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BACKGROUND DOCUMENT ON THE DEVELOPMENT OF PRACTICAL GUIDANCE AND TOOLKITS TO MINIMIZE AND MITIGATE THE SIGNIFICANT ADVERSE IMPACTS OF ANTHROPOGENIC UNDERWATER NOISE ON MARINE AND COASTAL BIODIVERSITY

Note by the Executive Secretary

1. At its eleventh meeting, the Conference of the Parties to the Convention on Biological Diversity, in its decision XI/18 A, requested the Executive Secretary to collaborate with Parties, other Governments, and competent organizations, including the International Maritime Organization (IMO), the Convention on Migratory Species (CMS), the International Whaling Commission, indigenous and local communities and other relevant stakeholders, to organize an expert workshop with a view to improving and sharing knowledge on underwater noise and its impacts on marine and coastal biodiversity, and developing practical guidance and toolkits to minimize and mitigate the significant adverse impacts of anthropogenic underwater noise on marine and coastal biodiversity, including marine mammals, in order to assist Parties and other Governments in applying management measures, as appropriate.

2. Pursuant to this request, the Executive Secretary convened an Expert Workshop on Underwater Noise and its Impacts on Marine and Coastal Biodiversity at the headquarters of the International Maritime Organization, in London, from 25 to 27 February 2014, with financial support from the European Commission. The final report of this meeting is available at http://www.cbd.int/doc/?meeting=MCBEM-2014-01.

3. With the financial support of the European Commission, the CBD Secretariat commissioned the preparation of a background document on the development of practical guidance and toolkits to minimize and mitigate the significant adverse impacts of anthropogenic underwater noise on marine and coastal biodiversity, as information for the above-mentioned workshop participants. This document was originally posted as UNEP/CBD/MCB/EM/2014/1/INF/1 and was revised based on inputs received during the workshop.

4. The revised background document is being submitted as information for the Subsidiary Body in its deliberation on the impacts of underwater noise on marine biodiversity

* UNEP/CBD/SBSTTA/18/1.

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BACKGROUND DOCUMENT ON THE DEVELOPMENT OF PRACTICAL GUIDANCE AND TOOLKITS TO MINIMIZE AND MITIGATE THE SIGNIFICANT ADVERSE IMPACTS OF ANTHROPOGENIC UNDERWATER NOISE ON MARINE AND COASTAL BIODIVERSITY

Executive Summary

Anthropogenic underwater noise levels in the marine environment have increased considerably over the last century as human utilization of coastal waters and oceans has expanded and diversified. Noise generating activities emit two main types of sound: impulsive or acute noise and continuous or chronic noise. Impulsive noise generating activities include seismic surveys during oil and gas exploration, the use of sonar during military exercises, explosions and impact pile driving during coastal and offshore construction. Chronic noise pollution at low frequencies is primarily caused by commercial shipping, although drilling, dredging and renewable energy operations also contribute to ambient sound levels. In the absence of mitigation, underwater noise levels are predicted to rise over the coming decades with projected increases in maritime transportation and the exploration and extraction of marine resources.

Sound is the primary sensory medium for many marine animals and is a key part of critical biological functions including feeding, communication, navigation, orientation and the detection of predators and hazards. Anthropogenic noise is known to affect a wide range of marine animals and negative impacts have been reported for at least 55 species to date. Intense levels of sound exposure have caused non-auditory physical damage to marine animals, while lower levels have led to loss in certain aspects of hearing. Exposure to noise can also cause changes in animal behaviour ranging from subtle changes in normal behaviour patterns to more drastic avoidance reactions. The degree of impact on an animal is not necessarily reflected in the strength of the behavioural reaction as serious population consequences can occur when behavioural responses are mild or absent. Elevated background noise levels have been shown to mask important acoustic cues or signals and reduce communication ability. Cumulative and long-term impacts may also lead to effects on populations of marine species but this has not been proven to date and can be difficult to detect.

The use of mitigation measures and protocols is well established in the military and in industries that produce impulsive noise emissions during seismic surveys or offshore construction. However there is considerable variation in mitigation procedures between regions and navies for seismic surveys and active sonar respectively. Although comprehensive mitigation guidelines are available they are not mandatory, with existing mitigation procedures dependant on national legislation. New international voluntary guidelines to reduce underwater noise from commercial vessels should encourage the shipping industry to use more efficient and quieter ships.

