1000	6 – 21	1 - 10	Omnidirectional
	Pile driving	228 Peak / 243 – 257 P-to-P	20 – 20 000	100 – 500	50	Omnidirectional
	Dredging (CSD)	172 – 185 rms	30 – 20 000	100 – 500	Continuous	Omnidirectional
	Drilling	145 – 190 rms**	10 – 10 000	< 100	Continuous	Omnidirectional
	Dredging (TSHD)	186 – 188 (rms)	30 – 20 000	100Hz-500Hz	Continuous	Omnidirectional
Shipping	Small boats and ships	160 – 180 rms	20 – 10 000	> 1000	Continuous	Omnidirectional
	Large vessel	180 – 190 rms	6 – 30 000	> 200	Continuous	Omnidirectional
Other activities	Acoustic deterrent / harassment devices	132 – 200 Peak	5000 – 30 000	5000 – 30 000	Variable 15 – 500 ms	Omnidirectional
	Tidal and wave energy devices	165 – 175 rms***	10 – 50 000		Continuous	Omnidirectional

2.2. Existing science on sound exposures limits

Proposals and guidance for sound exposure limit criteria are available according to studies carried out in the United States by several research teams, though these criteria are to be used with caution. This section describes the assessment criteria and guidelines proposed by the US National Marine Fisheries Service (NMSF, 1995) (40), by the US National Oceanographic and Atmospheric Administration (NOAA, 2006) (41), by Southall and co-authors (2007) (42), by the High Energy Seismic Survey (HESS) Team (1999) (43) and by Finneran and

Jenkins (2012) (44). Table-3 has been compiled from a report of Kongsberg Maritime Ltd (2010) (45), in which a summary of the NMFS, NOAA, HESS and Southall *et al* criteria is given, with additional information from Finneran and Jenkins. Values in **Table-3** are received sound levels.

Table 3. Summary of guidelines on impact criteria. Values are received sound levels (adapted from Kongsberg Maritime Ltd (2010) (45) **with additional information from Finneran and Jenkins, 2012). PTS = Permanent Threshold Shift; TTS = Temporary Threshold Shift; LF = low frequency cetaceans; MF = mid frequency cetaceans; HF = High frequency cetaceans; II = Type II Weighting (Finneran and Jenkins, 2012); I = Type I Weighting (Finneran and Jenkins, 2012); M = M-Weighted (Southall et al, 2007); RMS = Root Mean Square.**

EXPOSURE LIMIT	EFFECT	SPECIES	REFERENCE
198 dB re 1μPa²s SEL (II)	PTS (sonar/other active sources)	LF and MF cetaceans	Finneran and Jenkins, 2012
198 dB re 1μPa²s SEL (II)	PTS (sonar/other active sources)	Beaked whales	Finneran and Jenkins, 2012
172 dB re 1μPa²s SEL (II)	PTS (sonar/other active sources)	HF cetaceans	Finneran and Jenkins, 2012
172 dB re 1μPa²s SEL (II)	PTS (sonar/other active sources)	Harbour porpoise	Finneran and Jenkins, 2012
197 dB re 1μPa²s SEL (I)	PTS (sonar/other active sources)	Phocids (in water)	Finneran and Jenkins, 2012
178 dB re 1μPa²s SEL (II)	TTS (sonar/other active sources)	LF and MF cetaceans	Finneran and Jenkins, 2012
178 dB re 1μPa²s SEL (II)	TTS (sonar/other active sources)	Beaked whales	Finneran and Jenkins, 2012
152 dB re 1μPa²s SEL (II)	TTS (sonar/other active sources)	HF cetaceans	Finneran and Jenkins, 2012
152 dB re 1μPa²s SEL (II)	TTS (sonar/other active sources)	Harbour porpoise	Finneran and Jenkins, 2012
183 dB re 1μPa²s SEL (I)	TTS (sonar/other active sources)	Phocids	Finneran and Jenkins, 2012
140 dB re 1μPa (RMS)	Behavioural disturbance (sonar/other active sources)	Beaked whales	Finneran and Jenkins, 2012
120 dB re 1μPa (RMS)	Behavioural disturbance (sonar/other active sources)	Harbour porpoise	Finneran and Jenkins, 2012
187 dB re 1μPa²s SEL (II)	PTS (detonations)	LF and MF cetaceans	Finneran and Jenkins, 2012
161 dB re 1μPa²s SEL (II)	PTS (detonations)	HF cetaceans	Finneran and Jenkins, 2012
192 dB re 1μPa²s SEL (I)	PTS (detonations)	Phocids (in water)	Finneran and Jenkins, 2012
172 dB re 1μPa²s SEL (II)	TTS (detonations)	LF and MF cetaceans	Finneran and Jenkins, 2012
146 dB re 1μPa²s SEL (II)	TTS (detonations)	HF cetaceans	Finneran and Jenkins, 2012
177 dB re 1μPa²s SEL (I)	TTS (detonations)	Phocids (in water)	Finneran and Jenkins, 2012
230 dB re 1μPa (Peak)	PTS (detonations)	LF and MF cetaceans	Finneran and Jenkins, 2012
201 dB re 1μPa (Peak)	PTS (detonations)	HF cetaceans	Finneran and Jenkins, 2012
218 dB re 1μPa (Peak)	PTS (detonations)	Phocids (in water)	Finneran and Jenkins, 2012
224 dB re 1μPa (Peak)	TTS (detonations)	LF and MF cetaceans	Finneran and Jenkins, 2012
195 dB re 1μPa (Peak)	TTS (detonations)	HF cetaceans	Finneran and Jenkins, 2012
212 dB re 1μPa (Peak)	TTS (detonations)	Phocids (in water)	Finneran and Jenkins, 2012
167 dB re 1μPa²s SEL (II)	Behavioural disturbance (detonation)	LF and MF cetaceans	Finneran and Jenkins, 2012
141 dB re 1μPa²s SEL (II)	Behavioural disturbance (detonation)	HF cetaceans	Finneran and Jenkins, 2012
172 dB re 1μPa²s SEL (I)	Behavioural disturbance (detonation)	Phocids (in water)	Finneran and Jenkins, 2012
230 dB re 1μPa (Peak)	PTS	cetaceans	Southall *et al*, 2007
218 dB re 1μPa (Peak)	PTS	pinnipeds	Southall et al, 2007
224 dB re 1μPa (Peak)	TTS	cetaceans	Southall *et al*, 2007
212 dB re 1μPa (Peak)	TTS	pinnipeds	Southall *et al*, 2007
198 dB re 1μPa²s SEL (M)	PTS	cetaceans	Southall *et al*, 2007
186 dB re 1μPa²s SEL (M)	PTS	pinnipeds	Southall *et al*, 2007
183 dB re 1μPa²s SEL (M)	TTS	cetaceans	Southall *et al*, 2007
171 dB re 1μPa²s SEL (M)	TTS	pinnipeds	Southall *et al*, 2007
215 dB re 1μPa²s SEL (M)	PTS	cetaceans	NOAA, 2006
195 dB re 1μPa²s SEL (M)	TTS	cetaceans	NOAA, 2006

190 dB re 1µPa (RMS)	Auditory injury criteria	pinnipeds	NMFS, 1995
180 dB re 1µPa (RMS)	Auditory injury criteria	cetaceans	NMFS, 1995
160 dB re 1µPa (RMS)	Behavioural disturbance for impulsive sources	cetaceans	NMFS, 1995
140 dB re 1µPa (RMS)	Low level disturbance	cetaceans	HESS, 1997
120 dB re 1µPa (RMS)	Behavioural disturbance for continuous sources	cetaceans	NMFS, 1995

However, it should be noted that criteria formulated before 2012 are quite controversial and out-dated at this time. Also, they have little or no validation under open water conditions and have never actually been used in regulations. Auditory injury data from controlled tests with a few captive animals have been used as the basis for developing the auditory injury, PTS and TTS guidance criteria. Observations of behavioural avoidance with concurrent acoustic measurements are sparse and highly variable, and hence the behavioural avoidance criteria are highly speculative. Thus, NMFS thresholds are currently under review and will be updated by the end of 2013, based on the recent work by Finneran and Jenkins (2012). This last work proposes a variety of thresholds according to auditory characteristics of marine mammals and to noise sources (active acoustic sources or detonations). It proposes also new weighting functions to calculate thresholds, based on recent research on acoustic biology. This might improve considerably the use of sound exposure criteria.

2.3. International guidelines

In European Union waters, four bodies have dealt with guidance on the impact of underwater noise, either directly addressing this issue related to each noise-producing activity (ACCOBAMS, ASCOBANS and ICES), or including noise into the range of impacts induced by specific human activities in the marine environment, particularly wind farm development (OSPAR and ICES). Relevant works from these bodies are the following:

- the Resolution 4.17 "G*uidelines to address the impact of anthropogenic noise on cetaceans in the ACCOBAMS area*" (31);
- the "*Final Report of the ASCOBANS Intersessional Working Group on the Assessment of Acoustic Disturbance*" (46);
- the OSPAR " *Overview of the impacts of anthropogenic underwater sound in the marine environment*" (38);
- the OSPAR "*Guidance on Environmental Consideration for Offshore Wind Farm Development*" (47);
- the ICES "*Report of the Working Group on Marine Mammal Ecology (WGMME)"* (48)
- the ICES "*Report of the Ad-hoc Group on the Impacts of Sonar on Cetaceans and Fish (AGISC), 2nd edition*" (49).

Additionally, we present some key concepts from the report *Reducing underwater noise pollution from large commercial vessels* prepared by Renilson Marine Consulting Pty Ltd (2009) (50) and submitted by IFAW (International Fund for Animal Welfare) and FOEI (Friends of the Earth International) to the Marine Environmental Protection Committee (MEPC) of the International Maritime Organisation in 2009. The IMO took note of this information in the paper *Noise from commercial shipping and its adverse impacts on marine life* (51). These concepts have further been published by Renilson and Leaper (2012)(52) and integrated in the draft guidelines prepared by the Drafting Group on Underwater Noise of the Sub-committee on Ship Design and Equipment of the IMO. This draft has been submitted to the MEPC with a view for approval in 2014.

ACCOBAMS and ASCOBANS guidelines were formulated on the basis of the same report presented at the 4th Meeting of the ACCOBAMS Scientific Committee (Pavan, 2006 (53)) and present, therefore, similar concepts. Nonetheless, the structure of the two texts is different. This issue is discussed in Paragraph **2.3.7.** These reports are specific to cetaceans and do not address the issue of threatened pinniped species. A document from OSPAR and one from ICES are specific to the issue of wind farm development, but comprehensive about the concern for pinniped conservation. Further, the OSPAR report named "*Overview of the impacts of anthropogenic underwater sound in the marine environment*" (38), includes more general text outlining mitigation measures concerning all noise-inducing human activities aforementioned (Cf paragraph **2.1.**), related to cetaceans and pinnipeds. Finally, the ICES report on the impacts of sonar deals with mitigation for military sonar use and concerns solely cetacean species and particularly beaked whales. Globally, these texts propose guidance as follows:

1. General concepts to consider for any project
2. Guidelines for sonar in military and civil activities
3. Guidelines for seismic surveys and airgun uses
4. Guidelines for coastal and offshore construction works, including windfarms and other offshore platforms
5. Guidelines for playback and Sound Exposure Experiments
6. Guidelines for maritime traffic, including commercial shipping, recreational craft and other tourist activities

2.3.1. General concepts to consider in any project

ACCOBAMS/ASCOBANS: The planning of operations should consider a wide range of factors including biological and ecological parameters (life cycles, distribution, density etc.), and the extent of possible impacts. Consequently, databases of cetacean ecological and biological parameters should be consulted and, if required information is lacking, dedicated surveys or monitoring projects should be carried out. Models of noise propagation should be run and verified in the field in order to determine exclusion/safety zones. The analysis of cumulative effects (noise + other possible stressors) should be the preferred framework. Precautionary and conservative principles should be applied in cases of uncertainty. Diversity and density hotspots or critical habitat (i.e. breeding or feeding grounds) should be avoided. Monitoring programs spanning the whole period of a project (before, during, and after) are to be implemented. Experienced observers and bio-acousticians, able to apply standardized protocols and to report to competent authorities, should be engaged in this kind of monitoring program. Finally, other measures to consider may be to alert stranding networks during sensitive operations.

OSPAR: General concepts largely agree with those mentioned above, namely, geographical and seasonal restrictions in order to avoid ensonification of sensitive species and habitats, are cited as the most effective measures. Soft-start / ramp-up procedures also are cited as measures to alert marine life to noise. Finally, acoustic deterrent devices are mentioned as a mean to drive away animals from impacted areas and therefore as a useful mitigating measure. Another important concept is that criteria need to be set for noise exposure that should not be exceeded.

ICES: the Working Group on marine mammals highlights the importance of international cooperation, in particular in the use of common standards for protocols, measurements, and exposure limits. Further concepts trace those already mentioned: use of visual observers and bio-acousticians, ramp up protocol and acoustic deterrent devices.

2.3.2. Guidelines for military sonar and civil high powered sonar

ACCOBAMS/ASCOBANS: In addition to general guidelines, the practices set out in this paragraph should be applied specifically to military and civil activities involving the use of high powered sonar. Thus, the lowest practicable source power should be used. The sequencing of sonar lines should be adapted to account for any predictable movements of animals across the survey area and to avoid blocking escape routes. Visual and passive acoustic monitoring (MMO and PAM) should be carried out continuously and with appropriate tools, such as "big eyes" for visual surveying. Inadequate conditions for visual or acoustic monitoring should cause a restriction of activities. Furthermore, increased precaution in deep waters and known areas of beaked whale presence is strongly recommended as well as application of ramp up/soft start protocols. In case of sightings in the Exclusion Zone (EZ), activities should be stopped, reduced or delayed. As a precautionary measure, a 30 minute interval (120 in increased concern situations and in areas with deep divers) without animals in the EZ before the beginning of noise emissions is required. Finally, no EZ for particularly sensitive or vulnerable species (i.e. beaked whales and sperm whales) should be adopted in order to enable the shut-down of noise sources whenever a sighting of such species occurs in the entire monitoring area.

OSPAR: Mitigating measures include: obtaining information about ecological and biological parameters (presence, density and distribution) in the chosen area and sensitivity to noise of target species; calculating the risk in light of such information; limiting overall use and the area of use (avoiding important habitats, especially for beaked whales), limiting the season of use (avoiding sensitive periods); using passive acoustic monitoring and marine mammal observer protocols; adapting the frequencies to where the animal's hearing is relatively insensitive; regulating the use of sound if marine mammals are detected close to the source; implementing noise monitoring programs; if applicable, carrying out marine mammal observation of reactions to stress by using tagging, passive acoustic monitoring to detect vocalisation or active acoustic monitoring; and finally, use the soft start protocols.

ICES: with regard to military use, the following guidelines are promoted in this report: consider the species that might be present, their density and sensitivity to the noise and hence the area that might be affected; consider the significance of the effect, or the risk of that effect, on those individuals or their stock; limit overall use, or the area and the season of use; reduce power, duration or frequency (in terms of number of times) of emissions; avoid areas of known beaked whale abundance; use MMO and PAM or AAM (active acoustic monitoring) protocols; avoid sensitive periods and areas (i.e. migratory routes, breeding grounds etc.); use of soft start / ramp up ; noise monitoring programs; where applicable, implement monitoring programs in order to detect reactions and effects to sound exposure.

2.3.3. Guidelines for seismic surveys

ACCOBAMS/ASCOBANS: Measures that apply to seismic surveys echo those for military and civil activities involving sonar use in addition to some specific measures presented here. Thus, the use of the lowest practicable source power is recommended as well as adopting suitable array configurations and pulse synchronization in order to limit horizontal propagation. The sequencing of seismic lines should be adapted to account for any predictable movements of animals across the survey area and avoid blocking escape routes. Moreover, multiple operating vessels should be regulated or prohibited. In the case of more than one seismic vessel operating in the same area, a minimum separation distance should be maintained. Model noise propagation verified in the field should be run to identify Exclusion/Safety Zones. Visual and passive acoustic monitoring (MMO and PAM) should be carried out continuously and with appropriate tools, such as the "big eyes" for visual surveying. Inadequate conditions for visual or acoustic monitoring (i.e. night, bad weather etc.) should cause a restriction of activities. Furthermore, increased precaution in deep waters and known areas of beaked whale presence is strongly recommended as well as application of ramp up/soft start protocols. In case of sightings in the Exclusion Zone, activities should be stopped, reduced or delayed or, if applicable, the vessel route changed. As a precautionary measure, a 30 minute interval (120 in increased concern situations or in the presence of deep divers) without animals in the EZ before the beginning of noise emissions is required. Finally, no EZ for particularly sensible/vulnerable species (i.e. beaked whales and sperm whales) should be adopted in order to enable the shut-down of noise sources whenever a sighting of such species occurs in the entire monitoring area.

OSPAR: The methods used to mitigate impacts of seismic surveys include: geographical and/or seasonal restrictions, source reduction or optimisation, buffer zones, surveillance of buffer zones by visual, acoustic or other means, soft-start techniques and reporting requirements.

2.3.4. Guidelines for coastal and offshore construction works, including windfarms and other offshore platforms

ACCOBAMS/ASCOBANS: Prior to the beginning of operations, sound propagation models should be run in order to define Exclusion/Safety zones. This would require as well the implementation of noise monitoring programs to verify model predictions. During the construction phase, alternative technologies should be used (instead of pile drivers or jackhammers). Additionally, the use of source-based mitigating technologies (i.e. bubble screens) is strongly recommended. Visual and acoustic monitoring programs should be carried out and noise inputs should be stopped, reduced or delayed in case of sightings in the Exclusion Zone. The 30 minute interval (120 in increased concern situations or in the presence of deep divers) without animals in EZ before beginning of emissions should be applied.

These represent requirements to ensure a minimum mitigation framework. They are suitable for operations for which noise is the most important issue to be addressed. In other cases, it is more suitable to establish monitoring and mitigation procedures on a case by case basis following a holistic environmental impact assessment. In such cases, compensatory measures can be defined taking into account the cumulative impacts, and operational planning can be developed according to study findings.

OSPAR: the guidance recommends mitigation measures to be applied according to the different phases of a wind farm project: licensing, construction and operation. The licensing phase is subject to the realisation of a comprehensive environmental impact assessment (EIA). The choice of site for the future wind farm is crucial and should be done on the basis of the EIA and in consideration of NATURA 2000 special areas of conservation under the Habitats Directive (92/43/EEC), as well as the special protection areas under the Bird Directive (79/409/EEC). Thus, baseline information about ecological and biological parameters (distribution, density, priority habitats, acoustics, etc.) should be obtained in order to facilitate the siting of the installation. Programs aiming to gather such information should be planned as well as monitoring projects before, during and after construction. The precautionary approach should be used to deal with uncertainty.

Concerning noisy activities during the construction phase, sensitive periods for marine wildlife should be avoided (e.g. seal pupping periods). Quieting or alternative technologies, such as enclosing the ramming pile with acoustically-isolated material or using hydraulic pile driving or drilling (as is used for tunnels), is preferred. Extending the duration of the impact during pile-driving, which can decrease the source level by 10-15 dB, might be a solution to apply as well. In any case, the use of best practices is required, such as soft start / ramp up for pile driving, visual and acoustic monitoring (use of MMO and PAM protocols) of marine mammals, as well as noise reducing technologies (i.e. bubble screen, able to decrease the source level by up to 20 dB). Noise inputs should be shut down, reduced or delayed in the case of marine mammal sightings near the noise source. Additionally, the use of acoustic deterrent devices (pingers, seal scarers etc.) may be employed. Finally, acoustic monitoring of noise should be carried out in order to, *inter alia*, verify predictions of propagation models eventually employed during the EIA phase.

Regarding the operational phase, besides the long term visual and acoustic monitoring programs that need to be accomplished, the OSPAR text states that “no mitigation measures” are “currently available” for mitigating operational noise effects. Moreover, the only way to prevent important barrier effects is a site selection that avoids key habitats and diversity/density hotspots as well as migratory routes.

ICES: Advice and recommendations are proposed by ICES in how to carry out monitoring programs and apply mitigation measures. These recommendations highlight the importance of optimizing efforts both at the national and international level in addressing the issue of wind farm impacts. For example, they encourage international cooperation in order to assess appropriate populations and/or management units of the relevant marine mammal species, irrespective of national borders. Further, the Working Group of the ICES recommends the use of common standards for noise monitoring as well as commonly accepted exposure limits for marine mammals. Concerning specific guidelines, the location of offshore wind farms should be done in light of EIAs that consider ecological and biological parameters as well as physical and hydrographical ones. As part of this, ICES recommends using methods to assess cumulative effects on marine mammals, particularly of the underwater noise caused by the simultaneous construction and operation at nearby sites. Then, acoustic deterrent devices should be used and research on new devices should be carried out, including realistic trials in the field to demonstrate their effectiveness. Finally, the Working Group recommends the development of alternative technologies (i.e. quieting technologies).

2.3.5. Maritime traffic, including commercial shipping, recreational craft and other tourist activities

ACCOBAMS/ASCOBANS: Noise from ships should be evaluated both at close range for its direct possible effects on local marine life and at long range for its contribution to background noise at low frequencies. Mitigation of noise impact depends largely on the use of quieting technologies rather than best practices protocols. However, lowering speed appears to be a very effective way to reduce ship noise as well as carrying out frequent maintenance of propeller blades. Alternative and new technologies are discussed in Chapter 3. Concerning tourist activities (recreational craft and whale watching), specific guidelines already exist and their distribution need to be supported as much as possible. Additionally, codes of conduct for whale watching are implemented in several countries.

OSPAR: In agreement with ACCOBAMS statements, their guidance mostly relies on the development of vessel-quieting technologies, for example technologies that minimize propeller cavitation. About operational measures that could have positive outcomes, routing and speed restriction seems to be the most workable measures, although this could have other negative effects that need to be evaluated as well.

IMO: texts discussed hereafter include the report from Renilson Marine Consulting (2009)(50), the paper from Leaper and Renilson (2012)(52) and the draft guidelines of the IMO DE sub-committee (2013). Computational models for estimating radiated noise are proposed in the draft guidelines in order to help ship owners, builders and designers to identify noise control measures. Further, reducing ship noise might be achieved by lowering the propeller cavitation. Hence, it is suggested that commercial ships carry out frequent dry-dock maintenance of propeller blades, as blade damage is identified as a possible source of cavitation. Propeller polishing and the use of modern antifouling also are suggested as practices that reduce radiated underwater noise. Moreover, it is proposed that a noise monitoring system be used onboard in order to alert operators when it would be cost effective to clean and/or repair a propeller as to improve its efficiency and reduce noise output. Finally, re-routing and speed selection are promoted as important measures to implement. Additionally, the use of quieting technologies is encouraged. Available technologies are presented in paragraph **3.1.** and in **ANNEX III**

2.3.6. Guidelines for playback & sound exposure experiments

ACCOBAMS/ASCOBANS: Experiments involving controlled sound exposure to wild animals need to be evaluated in a case by case basis. It is particularly important that they are carefully designed and conducted and their limitations and risks acknowledged. Avoidance of duplicative or overlapping research will also help to prevent any unnecessary introduction of noise into the marine environment.

2.3.7. Comparing ACCOBAMS and ASCOBANS guidelines

This section highlights some differences between ACCOBAMS and ASCOBANS guidelines, with the aim of discussing which might be used as a reference by countries to develop or improve their own national guidelines. Especially, this paragraph focuses on the clarity of the recommendations formulated in these two texts, rather than discussing the effectiveness of current mitigation measures or their scientific basis. Texts discussed here are the ACCOBAMS Resolution 4.17 (2010) and the Final Report of the ASCOBANS Intersessional Working Group on the Assessment of Acoustic Disturbance (2009).

First of all, both texts are structured in subsections that deal with general guidelines, sonar use, seismic surveys, coastal and offshore works, exposure experiments and shipping (Cf **Paragraph 2.3.**). Hence, relevant mitigation measures are advocated in each subsection, according to the argument discussed. A further structure is used in the ASCOBANS guidelines for which mitigation measures are assigned to the following three phases:

1. Planning
2. Real-time mitigation
3. Post activity monitoring & reporting

This framework is used for each subsection aforementioned. Such a structure generally follows the phases proposed by TNO (2011) about noise measurement and reporting procedures to be used for offshore wind farm development in The Netherlands. The proposal from TNO could be used as a basis for international standardisation concerning measurements and terminology[1] (54,55). It appears thereby that the ASCOBANS guidelines structure is a more straightforward way to show how mitigation frameworks should be implemented.