Recent examples of best environmental practise used by or developed for industry are presented for seismic surveys and offshore construction. These involve drawing up detailed planning, mitigation and monitoring strategies that are specifically designed for each operation. They also include substantial pre-and post-operation stages containing comprehensive environmental impact assessments and an evaluation of mitigation effectiveness respectively. Examples of current guidance on mitigation and monitoring protocols during operations are provided with specific reference to marine mammals. Most existing protocols are not designed for other marine taxa. It would be useful to develop and test operational protocols for species of concern in other taxa such as teleost fish, marine turtles and invertebrates.

A review of best available technologies to reduce noise emissions that are in development or actual use is provided for the main industrial activities in the marine environment. These include various designs for ships to quieten propulsion systems and minimise acoustic emissions from the hull, alternative technologies for seismic surveys such as marine vibroseis and alterations in airgun design, and a range of techniques to reduce or eliminate noise propagation from pile driving including the use of alternative non-impact foundation designs.

Recent developments for acoustic and species mapping of coasts and oceans are discussed with a current emphasis on mapping the distribution and abundance of cetaceans. Acoustic mapping tools are being developed to provide spatio-temporal assessments of low frequency noise for specific regions. Cetacean density maps are also being created using field data and predictive modelling of environmental factors. When combined, these tools can provide relevant information for risk assessment and decision making processes with regard to temporal and spatial noise restrictions in sensitive areas. Modelling tools have also been developed to measure communication masking in cetaceans which can support the development of management guidelines for a particular region or species.

The use of acoustics monitoring tools in mitigation strategies is now well established. A range of GIS-based passive acoustic monitoring (PAM) tools are available that enable detailed real-time monitoring of vocalising marine mammals during industrial or military operations. Clear guidelines for the use of PAM in monitoring protocols are set out in legal codes of conduct for some countries. Although PAM does have some limitations it is quickly developing into a useful tool for certain (vocal) species of marine mammal. Further development and testing of PAM systems is required to determine whether it can be used for vocalising species of other taxa. Active acoustic monitoring (AAM) tools are also available and may be better suited to marine fish and some invertebrates. However, AAM tools also emit sound which may affect cetaceans.

A range of existing management frameworks for the marine environment that currently consider underwater noise or have the potential to do so are provided. These include marine spatial planning approaches as part of an overall ecosystem-based management strategy that considers multiple stressors, and risk or impact assessments, usually for particular species of concern. Examples are provided from a number of countries. A more generic framework for the spatio-temporal prioritization of noise mitigation developed for cetaceans could also be adapted and applied to other marine taxa.

Recent developments made by regional and international agreements to manage and mitigate the effects of underwater noise on marine fauna are reviewed, with an emphasis on European regional initiatives. The setting of national, regional and international standards for the measurement of underwater sound is still at a relatively early stage with progress made in the United States, European Union and by the International Standards Organisation. Examples of a number of other types of standard regarding underwater noise are also provided including training and data collection standards during monitoring and regional standards for noise mapping and marine spatial planning.

Although mitigation practises have developed considerably over the last few decades there has been an overall focus on marine mammals (cetaceans in particular) and the use of simplistic dose-response techniques involving exposure thresholds. There is a need to develop mitigation measures that take into account behavioural and cumulative effects where known, but also consider noise impacts in combination with other stressors. Specific mitigation guidelines are required for marine taxa other than mammals but this will also involve substantial further research to determine the effectiveness of existing practises for these groups.

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1. Background and Introduction

This section briefly outlines the issue of underwater noise in the marine environment and the need for regulation. Changes in the acoustic marine environment over time in terms of the increase in noise types and levels and the known impacts on marine fauna to date are highlighted. The lack of data on underwater noise effects for many marine taxa, including cumulatively, and the need for considerable precaution in data-poor scenarios is mentioned. A summary of the Convention on Biological Diversity's work to date on underwater noise, in terms of decisions and the production of a scientific synthesis on the topic in 2012 is also provided.

Anthropogenic noise in the marine environment has increased markedly over the last century as man's use of the oceans has expanded and diversified.[1][2] Technological advances in vessel propulsion and design, the development of marine industry and the increasing and more diverse anthropogenic use of the oceans have all resulted in a noisier underwater environment. Long-term measurements of ocean ambient sound indicate that low frequency anthropogenic noise has increased in certain areas over the last 50 years, which has been primarily attributed to commercial shipping noise.[3][4] As well as an increase in commercial shipping the last half century has also seen an expansion of industrial activities in the marine environment including oil and gas exploration and production, commercial fishing and more recently the development of marine renewable energy. In coastal areas the increase in the number of small vessels (mainly fishing and recreational boats) is also a cause for localised concern where their sounds can dominate some coastal acoustic environments such as partially enclosed bays, harbours and estuaries.[5]