On the other hand, we observe that both texts may appear redundant, in the detriment of clarity. Concerning ACCOBAMS guidelines, quite similar concepts or parts of concepts are repeated in different points of the same subsection, while in the ASCOBANS guidelines the same concepts are proposed both for the planning and the real-time mitigation phase. Hence, we believe that both guideline texts should be simplified in order to be more easy-to-understand for all relevant stakeholders (including industrial companies, maritime transport authorities, etc.).

We further believe that the terminology used for discussing mitigation measures is an issue that needs to be addressed. As an example, the expressions “seasonal and spatial restrictions”, “geographical and seasonal restrictions” and “avoidance of sensitive habitat and sensitive periods” represent the same fundamental concept. On the other hand, “Exclusion Zone”, “Buffer Zone” and “Areas of Exclusion” express different concepts while using similar terminology. We observe that stating the meaning of terms in an introductory dedicated paragraph would be an easy solution in order to facilitate the comprehension of guidelines by all concerned stakeholders.

In conclusion, the structure used for formulating ASCOBANS guidelines appears to be more convenient, though further work toward the simplification and clarification of terms needs to be carried out.

[1] It has to be noted that, as this report is focused on the issue of wind farm development, a fourth phase is considered, namely the decommissioning phase.

Table 4. Comparison between ACCOBAMS/ASCOBANS, OSPAR and ICES guidelines and recommendations

	ACCOBAMS/ASCOBANS	OSPAR	ICES
General concepts	Apply precautionary principle Get information on ecology and biology of target species Plan monitoring programs Avoid known key habitats and MPAs Run noise propagation models Realize cumulative effects analysis (EIA) Define safe/harmful levels Define Buffer Zones Define Exclusion Zones Alert Stranding Networks Use MMO and PAM protocols Stop emissions in case of strandings or behaviour reaction Logging acoustic source in order to further post-analysis reporting	Apply precautionary principle Apply geographical and seasonal restrictions Use of acoustic deterrent devices (ADD) Set criteria for noise exposure that should not be exceeded	Use common standards for protocols, measurements, exposure limits Use appropriate population/management units for ecological assessments (developing international collaborations) Use MMO and PAM protocols Avoid sensitive areas and periods Apply ramp up protocol Use acoustic deterrent devices (ADD) Use alternative technologies (quieting technologies)
Sonar (military and civil)	**General guidelines and:** Apply the lowest practicable source power Adapt the sequencing of source lines to account for predictable movement of animals Avoid blocking escape routes Use big eyes for MMO Night and day PAM Restrict activities during inadequate monitoring conditions (bad weather, night etc.) Apply ramp up / soft start protocols Stop/reduce/delay noise inputs in case of sightings inside the Exclusion Zone Apply 30 minute interval without animals in EZ Apply 120 minute interval for beaked whales and other vulnerable species (no EZ) Apply 120 minute interval in any increased concern conditions Shut-down of noise inputs in case of beaked whale or sperm whale sightings (no EZ)	**(Military only)** Get information on ecology and biology of target species Get information about sensitivity of species Calculate the risk Limit/adapt source power Limit areas of use (avoid important habitats) Limit season of use (avoid sensitive periods) MMO and PAM Regulate sound emissions if animals are detected close to the source Plan noise monitoring program Study the reactions of animals to noise exposure	**(Military only)** Consider the species that might be present and their density Consider their sensitivity to the noise Calculate the area that might be affected Consider the significance of the effect, or the risk of that effect, on those individuals or their stock Limit overall use Avoid sensitive periods and areas (i.e. migratory routes, breeding grounds etc. Reduce power, duration or frequency (in terms of number of times) of emissions Avoid areas of known beaked whale abundance Use MMO and PAM or AAM (active acoustic monitoring) protocols Use of soft start / ramp up techniques Realize noise monitoring programs; Implement monitoring programs in order to detect reactions and effects to sound exposure

Seismic surveys	**General and Sonar guidelines and**: Adopt suitable array configurations and pulse synchronization in order to limit horizontal propagation Avoid multiple operating vessels In case of multiple vessels operations use a minimum separation distance Change vessel route	Avoid sensitive areas and periods Adapt/optimize/reduce noise source Define buffer/exclusion zones Use MMO and PAM Apply soft start protocol reporting	
Coastal and offshore works **(harbours, wind farms, offshore platforms etc.)**	**General guidelines and**: Wide EIA required in complex projects (i.e. windfarms) Noise monitoring program to verify model predictions Use of alternative construction technologies (quieting technologies) Source-based mitigation technologies (bubble screen etc.) Stop/reduce/delay noise inputs in case of sightings inside the Exclusion Zone Apply 30 minute interval without animals in EZ Apply 120 minute interval in any increased concern conditions Mitigation and compensatory measures on a case by case basis in complex projects	Prepare a broad EIA (accounting for NATURA 2000 and Bird Directive special areas) Noise monitoring program Choose the site on the basis of the EIA Get information on ecology and biology of target species Plan monitoring programs Avoid known key habitats, MPAs Avoid sensitive periods (i.e. mating, pupping) MMO and PAM Stop/reduce/delay noise inputs in case of sightings close to the source Use of alternative construction technologies (quieting technologies) Extend the duration of pile driving blows Source-based mitigation technologies (bubble screen etc.) Mitigation and compensatory measures in a case by case basis **No mitigation available for operational phase** **No mitigation available for barrier effect**	**(Wind Farms)** Prepare a broad EIA Use cumulative effect methods for EIAs Consider ecology and biology of concerned marine mammal populations Consider physical and hydrographical parameters Choose the site on the basis of the EIA Use Acoustic Deterrent Devices Test the effectiveness of new devices Use and develop alternative (quieting) technologies
Maritime traffic **(Shipping, recreational craft etc.)**	**General guidelines and**: Evaluate close range and long range effects Use of quieting technologies Guidelines for tourist traffic already available Code of conduct for whale watching already in force in many countries	**(Shipping)** Use quieting technologies Manage routing and vessel speed	
Sound Exposure Experiments	Evaluate case by case cost/benefits in terms of noise production/scientific value Avoid duplicative and overlapping research		

2.4. Rules of the Marine Strategy Framework Directive

As stated above in the text, the level of noise in the marine environment is a descriptor of the environmental status (Descriptor 11). Achieving "good environmental status" means that qualitative descriptors, as reported in ANNEX I to the MSFD (37), must be satisfied. Thus, according to the definition of Descriptor 11, "the introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment". Hence, defining these levels is currently the main objective of the ad-hoc scientific groups supporting the implementation of the Directive. Based upon the work of the Task Group 11 (56), two criteria, and consequently two indicators, have been selected by the European Commission (Decision 2010/477/EU) (57):

11.1. Distribution in time and place of loud, low and mid frequency impulsive sounds

- Proportion of days and their distribution within a calendar year over areas of a determined surface, as well as their spatial distribution, in which anthropogenic sound sources exceed levels that are likely to entail significant impact on marine animals measured as Sound Exposure Level (in dB re 1µPa 2 .s) or as peak sound pressure level (in dB re 1µPa peak) at one metre, measured over the frequency band 10 Hz to 10 kHz (**11.1.1**).

11.2. Continuous low frequency sound

- Trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re 1µPa RMS; average noise level in these octave bands over a year) measured by observation stations and/or with the use of models if appropriate (**11.2.1**).

As stated in the report of the Technical Subgroup (TSG) on Underwater Noise and other forms of energy (55), the description of these indicators might not be unambiguous and, therefore, the TSG Noise propose interpretations in order to solve ambiguity. Yet, for both indicators, levels and threshold are to be defined. In the report of TSG Noise, three choices are proposed for indicator 11.1.1:

- Unique Fixed Threshold at source according to Southall *et al* 2007 (**source level 183 dB re 1 µPa² m² s or the zero to peak source level of 224 dB re 1 µPa² m²**)(42)
- Variable thresholds based on risk assessment
- Unique thresholds by type of source, according to different type of human activities

The first option is currently the only one suggesting a threshold. The second is theoretically the best option, since it is based upon a robust scientific approach, while the third is a combination of both the first and the second *scenario*. Other issues currently under discussion concern the spatial and seasonal extent to which the monitoring of anthropogenic impulsive sounds should be carried out.

Regarding the indicator 11.2.1, the discussion is focused on both thresholds and how to meaningfully detect the "trends" in ambient noise, but the thresholds are on a longer timeline for development. However, the Task Group 11 on underwater noise and other forms of energy suggested that a threshold of **100 dB re 1µPa rms over a year** should not be exceeded (56).

2.5. National Implementation

The international recommendations summarised above have been implemented by different countries in the European region, either by means of dedicated national laws, or by applying the international recommendations, though a gap in the national legal framework exists. For instance, the use of marine mammal observers (MMOs) is mandatory on UK, German, and Norwegian naval ships operating active sonar (38). On the other hand, in French waters seismic surveys are carried out applying a self-regulated mitigation framework, as no recognised legal obligations exist. During the review exercise we analysed several texts dealing with national implementation of mitigation measures, including both national texts and third parties reviews (48,58–72). Detailed information, by country and by activity is shown in ANNEX II. However, for several Parties to the ACCOBAMS and ASCOBANS agreements, no or lacking information was gathered. We recommend hence that tables of ANNEXE II be updated with new information. For this reason, in this paragraph we highlight which measures and procedures are used in a sample of European countries, by activity.

- **SONAR**: Navies of the UK, Norway and the Netherlands are endowed with software tools (ERMS, SONATE and SAKAMATA, respectively (38,58,59)) that are used, prior to naval operation, in order to automatically evaluate the risk of such activities in the foreseen areas and seasons, and hence apply the guidelines that best fit the particular conditions of each naval exercise. Furthermore, the review exercise carried out for compiling **Figure-1** points out a discrepancy between two texts. Specifically, Dolman and co-authors (2011) (62) state that MMOs are not required during Norwegian navy operations whilst OSPAR (2009) (38) affirms that they actually are. More details about mitigation measures applied during military sonar exercises are reported in ANNEX II to this text.

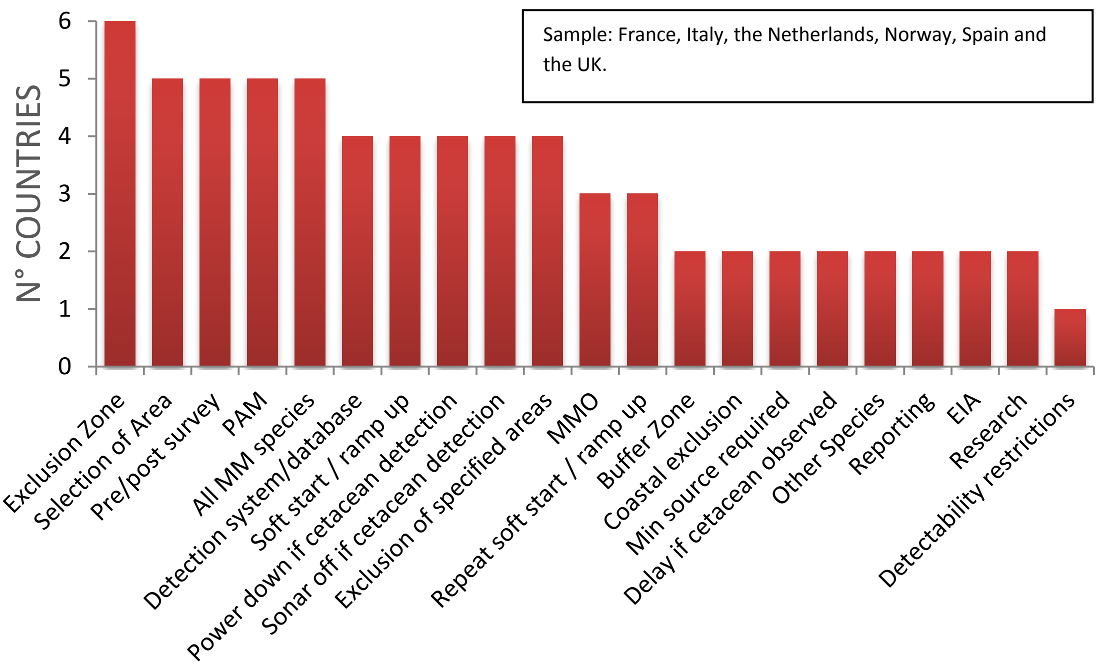

Figure 3. Measures implemented in a sample of European countries during military operations

- **SEISMIC SURVEYS**: JNCC guidelines are statutory for the UK and currently represent an informal reference for developing national guidelines in other countries (60). Denmark guidelines only concern seismic surveys carried out in Greenland waters (61), while the French guidelines we analyzed were developed for Guyanese waters (71), though both echo JNCC ones. Finally, It must be noted that, concerning Norway, seasonal and spatial selection are mainly a consequence of increasing conflicts with fishery activities, rather than avoiding marine mammal habitats (58,72). More details about mitigation measures applied during seismic surveys are reported in ANNEX II to this document.