Anthropogenic noise has gained recognition as an important stressor for marine life and is now acknowledged as a global issue that needs addressing. The impacts of sound on marine mammals have received particular attention, especially the military's use of active sonar, and industrial seismic surveys coincident with cetacean mass stranding events.[6][7] Extensive investigation mainly over the last decade by academia, industry, government agencies and international bodies has resulted in a number of reviews of the effects of sound on marine fauna. The issue of underwater noise and its effects on marine biodiversity has also received increasing attention at the international level with recognition by a number of regional and international agencies, organizations and commissions. Further details for reviews and recognition are provided in the 2012 background document of the impacts of underwater noise on marine biodiversity.[8]

The underwater world is subject to a wide array of man-made noise from activities such as commercial shipping, oil and gas exploration and the use of various types of sonar[9]. Human activity in

[1] NRC (National Research Council). (2003). Ocean noise and marine mammals. Washington, D.C.: The National Academies Press. 192pp

[2] Hildebrand, J.A. 2009. Anthropogenic and natural sources of ambient noise in the ocean. Mar. Ecol. Prog. Ser 395:4-20

[3] Andrew RK, Howe BM, Mercer JA, Dzieciuch MA 2002. Ocean ambient sound: comparing the 1960s with the 1990s for a receiver off the California coast. Acoust Res Lett Online 3:65–70

[4] McDonald MA, Hildebrand JA, Wiggins SM, Ross D 2008. A fifty year comparison of ambient ocean noise near San Clemente Island: a bathymetrically complex coastal region off southern California. J Acoust Soc Am 124:1985–1992

[5] Kipple B, Gabriele C (2003) Glacier Bay watercraft noise. Technical Report NSWCCDE-71-TR-2003/522, prepared for Glacier Bay National Park and Preserve, Naval Surface Warfare Center, Bremerton, WA

[6] NRDC, 2005. Sounding the depths II: The rising toll of sonar, shipping and industrial ocean noise on marine life. Natural Resources Defense Council November 2005.

[7] Hildebrand, J. A. 2005. Impacts of anthropogenic sound. – in: Reynolds, J.E. et al. (eds.), Marine mammal research: conservation beyond crisis. The Johns Hopkins University Press, Baltimore, Maryland, pp. 101-124

[8] CBD Secretariat, 2012. Scientific Synthesis on the impacts of underwater noise on marine and coastal biodiversity and habitats. 93 pp. UNEP/CBD/SBSTTA/16/INF/12

[9] Ibid.

the marine environment is an important component of oceanic background noise[10] and can dominate the acoustic spectrum of coastal waters and shallow seas. Although there is a continuum in sound characteristics, man-made noise can be broadly split into two main types: impulsive and non-impulsive sounds. Examples of impulsive sounds are those from explosions, airguns, navigation (depth-finding) sonar or impact pile driving, while non-impulsive sounds result from activities such as shipping, construction (e.g., drilling and dredging), or renewable energy operations. At range, lower frequency impulsive sounds can "smear" and become non-impulsive. The level of human activity and corresponding noise production in the marine environment is predicted to rise over the coming decades as maritime transportation and the exploration and extraction of marine resources continues to grow.[11]

Sound is extremely important to many marine animals enabling them to detect the 'acoustic scene' and collect information about their environment. Sound plays a key role in communication, navigation, orientation, feeding and the detection of predators and hazards.[12] Almost all marine vertebrates rely to some extent on sound for these biological functions. Marine mammals use sound as a primary means for underwater communication and sensing. Underwater sound is especially important for Odontocete cetaceans that have developed sophisticated echolocation systems to detect, localise and characterise underwater objects,[13] for example, in relation to feeding behaviour. However, the use of sound is also extremely important for any animal that uses this medium during key life-history stages.

Many other marine taxa also rely on sound on a regular basis including teleost fish and invertebrates such as decapod crustaceans. Fish utilize sound for navigation and selection of habitat, mating, predator avoidance and prey detection and communication.[14][15] Although the study of invertebrate sound detection is still very limited, it is becoming clearer that many marine invertebrates are sensitive to sounds and related stimuli. However, the importance of sound for many marine taxa is still poorly understood and in need of considerable further investigation.