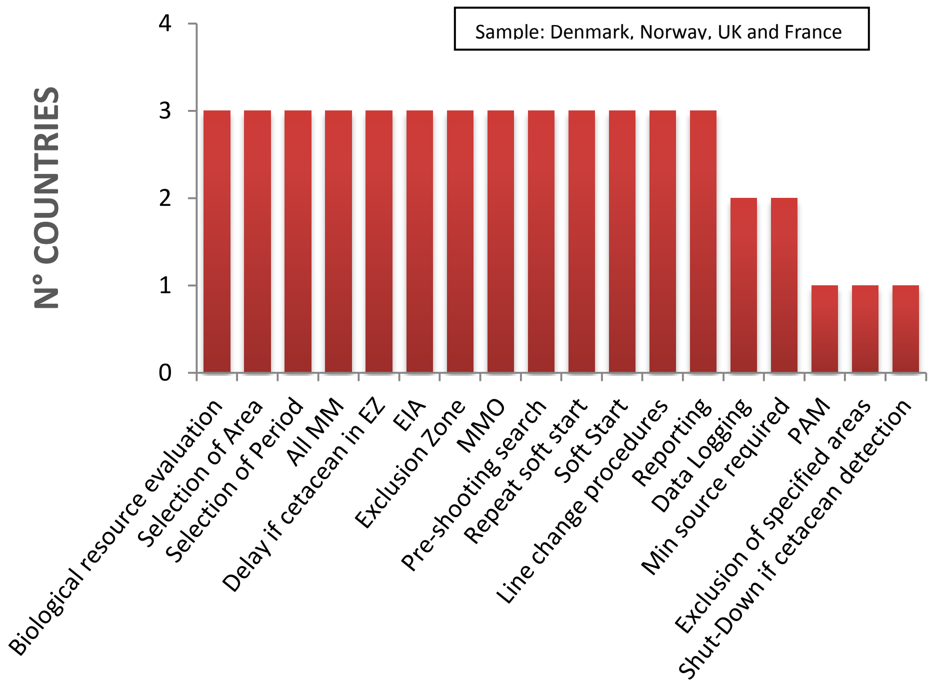

Figure 4. Measures implemented in a sample of European countries during seismic surveys

- **COASTAL AND OFFSHORE WORKS**: measures shown in this section mainly concern wind farm development. Only Germany applies a legally binding noise threshold (160dB SEL and 184 dB (peak) SPL , 750 away from piling site (48)). This accelerated the development and use of noise-reduction technologies. Globally, the use of acoustic deterrent devices is the most used (or promoted) practice, followed by the soft start protocol. Underwater noise is taken into account in the impact assessment for all countries we analysed. More details about mitigation measures applied during coastal and offshore works are reported in ANNEX II to this document. It is noteworthy that other coastal and offshore works are very poorly taken into account. For example, only the UK has statutory guidelines (67) regulating underwater detonations, which are the loudest point source of underwater noise.

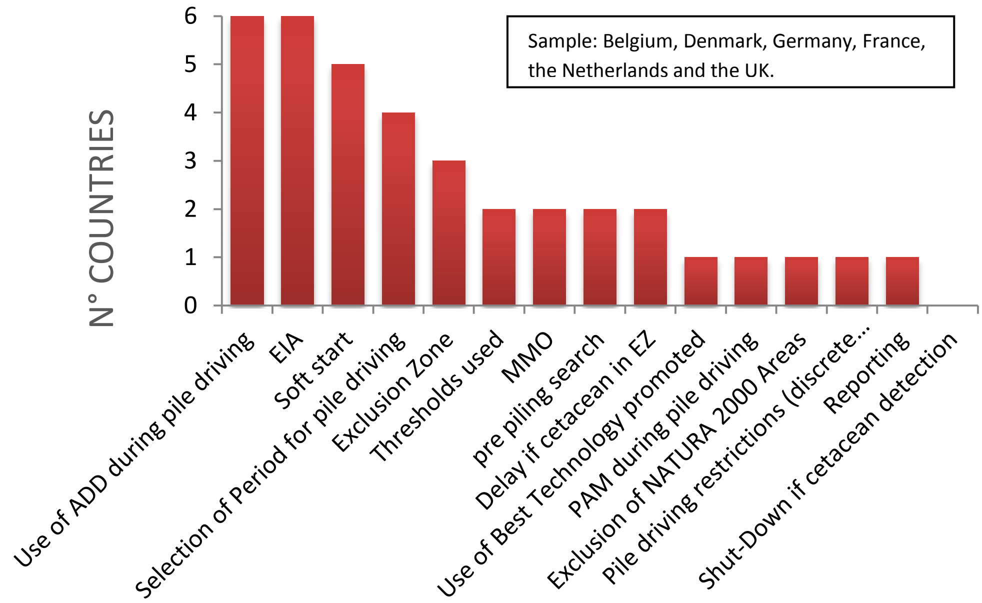

Figure 5. measures implemented in a sample of European countries during coastal and offshore works

No mitigation measures are currently implemented in order to address shipping noise and other marine traffic noise. Actions proposed by Renilson Marine Consulting Ltd (2009), Renilson and Leaper (2012) and the IMO (2009, 2013) are presented in the paragraph **2.3.5** in the present work.

2.6. Conclusions

The main topic highlighted in this chapter is that the scientific community and the advisory bodies working in the European region agree about the general mitigation frameworks to employ. However, uncertainties in scientific knowledge lead sometimes to discrepancies in formulating recommendations. Despite this work is focused on the European Union, it is worth underlining that in the United States it is recommended that seismic vessels continue shooting during line changes, whilst European countries recommend stopping. Furthermore, due to their complexity, in terms of important financial, technological and human support, guidelines could be unworkable for stakeholders (see ASCOBANS, 2011 (73)) and at the same time might not be meeting the conservation requirements of the European Directives. Nonetheless, it is widely agreed that certain measures, such as avoidance of biologically important areas and employment of best available quieting technologies, are generally effective.

Further, concerning particular areas, it seems difficult to address particular guidelines while preserving a general aim. For example, offshore platforms such as wind farms are subject to a varied range of local factors that may affect decisions about their siting, the work plan and the best mitigation measures to be adopted. Moreover, the construction of such installations induces a variety of impacts, such as socio-economic and landscape impacts besides environmental and ecological ones, whereby cumulative impact assessment become the most reliable tool in order to find the best way to apply mitigation measures.

High-powered military sonar is of great concern because of the mass stranding events of beaked whales and other deep-diving toothed whales correlated in space and time with naval exercises, thus warranting many mitigation measures. Most of strandings are well-linked to naval sonar (74–78), although the physiological mechanisms causing such events are still unclear (79) and some areas known to be important habitat for beaked whales appear to be less affected by military manoeuvres (80). Dedicated software for risk assessment is available for three national navies (UK, the Netherlands and Norway), notably enabling a scientific approach during the planning phase. However, how effective such risk assessment actually is in preventing harm is unclear. The best proven mitigation thus far is preventing naval exercises in areas at high risk for strandings, such as the Canary Islands (70,81).

Effects of the seismic exploration on marine mammals (82–85) and on fish and fishery (86–89) are well documented as well. Information gathered so far shows us that country authorities regulate (or strongly support) the use of mitigation measures as recommended by international bodies. Although the present work does not directly discuss about mitigation framework employed for managing conflicts between fishery and seismic exploration, it is worth noting that in some countries, e.g. in Norway, this appears to be a priority topic compared with cetacean conservation. Also, we observe that powerful tools such as passive acoustic monitoring are not widely supported, and no automatic risk assessment software is currently employed during the planning phase. Finally, other not common but relevant measures are listed and discussed in some independent reviews (e.g. Castellote *et al*, 2007) (90), such as the use of infra-red or night vision binoculars for night visual monitoring, aerial surveys to be carried out pre- and post-activity, or the use of multiple safety zones where mitigation protocols that are applied are species-dependent. Such measures are generally not encouraged in national guidelines.

Further, despite the great concern about the acoustic impact of constructing offshore wind farms, relatively few mitigation procedures are applied (or strongly recommended) by some countries involved in offshore wind energy development. Whilst the planning phase appears adequately regulated, mitigation measures applying to the construction phase are poorly employed. Neither MMO nor PAM protocols are recommended by most countries we analysed. Further, all countries but Germany do not currently restrict developing such projects in NATURA 2000 Special Areas of Conservations. Lastly, the lack of certainties about acoustic impacts on marine mammals makes it difficult to decide on acceptable thresholds, and consequently the extent of exclusion or buffer zones, although a precautionary approach can be used in establishing distances. Only Germany applies a legally binding threshold of 160dB SEL and 184 dB (peak) SPL that must not be exceeded at 750 m away from piling site (48). In this regard, the result of the work undertaken by the TSG Noise to quantify the Descriptor 11 of the MSFD (defining thresholds, the spatial and temporal extent for monitoring noise etc.) will soon benefit the application of mitigation measures on coastal and offshore human activities.

Finally, it appears that other coastal and offshore activities introducing anthropogenic noise into the marine environment are inadequately mitigated by countries and treated on a case-by-case basis. Particularly, underwater detonations, which are the loudest point source of underwater noise, are not regulated in all countries except UK.

3. MITIGATION TECHNOLOGIES

The terms "mitigation technologies" refer to those technologies that enable a reduction of the risk of behavioural and/or physiological impacts due to underwater noise exposure. Existing technologies can be divided in the following categories:

1. *Source-based noise-reduction technologies*. Two types of solutions: alternative quieter technologies employed instead of the conventional noisy ones and technologies that lower the noise emitted during conventional noisy operations. They can be applied to coastal and offshore industrial projects as well as shipping engineering and seismic surveys. Little work has been done on safer alternatives to high-powered naval sonar. The effectiveness is assumed to reduce the radius of injury, disturbance and other behavioural impacts.

2. *Target-based active acoustic devices*. Acoustic Mitigation Devices (AMD) are employed to drive away cetaceans and pinnipeds from specified areas. They are usually used for handling conflicts between fishery activities (including fish-farms) and marine mammals, but are increasingly used around wind farm development. They themselves introduce noise pollution, which may cause injury at close range. Their effectiveness is debated.

3. *Monitoring devices*. Acoustic hardware used for implementing passive and active acoustic monitoring as well as noise monitoring programs. They include fixed and towed hydrophones.

4. *Software/Informatics*. Available software is used at two stages: the planning phase and the operational phase. The former case concerns software used for providing risk assessments, the latter is used during mitigation procedures to carry out real-time detection and localisation of marine mammals.

3.1. Source-based noise-reduction technologies

Alternative and quieting technologies may be applied to shipping as well as coastal and offshore construction works and seismic surveys. Concerning shipping, the following works should be noted:

- *Reducing underwater noise pollution from large commercial vessels* (Renilson Marine Consulting Pty Ltd, 2009) (50)
- *Noise from commercial shipping and its adverse impacts on marine life* (IMO, 2009) (51)
- *A review of practical methods for reducing underwater noise pollution from large commercial vessels* (Leaper and Renilson, 2012)
- draft *Provisions for reducing noise from commercial ships and its adverse impact on marine life* (IMO, 2013)

These works review and propose the technologies that might be used in order to reduce noise output in the marine environment from new and existing vessels. The best practices, like speed and route management, proposed in the IMO draft guidelines are presented in **Paragraph 2.3.5.** The cavitation phenomenon due to propeller movement is identified as the greatest source of noise in ships. Thus, the most efficient technologies are those that can reduce cavitation. Two major aspects influence the level of cavitation:

1. propeller design;
2. wake flow into the propeller.

Several new-design propellers with low cavitation are currently available (summarized in **ANNEX III**). Beyond their use in new ships, these propellers can be assembled during the dry dock period in existing ships. Additionally, for new ships, the wake flow can be improved by more careful design, which will require an increased design effort, including careful model testing and computational fluid dynamics analysis. Furthermore, there is the potential to improve the wake flow into the propeller for existing ships by fitting appropriately designed appendages such as wake equalising ducts, vortex generators or spoilers. Existing solutions are presented in **ANNEX III**. Nevertheless, there is currently a lack of knowledge on the relative cost, effectiveness, and energy-efficiency benefits of these technologies in reducing noise from commercial ships. Indeed, some of them have been primarily developed to increase the propeller efficiency and reduce internal noise rather than reduce external noise output. Therefore, a number of recommendations are addressed by the IMO about research to undertake in the next future. This issue will be discussed in Chapter 5.

Regarding coastal and offshore construction, most effort is being carried out to find solutions that apply to noise-producing operations related to wind energy exploitation. An overview of technologies is given in **ANNEX III**, based on the work of the German Federal Agency for Nature Conservation (draft from Koschinski & Luedemann in prep) (91). Development of these technologies is oriented both towards using alternative quieter technologies and mitigating the noise emitted during conventional operations. Examples of the former case are the bucket foundations, the gravity based foundations, the drilled monopiles and the floating foundations. It is noteworthy that for converter platforms bucket foundations are already being used as alternative to pile driving. Concerning the latter case, the bubble curtain is currently the most employed technology. However, other solutions are proven and market available, such as the IHC double-wall steel tube with inner bubble curtain, the Cofferdam and the Hydro-Sound Damper net (92–94).The Symposium on Sound Solutions (95), held in The Netherland in February 2012, considered as the most interesting solutions the following:

- Hydro-Sound Dampers
- Dewatered Cofferdam
- Bucket Foundations

Details about these and other solution are found in **ANNEX III**. Furthermore, the bubble curtain appears to be the best available technique in order to reduce the shock wave of underwater detonations. This has been shown during experiments of the German Navy (Koschinski, pers. comm.).

Considerable efforts are being undertaken to reduce noise due to seismic surveys. In February 2013, the US Bureau of Ocean Energy Management held a workshop in Silver Spring, Maryland, on quieting technologies for seismic surveys, pile driving, and shipping, showing how technological approaches are increasingly being sought (BOEM, 2013) (96). Regarding seismic surveys, the most interesting technologies are those that lower the total amount of energy that is put into the water and that better control the output signal waveform, reducing the production of non-seismic frequencies (>100 Hz). Among these technologies, there is currently a general consensus that the Marine Vibroseis presents a viable alternative to airguns for shallow waters or transition areas (intertidal), though more development efforts are needed for deep offshore waters. Such technology was thought to be commercially available for shallow waters by the end of 2013 (97). This has been postponed to mid 2014 due to delays in funding contracts (Castellote, pers. comm.). Other promising technologies are the Low-Frequency Acoustic Source (LACS) and the Deep Towed Acoustic/Geophysics System (DTAGS).

Other alternative solutions are discussed in the BOEM review, such as the Low-Impact Seismic Arrays and the Underwater Tunable Organ-Pipe. However, due to lacking information and/or to the early stage of development, their performances are not well understood. Further technologies, such as passive seismic methods and electromagnetic surveys, are mentioned by the BOEM report as complementary low impact methods. Increasing the use of these complementary methods could reduce the overall use of the airgun in seismic exploration, and hence lower the amount of noise put into the marine environment. Finally, among methods that could reduce unwanted noise from airguns, the airgun silencer were agreed in the BOEM meeting as having strong potential as mitigation technology. Preliminary tests have shown potential for significant reduction of high frequency contents. Mitigation technologies for seismic surveys are summarized in **ANNEX III**.

3.2. Target-based acoustic active devices

Acoustic mitigation devices (AMD) like pingers and seal-scarers are available and already used in mitigation programs. A problem usually highlighted is the controversial knowledge about their effectiveness, due *inter alia* to their potential for causing injury at close range. Further, the effects of such devices on the biology and ecology of marine mammals are understudied at present. However, it is well known that, based on fishery-related experiences, adaptation of some species to acoustic deterrent signals may occur and even be used by animals as an indicator of concentrations of prey. Moreover, the addition of more noise into the environment as mitigation for noise is problematic and a large-scale use of such devices may have significant negative effects on marine wildlife, particularly on critically endangered species (98).

As applied to anthropogenic noise, AMD are employed during the implementation of mitigation frameworks before noisy activities begin in order to displace animals from dangerous noisy areas (Cf paragraph **2.5.**). A list of available devices is given in **ANNEX III** to the present work.

3.3. Devices for acoustic monitoring

Technologies widely used for acoustic monitoring include fixed and towed hydrophones. Fixed hydrophones are usually moored on the sea bottom or mounted on buoys. Moored systems can be autonomous and require to be recovered to collect data or can be cabled to shore to provide data in real-time or allow data archival on land. An advantage of using buoys is that they can be fitted with wireless systems, GSM cell phone technology or satellite link to provide the data in real-time or near real-time. The table given in **ANNEX III** shows a sample of devices and their use with some examples of monitoring projects.

3.4. Software/Informatics

3.4.1. Tools for the planning phase

Software employed at the planning phase is available for Norway, Dutch and UK navies (66). The Norway navy tool, **SONATE**, provides maps of distribution of fishery activity and the position of fish farms as well as the distribution range of marine mammals and fish, also accounting for year-round variations in such information. Hence, the user builds up the spatial and temporal *scenario* of the foreseen naval exercise and the software provides him/her with consistent guidelines that should be used in that particular *scenario*. Detailed presentation of the software is available (58).

General information on UK navy tool, **ERMS**, is found in the OSPAR report on underwater noise effects (38). The definition given by this report is that this tool is an “intelligent database of Sonar parametric, hydrographical, climatological, legislative and biological data [that] calculates the risk of potential adverse effects on marine mammals within an area where sonar may be operated by the Royal Navy”. However, based on publicly available documents, it is not clear how this tool works.

Finally, the Dutch navy software, **SAKAMATA**, combines information on the biology and ecology of marine mammals with noise propagation models. Therefore, a full assessment of the impact of a given naval exercise is given during the planning phase. Consequently, mitigation measures are adapted to that particular situation (59).

In parallel, public web platforms where information on distribution, range, diversity and other ecological parameters can be easily accessed exist (e.g. the **IUCN red-list** website http://www.iucnredlist.org/; the **OBIS SEAMAP** project http://seamap.env.duke.edu/ and the **INTERCET** project www.intercet.it in the Pelagos Sanctuary area). Nevertheless, such platforms present different issues to be discussed. In the case of an IUCN-type platform, information can be accessed on a species by species basis. Further, the distribution of species is presented under the form of the maximum known extent of the range of a given species. On the other hand, in the OBIS-type platform, based on contributor sighting databases, the occurrence of species is shown as a sighting point or as a cell of presence, allowing for species richness visualisation. However, as this platform relies on contributors that voluntarily upload their databases, complete information is often unavailable with no possibility for checking the validity of the information gathered. Additionally, NOAA has developed models and maps of cetacean densities and underwater noise levels, and created a public interface (www.cetsound.noaa.gov) to display them; while these products generally do not extend to European waters, they offer strategies for developing and compiling this information for other regions.

3.4.2. Tools for the operational phase

Concerning the operational phase, real-time monitoring software is mainly used during passive acoustic monitoring. Popular software packages for assisted or automated detection and classification of cetacean vocalisations include **ISHMAEL** (99), **PAMGUARD** (100), **SeaPro** (101), **RainbowClick** and **Whistle** (IFAW). By using these tools, PAM operators support marine mammal observers during daylight hours and good weather conditions whilst they become the most important resource during night-time and bad weather conditions. Passive monitoring tools have become popular in the last decade; however the correct implementation under real operative conditions is often problematic.

4. FUTURE WORK

Underwater noise mitigation is increasingly focused on measures that can reduce cumulative chronic, sub-lethal noise exposure and impacts, rather than only on those that address acute impacts close to a noise source. It is likely that for a broad range of marine mammals, acoustic masking is having an increasingly prevalent impact on acoustic information transfer including both communication and other key activities such as navigation and prey/predator detection (102). For this reason, several intergovernmental guidelines and reports have emphasised the use of such measures as habitat planning, time-area closures, and development and use of best available quieting technologies as critical means of reducing cumulative and sub-lethal effects. In the IUCN report on marine traffic effects on biodiversity (2008) (103) the novel concept of acoustic comfort is expressed: in addition to defining which impacts should be avoided or mitigated, there is also the need to draw up a model of ‘acoustic comfort (103,104) that should be guaranteed to animals, at least over sufficiently extensive protected areas. In other words each species needs its own level of acoustic comfort to behave according to its own evolution path. Acoustic ecology research leads to the conclusion that there are costs associated with the loss of acoustic habitat (e.g. the reduction of feeding efficiency, mating success, predator avoidance), and these costs can affect primarily individuals and then population. This means that the (near to) zero-impact noise level that a habitat should have for each type of marine life should be defined. Movement along these lines should be encouraged.

Current mitigation frameworks might be improved (and their use spread) by gathering more baseline information on the distribution, abundance, seasonality and the acoustic ecology of cetaceans. Further, consulting the private sector would help the dissemination and comprehension of current mitigation measures as well as to determine the cost of particular measures. In addition, some existing solutions (best practices and best available technologies) need to be tested in order to confirm (or reject) their effectiveness and agencies should accelerate development and use of noise-quieting technologies through incentives and regulations. Finally, we observe that more effort is needed in order to simplify and/or clarify guidelines from ACCOBAMS and ASCOBANS, as to enhance their comprehension by all relevant stakeholders.

In short, existing knowledge gaps concerning mitigation should be filled up and/or expanded and best practices should be further refined, developed, and prioritised. Research topics and actions are proposed in the next paragraphs, as to be consistent with proposals reviewed in recent works (34,55,65,66).

4.1. Baseline actions

Generally, future work should be oriented in order to:

I. Identify and quantify **noise sources**. Whilst most of them are known (see paragraph **2.1** or OSPAR 2009 (38)), some are under-studied. Particularly, effects of high powered active transducers (echo-sounders, single-, split- and multi-beam, side scan sonar, sub-bottom profilers etc.) are poorly known and poorly addressed by mitigation measures applied by countries and industrial companies. However, as most active transducers are of high frequencies and directed downward, they are not likely as dangerous over larger areas to most marine life as the sources mentioned thus far.

II. Develop a **standard procedure** for **the measurement** of noise. At present, there are no internationally accepted standards for measurements and terminology. Chapter 4 in TNO (2011) (54) describe proposals for a common measurement procedure. In addition, the terminology used in this report is recommended by Van der Graaf and co-authors in the report of the Technical Subgroup on Underwater Noise and other forms of energy (55), as a basis for formal (ISO-) standards.

III. Deepen **research** in the **acoustic biology** of marine species, especially endangered and data-deficient ones. Basic knowledge about the acoustic biology of marine mammals would help guide policy makers in the decision processes about marine environment issues. For detailed priorities about research topics we invite you to read chapter V of the "scientific synthesis on the impacts of underwater noise on marine and coastal biodiversity and habitats" (34).

IV. Improve knowledge of distribution, abundance, seasonality and life history of cetacean species especially endangered and data-deficient ones. **Biologically important areas** and **periods** should be **identified** and that information disseminated to relevant coastal states, for use in management decisions, activity planning, and establishment of time-area closures and protected areas.

V. Quantify **effects** on marine mammals at the population level and set meaningful **thresholds** or noise exposure levels, according to the MSFD objectives, though this is a very difficult task. Succeeding in defining effects and setting "sustainable" thresholds might have the positive effect to help the assessment, which may be necessary in some jurisdiction, of the cost/benefit tradeoffs. Finally, testing the effectiveness of the best practices (i.e. soft start; etc.) during mitigation operations would help as well to improve the mitigation framework currently applied.

VI. Consult the **private sector**. This action is needed in order to, on one hand, enhance the dissemination (and comprehension) of best available practices and best available technologies and, on the other hand, gather fundamental information about the feasibility of mitigation measures and their impact on the planning and economy of a given maritime activity. A direct link between the scientific community and the private sector (and other stakeholders, including conservation organisations and civil society) would help considerably to allow for sustainable management of anthropogenic noise.