A variety of marine animals are known to be affected by anthropogenic noise. Negative impacts for at least 55 marine species (cetaceans, teleost fish, marine turtles and invertebrates) have been reported in scientific studies to date. However, other studies have also reported no effects of noise on marine taxa. A wide range of effects of increased levels of sound on marine fauna have been documented both in laboratory and field conditions. The effects can range from mild behavioural responses to complete avoidance of the affected area, masking of important acoustic cues, and in some cases serious physical injury or death. Low levels of sound can be inconsequential for many marine animals. However, as sound levels increase the elevated background noise can disrupt normal behaviour patterns potentially leading to less efficient feeding for example. Masking of important acoustic signals or cues can interfere with communication between con-specifics[16] and may interfere with larval orientation which could have implications for recruitment, although further research is required to verify the latter.

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[10] Hildebrand, J.A. 2009. Anthropogenic and natural sources of ambient noise in the ocean. Mar. Ecol. Prog. Ser 395:4-20

[11] Boyd, I.L., G. Frisk, E. Urban, P. Tyack, J. Ausubel, S. Seeyave, D. Cato, B. Southall, M. Weise, R. Andrew, T. Akamatsu, R. Dekeling, C. Erbe, D. Farmer, R. Gentry, T. Gross, A. Hawkins, F. Li, K. Metcalf, J.H. Miller, D. Moretti, C. Rodrigo, and T. Shinke. 2011. An International Quiet Ocean Experiment. *Oceanography* 24(2):174–181

[12] Richardson, W.J., Malme, C.I., Green, C.R. Jr. and D.H. Thomson. 1995. Marine Mammals and Noise. Academic Press, San Diego, CA 576 p.

[13] Au, W.W.L. 1993. The sonar of dolphins. Springer-, New York. 277p.

[14] Popper, A.N. and Hastings, M.C. 2009. The effects of anthropogenic sources of sound on fish. Journal of Fish Biology, 75: 455 – 489

[15] Simpson, S.D., Meekan, M.G., Montgomery, J., McCauley, R.D., Jeffs, A., 2005a. Homeward sound. Science 308, 221–228

[16] Clark, C.W., Ellison, W.T., Southall, B.L., Hatch L., van Parijs, S.M., Frankel, A. and Ponirakis, D. 2009. Acoustic masking in marine ecosystems: intuitions, analyses, and implication. Marine Ecology Progress Series, 395: 201 – 222

Mitigation of marine noise in the oceans is in place for industrial and military activities in some regions of the world through the use of practical measures and guidelines. However, critical analysis of this guidance has identified a number of limitations[17][18] including considerable variation in standards and procedures between regions or navies. Mitigation of anthropogenic sound levels in the marine environment require regular updating to keep in touch with changes in acoustic technology and the latest scientific knowledge of marine species such as acoustic sensitivity and population ecology. There have been calls for the setting of global standards for the main activities responsible for producing anthropogenic sound in the oceans. Progress is being made with regard to commercial shipping and quieting. Standards for naval sonar or seismic surveys would help to further reduce impacts on marine species, taking into consideration national legislation where appropriate.

Mitigation and management of anthropogenic noise through the use of spatio-temporal restrictions (STR) of noise generating activities has been recommended as the most practical and straightforward approach to reduce acoustic effects on marine animals.[19] However, preventing an intentional noise source in a targeted location is not always possible especially if there is a temporal overlap between the window of opportunity for industrial activities and the presence of the species of concern. In this situation detailed and comprehensive mitigation procedures and measures are recommended, with more stringent measures needed if the area contains areas used by sensitive marine fauna for feeding, breeding, nursing or spawning.[20] The extensive data and knowledge gaps for many species also emphasises the need for a precautionary approach to minimise potential noise effects.

Although research is opening our eyes to some of the less obvious behavioural effects of noise on aquatic animals (e.g., stress responses,[21][22][23] communication masking,[24][25] cognitive bias, fear conditioning, and attention and distraction[26]) we still have very restricted knowledge and understanding of how these effects influence overall impacts on populations. In addition, very little is known about cumulative effects on marine fauna or their recovery from such effects. Most current mitigation measures are not very effective in reducing possible cumulative and synergistic impacts on marine fauna.[27] They also do not fully consider the exposure context of individuals and how a

[17] Weir, C., Dolman, S.J., 2007. Comparative review of the regional marine mammal mitigation guidelines implemented during industrial seismic surveys, and guidance towards a worldwide standard. Journal of International Wildlife Law and Policy 10, 1–27

[18] Dolman, S. J., Weir, C.R., and Jasny, M. 2009. Comparative review of marine mammal guidance implemented during naval exercises. Marine Pollution Bulletin 58 pp. 465-477.