VII. Clarify and simplify guidelines from ACCOBAMS and ASCOBANS. The **terminology** used to espouse best practices might appear redundant and repetitive, to the detriment of clarity. An introductory paragraph defining terms used for guideline texts would be an easy solution to this issue.

VIII. Identify **areas of special concern** where strict measures should be applied, at least for endangered and sensitive species

4.2. Sonar (military and civil) and Seismic surveys

IX. Develop **risk assessment software**. On the basis of existing software available to the Dutch, Norway and UK navies, the dissemination of such tools to other navies and to seismic companies might strengthen the application of mitigation measures.

X. Enhance the creation of national or basin-wide level databases of presence/distribution/abundance with input from the industry. The effectiveness of selecting areas and periods as a mitigation measure also relies on the possibility for companies to consult such databases. Public web platforms already exist ((i.e. **OBIS SEAMAP**, the **IUCN Red-List** website and the **INTERCET** platform in the Pelagos Sanctuary) where information can be easily consulted. About the ACCOBAMS area, an interactive web map platform, promoted by the ACCOBAMS Agreement, is currently under construction. This new tool will store and spread information on past and ongoing research projects, on the distribution of cetacean populations, on maritime protection zones (such as MPAs and EBSAs) etc. However, awareness of the existence of such tools is often limited to marine ecologists. Thus it seems important that the use of these platforms be spread to industrial companies.

XI. Accelerate the development and use of alternative seismic technologies by **requiring** or **incentivising** them. For example, governments could put biologically important areas off limits until certain standards are met, along the lines of what Germany has prescribed for pile driving noise.

4.3. Coastal and Offshore works

XII. Deepen the understanding of **cumulative impacts**

XIII. Test the **effectiveness** of source-based technologies (i.e. bubble screen; hydro-sound dampers; vibro-drilling etc.)

XIV. Test the **effectiveness** of target-based technologies (Acoustic Mitigation Devices).

4.4. Maritime traffic

XV. Test the **effectiveness** of new design **propellers** and other devices for shipping (e.g. skewed propellers, appendages for improving wake inflow; etc. (Cfr paragraph **3.1**.). Currently, tests are mainly carried out by developers, so that independent testing is needed. Further, the primary impulse to develop new types of propellers is to improve efficiency of the propeller, not to lower the emission of noise. The relationship between increased efficiency and lower noise output is speculative and needs to be investigated (50). Investigation on the possibility to adopt quieting technologies already in force in military and scientific vessels, e.g. electric propulsion driven by diesel-electric generators (hybrid propulsion), should be assessed

XVI. Promote the adoption of alternative quieter boats for whale-watching and touristic trips in sensitive areas and in MPAs such as electric boats.

XVII. Develop **indicators** for quantifying **shipping noise**. Defining the relationships between vessel speed and emitted noise and between internal and external noise emission would allow development of an onboard monitoring system that would alert operators of the need of to inspect the vessel and repair possible damage.

XVIII. Assess the feasibility of operational measures for shipping (**route** and **speed** management)

XIX. **Require** and incentivise **compliance** with the pending IMO guidelines and reward achievement in noise reduction

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ANNEX I

A. Synthesis of the main issues treated in each international law text mentioned in Paragraph **1.1.**

Table 5. Main issues treated in each international law text mentioned in Paragraph 1.1. The following table summarizes the main issues treated in each international law text mentioned above. (General = the text recognizes human-induced underwater noise as a problem to be faced , calling for actions that can apply to all areas of intervention, without focusing on particular human activities; MRE = Marine Renewable Energies, means that the text deals with impacts, including noise, related to MRE installation; Sonar = military and civil sonar ; Seismic = industrial and academic seismic surveys; Traffic = noise caused by maritime traffic; Status = conservation status, means that a text deals with the consideration of the acoustic environment in the assessment of the status of species and habitats).

TEXT / ISSUE TREATED	General	MRE	Sonar	Seismic	Traffic	Status	Offshore
IWC/Resolution 1998-6	x						
CMS/COP/Resolution 7.5		x					
EP/Resolution P6_TA(2004)0047			x				
IUCN/Resolution 3.068	x					x	
ACCOBAMS/Resolution 2.16	x						
CMS/COP/Resolution 8.22	x						
ASCOBANS/Resolution 5.4	x	x		x	x		x
UN/Resolution 61/222	x						
ACCOBAMS/Resolution 3.10	x					x	
IUCN/Resolution 4.066	x						
IUCN/Resolution 4.023						x	
CMS/COP/Resolution 9.19			x				
ASCOBANS/Resolution 6.2		x					
ECS/Resolution 2009			x				
IWC/Resolution 2009-1	x						
CBD/COP/Decisions X/29	x						
ACCOBAMS/Resolution 4.17	x	x	x	x	x		x
CMS/COP/Resolution 10.24	x	x					
CBD/COP/11/1	x						

B. Synthesis of the principle actions promoted by international law texts we analyzed

Table 6. Main actions promoted by international law texts we analyzed. The following table outlines, for each international law text, the priority actions promoted in order to address the related issue(s) treated (Research = call to further research on the impacts of noise, or on the effectiveness of guidelines and mitigation measures; Guidelines = means that the text calls for editing guidelines related to one or more human activities; Measures = mitigation measures, means that the text calls, in a general manner, the Parties to implement existing mitigation measures, or to develop new ones; MPA = Marine Protected Areas are noted as a valid conservation tool to be better utilized, or noise is promoted as a descriptor for MPAs action plans; NPA = Noise Protection Areas, the text calls for assessment of the benefits in establishing these kinds of zones); EIA/SIA = Environmental Impact Assessment and/or Strategic Impact Assessment, underwater noise is promoted to be included in EIAs/SIAs; New Tech = the text encourages the development of new/quieting technologies for mitigating noise; Cooperation = international cooperation is emphasized as being the best framework to implement conservation actions concerning transboundary areas; Industrial = the text calls for consulting with industrial companies to better fulfill the mitigation needs of maritime projects; Monitoring = the text proposes exploring the benefits of Noise Monitoring Programs; Restrictions = the text recommends the application of geographical or seasonal restrictions to noise generating human activities).

TEXT / Action	Research	Guidelines	Measures	MPA	NPA	EIA/SIA	New Tech	Cooperation	Industrial	Monitoring	Restrictions
IWC/Resolution 1998-6	x										
CMS/COP/Resolution 7.5	x	x				x					
EP/Resolution P6_TA(2004)0047	X	x					x				x
IUCN/Resolution 3.068	x	x		x							
ACCOBAMS/Resolution 2.16		x									x
CMS/COP/Resolution 8.22								x			
ASCOBANS/Resolution 5.4	x	x	x			x					
UN/Resolution 61/222	x			x							
ACCOBAMS/Resolution 3.10		x		x		x	x	x			
IUCN/Resolution 4.066								x			
IUCN/Resolution 4.023			x								
CMS/COP/Resolution 9.19			X		x				x		
ASCOBANS/Resolution 6.2	x	x	x			x	x				
ECS/Resolution 2009											x
IWC/Resolution 2009-1	x										
CBD/COP/Decisions X/29			x	x		x					
ACCOBAMS/Resolution 4.17		x	x			x					x
CMS/COP/Resolution 10.24	x	x	x	x		x	x		x		x
CBD/COP/11/1	x									x	

ANNEX II

In the following tables, information on the use of mitigation measures by countries is shown. However, for several Parties to the ACCOBAMS and ASCOBANS agreements no or lacking information was gathered. We recommend hence that the tables presented hereinafter be updated in the next future, for example by setting up a consultation process involving relevant stakeholders able to provide this information.

Table 7. Mitigation measures by countries concerning sonar use. Y = Yes, N = No, N/R = not required. B = Belgium; DK = Denmark; D = Germany; F = France; I = Italy; E = Spain; NL = Netherlands; N = Norway; GB = United Kingdom. Blank means that no information was gathered. * Only Canary Islands. ** Dolman et al (2011) states that MMO are not required on Norwegian vessels while OSPAR (2009) affirm that they actually are

ACTIVITY	MITIGATION	B	DK	D	F[2]	I[2]	E[2]	NL[3]	N[2]	GB[2]
sonar	Selection of Area				Y	Y	N	Y	Y	Y
	Buffer Zone				N	Y	N	Y	N	N
	Coastal exclusion				N	N	50 nm*	N (but low power used)	N	N
	Detection system/database				N	Y	N	Y	Y	Y
	Pre/post survey				Y	Y	N/R	Y	Y	Y
	MMO				N	N	N/R	Y	N/Y**	y
	PAM				Y	Y	N/R	Y	Y	Y
	Detectability restrictions				N	N	N/R		N	Y
	Other monitoring				N	N	N/R		N	N
	Min source required				N	N	N/R	Y	Y	N
	Propagation conditions				N	N	N/R		N	N
	Soft start / rump up				Y	Y	N/R	Y	Y	N
	Delay if cetacean observed				N	N	N/R	Y	Y	N
	Repeat soft start / rump up				N	Y	N/R	Y	Y	N
	Power down if cetacean detection				Y	N	N/R	Y	Y	Y
	Sonar off if cetacean detection				Y	N	N/R	Y	Y	Y
	Exclusion Zone				Y	Y	Y	Y	Y	Y
	All MM species				Y	Y	N/R	Y	Y	Y
	Other Species				N	N	N/R		Y	Y
	Reporting				N	N	N/R	Y	N	Y
	EIA				N	N	N/R	Y	N	Y
	Exclusion of specified areas				N	Y	Y	Y	N	Y
	Research				N	N	N	Y	Y	N

[2] Information adapted from Dolman *et al* (2009, 2011) and OSPAR (2009)(38,62,66)
[3] From OSPAR (2009) (38)

Table 8. Mitigation measures by countries concerning seismic surveys. Y = Yes, N = No. B = Belgium; DK = Denmark; D = Germany; F = France; I = Italy; E = Spain; NL = Netherlands; N = Norway; GB = United Kingdom. Blank means that no information was gathered. * Related to spawning fish. ** 200 m EZ during soft start, 500 m during full power shooting. * 30 min in shallow waters, 60 min in deep water (> 200 m isobaths). **** Key habitat of narwhal and walrus.**

ACTIVITY	MITIGATION	B	DK[4]	D	F[5]	I	E	NL	N[6]	GB[7]
seismic	Selection of Area		Y						Y	Y
	Selection of Period		Y						Y	Y
	Biological resource evaluation		Y						Y*	Y
	Min source required		Y							Y
	Exclusion Zone		200/500 m**		500 m					500 m
	EIA		Y		Y					Y
	MMO		Y		Y					Y
	PAM		N		N					Y
	Soft Start		Y		Y					Y
	Repeat soft start		Y		Y					Y
	Reporting		Y		Y					Y
	Pre-shooting search		30 min		60 min					30/60 min***
	Shut-Down if cetacean detection		Y		N					N
	Delay if cetacean in EZ		Y		Y					Y
	Line change procedures		Y		Y					Y
	Data Logging		Y							Y
	Exclusion of specified areas		Y****							N
	All MM		Y		Y					Y

[4] Guidelines from the National Environmental Research Institute of Denmark (NERI, 2009) (61)
[5] Mitigation protocol from Uni Paris-Sud-CNRS-AgroParisTech – UMR 8079 (2009) (71)
[6] Information extracted from OSPAR (2009) and the *Manual for fishery experts on board seismic survey vessel on Norwegian Continental Shelf* (2010) (38,72)
[7] JNCC *guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys* (67)

Table 9. Mitigation measures by countries concerning coastal and offshore works. Y = Yes, N = No. B = Belgium; DK = Denmark; D = Germany; F = France; I = Italy; E = Spain; NL = Netherlands; N = Norway; GB = United Kingdom. Blank means that no information was gathered. * Legally binding threshold. Noise at 750 m away from piling site must be inferior to 160dB SEL and 190 dB SPL

ACTIVITY	MITIGATION	B[8]	DK[8]	D[8]	F[9]	I	E	NL[8]	N	GB[8,10]
Coastal and offshore works	Exclusion Zone			750 m	500 m					500 m
	Thresholds used			Y*	N			Y		N
	Use of Best Technology promoted				Y					
	Use of ADD during pile driving	Y	Y	Y	Y			Y		Y
	MMO	N	N	N	Y			N		Y
	PAM during pile driving	N	N	N	N			N		Y
	Selection of Period for pile driving	Y	N	N	Y			Y		Y
	Soft start	Y	Y	Y	Y					Y
	Exclusion of NATURA 2000 Areas	N	N	Y	N			N		N
	Pile driving restrictions (discrete pile driving etc.)				Y			Y		
	pre piling search				30 min					30 min
	EIA	Y	Y	Y	Y			Y		Y
	Delay if cetacean in EZ				Y					Y
	Shut-Down if cetacean detection				N					N
	Reporting				N					Y

[8] From ICES (2010)(48)
[9] From the *Ministère de l'Ecologie, du Développement Durable et de l'Energie* (2012) (63)
[10] JNCC *protocol for minimising the risk of disturbance and injury to marine mammals from piling noise* (2009) (69)

ANNEX III

BEST AVAILABLE TECHNOLOGIES

A- *Source-based technologies*. Alternative quieter technologies employed instead of conventional noisy ones.

Cavitation is the main factor affecting noise output from shipping. Reducing cavitation effect would result in reducing noise emission. All the technologies presented thereafter are discussed in Renilson Marine Consulting Pty Ltd (2009) and Renilson and Leaper (2012) (50,52).

The overall problem with solutions proposed hereinafter is that neutral testing is very often unavailable, that is, improved efficiency and/or reduction of cavitation is claimed by developers but not confirmed by means of independent research. Moreover, the relationships between efficiency/cavitation/noise need to be further studied as the effect that alternative technologies have on noise reduction is speculative in most cases.

Table 10. Noise reduction technologies for shipping. New design propellers

New design propeller	Brief outline	Owner
High skew propellers	This kind of propeller has the combined effect of causing the blade to pass through the varying wake field (particularly near the top of the cycle) in a more gradual manner, and in improving the cavitation pattern on the blades	MAN/Diesel
Contracted and loaded tip propellers (CLT)	These propellers are designed with an end plate which reduces the tip vortices, thereby enabling the radial load distribution to be more heavily loaded at the tip than with conventional propellers. In turn, this means that the optimum propeller diameter is smaller, and there is the possibility of reducing cavitation	SISTEMAR
Kappel propellers	The tips are smoothly curved towards the suction side of the blades	MAN Diesel
New blade section propellers (NBS)	The improved blade cross section might provide higher efficiency and reduce cavitation	
Propeller Boss Cap Fins	small fins attached to the propeller hub which are designed to reduce the magnitude of the hub vortices, thereby recovering the lost rotational energy, and reducing the cavitation	Mitsui O.S.K.Techno-Trade
Propeller Cap Turbine	This solution comprises a number of hydrofoil shaped blades integrally cast into the hub cap. Energy from the rotating fluid coming from the propeller hub is recovered, resulting in energy savings.	Ship Propulsion Solutions, LLC

Table 11. Noise reduction technologies for shipping. Further solutions concerning the interaction between propeller and rudder.

Propeller/Rudder Interaction	Brief outline	Owner/Reference
twisted rudder	Better designed to account for the swirling flow from the propeller	Molland and Turnock, 2007 in Renilson Marine Consulting Pty Ltd, 2009
rudder fins	Designed to recover some of the rotational energy	Molland and Turnock, 2007 in Renilson Marine Consulting Pty Ltd, 2009
Costa Propulsion Bulb (CPB)	The propeller is integrated hydrodynamically with the rudder by fitting a bulb to the rudder in line with the propeller shaft	Ship Propulsion Solutions, LLC

Table 12. Noise Reduction Technologies for Shipping. Appendages that increase efficiency of propellers and reduce cavitation by improving wake inflow.

Improving Wake Flow	Brief outline	Owner
Schneekluth duct	designed to improve the flow to the upper part of the propeller, and as such causes the formation of cavitation at the blade tips to be less pronounced, resulting in lower pressure pulse levels	Schneekluth
Mewis duct	No details available	Becker Marine Systems
Simplified compensative nozzle	The improved efficiency is achieved by re-shaping the nozzle to improve uniformity of wake flow into the propeller. This is accomplished by having a more vertical or cylindrical shape, rather than remaining circular	Ship Propulsion Solutions, LLC
Grothues spoilers	It consist of a small series of curved fins attached to the hull just ahead of the propeller. They straighten the flow into the propeller, thereby improving the propeller efficiency	Schneekluth
Changes to hull form	Asymmetrical afterbodies for single screw merchant ships take into account the asymmetrical flow around single screw ships about the centreline, improving the efficiency.	Schneekluth, 1987; Breslin and Andersen, 1994 in Renilson Marine Consulting Pty Ltd, 2009

Further, a range of solutions for reducing noise concerning wind farm construction is given in **table 13** and **14**, based on the work of the German Federal Agency for Nature Conservation (draft from Koschinski & Luedemann in prep) (91). Development of these technologies is oriented both to mitigate the noise emitted during conventional operations (pile driving) and to use alternative quieter technologies (low-noise foundations). Some of the former technologies might be applied as well for other kinds of offshore and coastal works (e.g. explosive use; dredging, etc.).

Table 13. Noise Mitigation Technologies for coastal and offshore works (mainly wind farm construction). The technologies presented thereafter are aimed to reduce source levels emitted during operations using conventional technologies (91)**. (n.s. = not specified; SEL = Single event sound pressure level). Note: Noise reduction specified as broadband levels are not directly comparable to those specified as mitigation levels in singular third octave band.**

	Mitigation measure	Noise reduction	Development status[1])	Questions, next steps
Bubble curtains	Big bubble curtain	• FINO 3: 12 dB (SEL), 14 dB (peak) (Grießmann et al. 2010), OWF *Borkum West II*: 11-15 dB (SEL), 8-13 dB (peak) (Bellmann 2012) • Double big bubble curtain (two half-circles): 17 dB (SEL), 21 dB (peak) (Hepper 2012)	• Proven technology, potential for optimisation • German160 dB threshold level can be met under certain environmental conditions	• Practical application in several commercial offshore wind farms (OWFs) • Application with larger pile diameters at larger water depth • Potential for optimization with respect to effectiveness and handling
	Little bubble curtain (several variations)	• Layered ring system (OWF alpha ventus): 12 dB (SEL), 14 dB (peak) (Grießmann 2009); OWF Baltic II: 15 dB (SEL) (Schultz-von Glahn 2011) resp. 11-13 dB (SEL) (Zerbst & Rustemeier 2011) • Confined little bubble curtain (ESRa): 4-5 dB (SEL) (Wilke et al. 2012))	• Pilot stage with full-scale test completed	• Practical application, currently no specific projects known

	Mitigation measure	Noise reduction	Development status[1])	Questions, next steps
		• Little bubble curtain with vertical hoses (SBC): 14 dB (SEL), 20 dB (peak) (Steinhagen 2012)		
Isolation casings	*IHC Noise Mitigation System*	• ESRa project: 5-8 dB (SEL) (Wilke et al. 2012) 2) • FLOW-project: OWF *Nordsee Ost:* 9 dB (SEL), Ijmuiden: 11 dB (SEL) • OWF *Riffgat*: 17 dB (SEL) (Gerke & Bellmann 2012))	• Pilot stage completed • First application at commercial OWF *Riffgat* • 160 dB threshold level can be met with small and intermediate piles at shallow depths	• During further applications a direct comparison with and without mitigation system is required • Application at greater water depths and with larger diameters
	BEKA-Shells	• ESRa project: 6-8 dB (SEL) (Wilke et al. 2012) 2)	• Pilot stage completed	• Full-scale test under offshore conditions • Currently no commercial application known
Cofferdam	Cofferdam	• Aarhus Bight: 23 dB (SEL), 17 dB (peak) (Thomsen 2012)	• Pilot stage for free-standing system completed • First application at commercial projects planned	• Full-scale test for larger monopiles (∅ about 5 m) • Practical application at commercial projects *HelWin A, BorWin* and *Sylwin A* planned • Further development of telescopic system
	Pile-in-Pipe Piling	• Model: 27 dB (SEL) (Frühling et al. 2011)	• Validated concept stage	• n. s.
Others	Hydro Sound Dampers (*HSD*)/ "encapsulated bubbles"	• *ESRa* project: 4-14 dB (SEL) (Wilke et al. 2012) [2]) • OWF *London Array:* n. s. • Feasibility study US: in singular third octave bands up to 18 dB (no broadband value given) (Lee et al. 2012)	• Pilot stage, application at commercial OWF *London Array*	• Further offshore test (OWF *Dan Tysk* planned for 2013 • Optimisation of *HSD* elements • Additional *HSD* elements and net-layers • Tests to reduce seismic influence
	Prolongation of pulse duration	• Model: 4 dB (SEL), 9 dB (peak) (Elmer et al. 2007a) • Schall 3: Model of *MENCK* test pile: 5 dB (SEL), 7 dB (peak). Model of *FINO 3* pile: 11 dB (SEL), 13 dB (peak) (Neuber & Uhl 2012) • Measurement of coiled steel cable as piling cushion: up to 7 dB (SEL) [2]) (Elmer et al. 2007a) • Measurement of piling cushions from Micarta: 7-8 dB , Nylon 4-5 dB [3]) (Laughlin 2006)	• 160 dB threshold level can be met with very small pile diameters, used as a means of protecting the equipment • Experimental stage for larger piles (numerical models and simulation)	• n. s.
	Modification of piling hammer	• n. s.	• Experimental stage	• Completion of research project *BORA* and publication of results

[1]) With regard to North Sea offshore conditions and water depths of about 40 m
[2]) *FINO 2* platform (pile diameter 3.3 m)
[3]) Cape Disappointment (pile diameter 0.3 m)

Table 14. Noise Reduction Technologies for coastal and offshore works: Low-noise foundations (91). **(n.s. = not specified)**

	Method / project	Noise emission during construction	Development status[1])	Questions, next steps
Vibratory pile driving	Vibratory pile driving	• Sound level reduced by about 15-20 dB compared to impact pile driving (Elmer et al. 2007a) • North Sea, OWF *alpha ventus*: broadband sound level 142 dB at 750 m from source; but high tonal component (Betke & Matuschek 2010), OWF *Riffgat*: 145 dB Leq (Gerke & Bellmann 2012) • Number of pile strikes reduced	• Proven technology for small piles and low anchoring depths and prior to the actual impact pile driving (OWF *Riffgat*)	• `Vibratory pile driving applicable to entire anchoring depths? • Is the same stability under load achievable?
Foundation drilling	*Ballast Nedam*	• n. s.	• Concept stage • Technical feasibility proven (Van de Brug 2011)	• Pilot stage planned at *FLOW* project
	Herrenknecht	• Measurement at watered shaft in Naples: 117 dB (SEL) at 750 m (Ahrens & Wiegand 2009)	• Technical feasibility proven (Ahrens & Wiegand 2009) • Onshore tests • Prototype under construction	• Investigations of carrying capacity • Construction of prototype for 2013 • Nearshore test 4. quarter 2013 • Offshore prototype-test beginning of 2014
	Fugro Seacore	• n. s.	• Proven technology for certain grounds (rock, sand- and limestone) and in combination with impulsive pile driving	• Investigations of resulting stability under load when founded without impulsive piling • Applicability to sandy sediments?
Gravity base foundations	Gravity base foundations	• No specific measurements available • Noise emissions during ground preparation works (if required) probably lower than during impulsive pile driving	• For offshore wind turbines: proven technology at water depths ≤ 20 m, pilot stage for deeper water • Onshore full scale test foundation • For oil & gas: proven technology also at greater water depths	• Question of detail on scour protection
Floating wind turbines	Floating wind turbines in general	• No specific measurements available • Noise emissions probably lower than during impulsive pile driving	• Oil and gas platforms: proven technology • Offshore wind turbines: experimental or pilot stage	• Details of anchorage • Operational noise of wind turbines possibly louder than with other foundation types
	HYWIND	• n. s.	• Pilot stage, Full-Scale-test in Norway, 2 year research project completed	• n. s.
Floating wind turbines	*Blue H*	• n. s.	• Pilot stage • Experimental stage with 75% model completed	• Subproject continued in a different form by *Blue H Engineering* (see below)

	Blue H Engineering	• n. s.	• Conceptual stage for 5 MW turbines	• Prototype planned for 2016
	GICON-SOF	• n. s.	• Experimental stage • Development of planning tool for technical, ecologic and economic design-basis for prospected research facility • Investigations in wave channel completed	• Prototype planned for 2012
	WindFloat	• n. s.	• 2011: Prototype erected in Portugal with Vestas V80	• 5 more turbines planned
	Sway	• n. s.	• Experimental stage completed: Dynamic simulations completed • Pilot stage: prototype approved	• Prototype planned for 2013
	WINDSEA	• n. s.	• Experimental stage with 1:40 model in wind- and wave-channel completed	• Search for investors
	INFLOW	• n. s.	• Experimental stage • Onshore demonstration model at a scale of 1:2 completed (output 35 kW)	• Prototype planned for 2013
	WINFLO	• n. s.	• Ongoing model-tests • Prototype under construction	• Prototype planned for 2013
	Poseidon 37	• n. s.	• Prototype (37 m width) with 3x11 kW output completed	• Larger prototype (80 m width) planned for 2015 • Subsequent prototype of 110 m width planned for 2016/2017
Bucket foundations	Bucket foundation for transformer platform	• n. s. • Noise emissions during suction dredging probably lower than during impulsive pile driving	• Oil and gas platforms: proven technology	• Construction of converter platforms at commercial OWFs *Veja Mate* and *Global Tech 1*
	Bucket foundation for offshore wind turbine		• Pilot stage for monopod: prototype at Frederikshavn/DK • Concept stage for Tri-jacket • Experimental stage for asymmetric three-legged construction (model tests completed)	• Tri-Jacket: full-scale prototype planned at virtual test field • Asymmetric three-legged construction: full-scale prototype planned

* With regard to North Sea offshore conditions and water depths of about 40 m

Finally, alternative and complementary technologies for seismic surveys are summarized in **Table 15**. Amongst alternative technologies, the Marine Vibroseis is considered to have suitable characteristics to replace the airgun for shallow water exploration (96,97).