[19] Agardy, T., Aguilar, N., Cañadas, A., Engel, M., Frantzis, A., Hatch, L., Hoyt, E., Kaschner, K., LaBrecque, E., Martin, V., Notarbartolo di Sciara, G., Pavan, G., Servidio, A., Smith, B., Wang, J., Weilgart, L., Wintle, B. and Wright, A. 2007. A Global Scientific Workshop on Spatio-Temporal Management of Noise. Report of the Scientific Workshop. 44 pages

[20] Nowacek, D. et al., 2013. Responsible practises for minimizing and monitoring environmental impacts of marine seismic surveys with an emphasis on marine mammals. Aquatic Mammals 39: 356-377

[21] Wright, J.W., Deak, T. and Parsons, E.C.M. 2009. Concerns Related to Chronic Stress in Marine Mammals. IWC SC/61/E16 7 pp.

[22] Rolland, R.M., Parks, S.E., Hunt, K.E., Castellote, M., Corkeron, P.J., Nowacek, D.P.,Wasser, S.K., and Kraus, S.D. 2012. Evidence that ship noise increases stress in right whales. Proc. R. Soc. B, doi:10.1098/rspb.2011.2429.

[23] Buscaino, G. et al. 2009. Impact of an acoustic stimulus on the motility and blood parameters of European sea bass (Dicentrarchus labrax L.) and gilthead sea bream (Sparus aurata L.). Mar. Environ. Res. 69, 136–142

[24] Tyack, P.L. 2008. Implications for marine mammals of large-scale changes in the marine acoustic environment. Journal of Mammalogy. 89: 549-558

[25] Codarin, A., et al. 2009. Effects of ambient and boat noise on hearing and communication in three fish species living in a marine protected area (Miramare, Italy). Mar. Pollut. Bull. doi:10.1016/j.marpolbul.2009.07.011

[26] Purser J, Radford A.N. 2011. Acoustic Noise Induces Attention Shifts and Reduces Foraging Performance in Three-Spined Sticklebacks (Gasterosteus aculeatus). PLoS ONE 6(2): e17478. doi:10.1371/journal.pone.0017478

[27] Wright, A.J. 2014. Reducing impacts of human ocean noise on cetaceans: Knowledge gap analysis and recommendations. WWF International, Gland, Switzerland

combination of acute and chronic noise can interact with animal condition to elicit a behavioural response[28], particularly in marine mammals.

Moreover, a behavioural response is not necessarily the most reliable measure of a population consequence, as harmful impacts can occur without any visible change in behaviour in some species and situations.[29] Animals do not always react in an observable or obvious manner even if they are seriously impacted. Individuals with lower energy reserves or no alternative habitat cannot afford to flee repeatedly from disturbance but are forced to remain and continue feeding, apparently unresponsive to disruption.[30]

The vast majority of mitigation measures in place have been primarily designed to reduce underwater noise effects on marine mammals. Similarly considerably more research has been conducted on hearing and acoustic impacts on these taxa than on non-mammal marine fauna,, with particular attention paid to cetaceans, although large knowledge gaps still exist for many species. There is scope to use or adapt the underlying mitigation frameworks and main procedures for non-mammal marine taxa such as teleost fish, marine turtles and invertebrates. However, specific mitigation measures and protocols for these animals are on the whole still lacking and are urgently needed for many vulnerable and/or important species. Development of mitigation procedures for non-mammal marine taxa should go hand-in-hand with research to better understand the effects of sound on these groups, especially for aspects such as particle motion and substrate vibration.[31]

This document does not attempt to update the scientific synthesis completed by the CBD Secretariat in 2012[32] in terms of new research findings, but instead focusses on identifying and highlighting recent examples of best environmental practise and best available technology that can be utilized to further develop practical guidance and toolkits to reduce the impact of anthropogenic noise on marine biodiversity.

The document is divided into sections that report on current best practise and best available technology for mitigation and monitoring procedures and measures; recent advances in monitoring and mapping tools to support mitigation; a number of assessment and management frameworks available for underwater noise, and progress in the development of regional and international standards for the measurement of underwater sound and noise from anthropogenic sources.

For this document the term ‘noise’ is defined as anthropogenic sound that has the potential to cause negative impacts on the marine environment.[33]

Underwater Noise and the Convention on Biological Diversity

The CBD Conference of Parties (COP 10) in Nagoya in 2010 requested that a scientific synthesis report is produced on the impacts of anthropogenic underwater noise on marine and coastal biodiversity.[34] This draft report was presented and finalised at SBSSTA 16 in Montreal and submitted as an information document[35] to COP 11 in Hyderabad in 2012.