Table 15. Noise reduction technologies for seismic surveys. The reference document for compiling this table is the BOEM report on mitigation technologies for seismic surveys, pile driving and shipping. (Na = information not available)

Technology	Brief outline	Source Level (dB re 1µPa)	Duration
Marine Vibroseis (MV)	Hydraulic and electromechanical MVs can be towed in the same configuration as airgun arrays or operated in a stationary mode much like land vibrators; MV's will have lower source signal rise times, lower peak pressures, and less energy above 100 Hz	223 rms	1000 ms
Low Frequency Acoustic Source (LACS 4A)	The LACS system is a combustion engine with a cylinder, spark plug, two pistons, two lids, and a shock absorber. It produces long sequences of acoustic pulses at a rate of 11 shots/s. The output signal waveform is controlled, reducing the amount of non-seismic (>100 Hz) frequencies produced. This system is suitable for shallow-penetration, towed-streamer seismic surveys or vertical seismic profiling	218 P-to-P	11 shots/s
Low Frequency Acoustic Source (LACS 8A)	The LACS 8A has the potential to compete with a conventional deep-penetration airgun seismic array. This system currently does not exist, and the project is presently on hold.	230 P-to-P	11 shots/s
Deep-Towed Acoustics/Geophysics System (DTAGS)	The system uses a solid state piezo-ceramic Helmholz resonator to generate a controlled broadband signal. The DTAGS is towed behind a survey vessel, usually at a height of 100 m above the seafloor and a vessel speed of 2 kts; it can operate at full ocean depths (6,000 m). A 450-m long, 48-channel streamer array is towed behind the source to record the reflected signals. The system has a limit of 1-km penetration in most marine sediments	200	Na
Low-Impact Seismic Array (LISA)	The system consists of a large array of small, but powerful, electromagnetic projectors using a low-frequency electromagnetic transducer system. Early stage development	223	Na
Underwater Tunable Organ-Pipe	The tunable underwater organ-pipe driven by an electro-mechanical piston source is used to create a tunable Helmholtz resonator capable of large acoustic amplitudes at a single frequency that is dependent on the length and other parameters of the tube. The system can create a high-amplitude sine sweep in the frequency range of interest. Early stage development	Na	Na
Complementary technologies			
Low-Frequency Passive Seismic Methods	Existing methods use natural seismicity, ocean waves or microseismic surface waves	No noise emission	
Electromagnetic Surveys	Controlled Source Electromagnetic Surveys (active source)	No noise emission	
	Magnetotelluric Surveys (passive source)	No noise emission	
Gravity and Gravity Gradiometry Surveys	Gravity and gravity gradiometry surveys are remote-sensing methods that measure variations in the naturally occurring gravity field. Both technologies have been used by both mining and oil and gas industries for decades	No noise emission	
Airgun noise dampening			
Airgun silencer	This system consists of acoustically absorptive foam rubber on metal plates mounted radially around the airgun	Up to 6 dB reduction (above 700 Hz)	

B- *Target based active acoustic technologies*. Devices designed in order to displace animals.

Table 16. Acoustic Deterrent Devices (ADD) commonly used for reducing cetacean depredation and bycatch. They are increasingly used during wind farm construction

Manufacturer	Model	Source level (dB re 1µPa @ 1m	Fundamental frequency	Frequency range	Pulse duration	Inter-pulse interval
Airmar Technology group	Gillnet pinger	132	10 kHz	Harmonics present	300ms	4 s
Aquatec Subsea Ltd	Aquamark 100, 200, 210, 300	145 – 150	Model 200, 210: 5-60 kHz frequency sweeps; Model 100: 20-60 kHz frequency sweeps; Model 300: 10 kHz tonal	Harmonics up to 160 kHz	50 - 300 ms (depending on model)	4 - 30 s (pseudo-randomised except for model 300)
Fumunda	FMDP 2000	132	10 kHz	-	300 ms	4 s
Marine Technology Marexi	Marexi Acoustic pinger V.2.2	132 ± 4	10 kHz	-	300 ms	4 s
SaveWave	"High impact saver" "Long line saver" "Endurance saver"	155 – 140	HI model: signal has two partials: 5 - 40 kHz and 30 - 160 kHz; wide band sweeps. LL model: 5 - 60 kHz wide band sweeps. ES model: 5-90 kHz	Harmonics up to 180 kHz	200-900 ms randomised (depending on model)	4 - 16 s (randomised)

Table 17. Acoustic Harassment Devices (AHD) commonly used for reducing pinniped depredation and bycatch. (Na = information not available). They increasingly used during wind farm construction

Manufacturer	Model	Source level (dB re 1µPa @ 1m	Fundamental frequency (kHz)	Frequency range	Pulse duration (ms)	Inter-pulse interval (ms)
Ferrant-Thomson	MK2, MK3, 4X Seal Scrammers	195-200	27/25/Na	Up to 40 kHz	20 (20 s duration)	40.
Airmar	Airmar dB Plus II	192	10.3	Up to 103 kHz	1.4 (145 s duration)	20
Lofitech	Seal Scarer	191	15	Na	500 (6 s duration)	Na
Ace-Aquatec	Ace-Aquatec	193 (rms)	10	Up to 70 kHz	3.3-14 (20 s duration)	Na
Terecos	Terecos type DSMS-4	178 (rms)	4.9	Up to 27 kHz	Varying structure	Na

C- *Acoustic Monitoring Devices*. Devices developed for monitoring populations and/or underwater noise.

Table 18. Sample of acoustic monitoring devices commercially available and commonly used during ecological and underwater noise monitoring. The table is partially based on the work from Sousa-Lima et al (2013) (105) **(Na = information not available)**

Device	Manufacturer	TYPE	Projects/reference
C-POD T-POD	Chelonia Ltd	Bottom	SAMBAH (http://www.sambah.org/)
EAR	Oceanwide Science Inst.	Bottom	Lammers *et al* (2008) (106)
AURAL M2	MultiElectronique	Bottom	www.multi-electronique.com
SM2M-DeepWater	Wildlife Acoustics	Buoy/Bottom	http://www.wildlifeacoustics.com
DASARA	Greenridge Science	Bottom	www.greeneridge.com
Haruphone	PMEL	Bottom	Dziak et al (2007) (107)
PAL	Univ. of Washington	Bottom	Anagnostou et al (2011) (108)
AMAR, AMAR G3, AMAR M3	JASCO	Bottom	www.jasco.com
MARU	Cornell University	Na	Sousa-Lima & Clark (2008) (109)
DSG Ocean	Loggerhead Instruments	Bottom	www.loggerheadinstruments.com
PAMBuoy	SMRU	Buoy	www.pambuoy.co.uk
DTAG	WHOI	Tag	Johnson & Tyack (2003) (110)
Acousonde	Acoustimetrics	Bottom	www.acousonde.com

D- *Software and Informatics tools*. Available software is used at two stages: the planning phase and the operational phase. The former case concern software used for providing risk assessments, the latter is used during mitigation to carry out real-time detection and localisation of marine mammals. Additionally, web platforms providing ecological information are presented.

Table 19. Available software and informatics' tools

SOFTWARE	CURRENT DOMAIN	CURRENT USE	SCOPE	COMMENTS	POSSIBLE EXTENSION
ERMS	SONAR	Planning	Risk assessment		SEISMIC
SONATE	SONAR	Planning	Risk assessment	Assessment based on distribution maps of species and fishery activity	SEISMIC
SAKAMATA	SONAR	Planning	Risk assessment	Assessment based on noise propagation models + distribution map	SEISMIC
ISHMAEL		Real-time monitoring	Passive acoustic monitoring		
PAMGUARD	SEISMIC	Real-time monitoring/searching	Passive acoustic monitoring	Detects, classifies and localizes clicks and whistles	SONAR, COASTAL & OFFSHORE
RAINBOWCLICK		Real-time monitoring/searching	Passive acoustic monitoring	Detects and localizes clicks (Sperm whales)	COASTAL & OFFSHORE
WHISTLE		Real-time monitoring/searching	Passive acoustic monitoring	Detects and localizes whistles	COASTAL & OFFSHORE
SEAPRO & PAM WorkStation	SEISMIC & SONAR Research & Cnservation	Real-time monitoring/searching	Passive acoustic monitoring	Detects and visualizes clicks and whsitles	COASTAL & OFFSHORE monitoring
WEB PLATFORMS The IUCN Red-List website www.iucnredlist.org	Conservation		Database consulting	Issues including the accuracy of range maps and completeness of available information need to be addressed	SONAR, SEISMIC, COASTAL & OFFSHORE
WEB PLATFORMS The OBIS SEAMAP projects http://seamap.env.duke.edu/	Research / Conservation	Information sharing	Database consulting	Issues including the completeness of available information need to be addressed	SONAR, SEISMIC, COASTAL & OFFSHORE
WEB PLATFORMS The INTERCET project in the Pelagos Sanctuary www.intercet.it	Research / Conservation	Information sharing	Database consulting	Issues including the completeness of available information need to be addressed	SONAR, SEISMIC, COASTAL & OFFSHORE
ACCOBAMS Interactive Platform (under construction)	Research / Conservation	Information sharing	Consult and download	Les partenaires peuvent rajouter et mettre à jour leurs activités/projets/données	SONAR, SEISMIC, COASTAL & OFFSHORE

ANNEX IV

FUTURE WORK

Table 20. Actions required for improving and strengthening the application of mitigation frameworks

Domain	Actions
General	- Study the effects of high powered active transducers - Develop standard procedure for measurement of noise - Deepen Baseline Biology Information - Improve knowledge on distribution, abundance of cetaceans, especially endangered and data-deficient species. - Study Effects at individual/population/community levels - Identify thresholds (according to MSDF objectives) - Test effectiveness of best practices currently employed - Identify areas of special concern where strict measures should be applied
Sonar and Seismic	- Develop risk assessment software - Spread the use of Public Ecological Databases to industrial companies - Accelerate the development and use of alternative seismic technologies (e.g. Marine Vibroseis) - Data sharing, national or basin-wide database creation
Coastal and Offshore Works	- Test the effectiveness of source-based technologies (i.e. hydro-sound dampers; bubble curtain; etc.) - Test the effectiveness of AMD
Maritime traffic	- Test the effectiveness of propellers - Investigate the adoption of quieting technologies already in force in military and scientific vessels (e.g. electric propulsion) - Adoption of alternative quieter boats for whale-watching and touristic trips in sensitive areas and in MPAs. - Test the effectiveness of appendages improving wake inflow - Study the relationship between vessel speed and noise emission - Study the relationship between internal noise and external noise - Study the relationship between underwater noise mitigation and fuel efficiency - Assess costs/benefits of route and speed management - Require and incentivise compliance with pending IMO guidelines