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[28] Ellison, W.T., Southall, B.L., Clark, C.W. and Frankel, A.S. 2011. A new context-based approach to assess marine mammal behavioural responses to anthropogenic sounds. Conservation Biology

[29] Weilgart, L.S. 2007. The impacts of anthropogenic ocean noise on cetaceans and implications for management. Can. J. Zool. 85: 1091-1116

[30] Gill, J.A. et al., 2001. Why behavioural responses may not reflect the population consequences of human disturbance. Biol. Conserv. 97: 265-268.

[31] Normandeau Associates Inc. 2012. Effects of noise on fish, fisheries, and invertebrates in the U.S. Atlantic and Arctic from energy industry sound generating activities. A Literature Synthesis. Prepared for the U.S. Department of the Interior, Bureau of Ocean Energy Management. Contract # M11PC00031. 135 pp.

[32] CBD Secretariat 2012. Scientific Synthesis on the impacts of underwater noise on marine and coastal biodiversity and habitats. 93 pp.

[33] Tasker, M.L, M. Amundin, M. Andre, A. Hawkins, W. Lang, T. Merck, A. Scholik-Schlomer, J. Teilmann, F. Thomsen, S. Werner & M. Zakharia. 2010 Marine Strategy Framework Directive. Task Group 11. Report Underwater noise and other forms of energy.

[34] CBD Secretariat 2012. Scientific Synthesis on the impacts of underwater noise on marine and coastal biodiversity and habitats. 93 pp.

[35] UNEP/CBD/SBSTTA/16/INF/12

Noting the gaps and limitations in existing guidance, including the need to update it in the light of improving scientific knowledge, and recognizing a range of complementary initiatives under way, COP-11 requested, in decision XI/18, the Executive Secretary to collaborate with Parties, other Governments, and competent organizations, including the International Maritime Organization, the Convention on Migratory Species, the International Whaling Commission, indigenous and local communities and other relevant stakeholders, to organize an expert workshop with a view to improving and sharing knowledge on underwater noise and its impacts on marine and coastal biodiversity, and to develop practical guidance and toolkits to minimize and mitigate the significant adverse impacts of anthropogenic underwater noise on marine and coastal biodiversity, including marine mammals, in order to assist Parties and other Governments in applying management measures.

Pursuant to the above request, the CBD Secretariat convened an expert workshop in London (25-27 February 2014), and the Executive Secretary invited Parties, other Governments and relevant organizations to provide relevant information concerning the objectives of the above-mentioned expert workshop, in particular regarding:

(i) The impacts of underwater noise on marine and coastal biodiversity;

(ii) Practical guidance and toolkits to minimize and mitigate the significant adverse impacts of anthropogenic underwater noise on marine and coastal biodiversity, including marine mammals.

COP-11 also requested the Executive Secretary to make the report of the workshop available for consideration by a meeting of the Subsidiary Body prior to the twelfth meeting of the Conference of the Parties.

This background information document was prepared in order to provide participants at the expert workshop with relevant up-to-date information that can contribute to the development of practical guidance and toolkits to minimize and mitigate the significant adverse impacts of anthropogenic underwater noise on marine and coastal biodiversity, including marine mammals. The research for preparing this document was undertaken through the generous financial support of the European Commission.

2. Mitigation Measures and Procedures

This section provides selected best practise examples of mitigation measures and procedures currently used by Governments and/or Industry for a number of anthropogenic noise generating industrial or military activities including marine construction (e.g. harbours and offshore renewable energy developments), naval sonar and explosives, and seismic surveys (for scientific exploration, as well as oil and gas) and shipping. Mitigation measures include the use of set noise exposure criteria; exclusion zones, spatio-temporal restrictions, operational procedures e.g. soft start / ramp-up, and quietening technology. The main technological and economic constraints of industry to meet best practise procedures are also discussed.

As well as undertaking specific real-time mitigation measures during the primary noise generating activity, mitigation procedures are becoming part of an overall process to assess the environmental characteristics of the area to be subjected to anthropogenic noise and identify, through modelling, the times and locations where species are most likely to be at risk. The vast majority of mitigation procedures have been designed for marine mammals, predominantly for cetaceans. However, many of the generic procedures are also applicable to other marine taxa such as fish and invertebrates, although particular mitigation measures may not be (e.g. the use of visual observers to determine species presence and proximity to a noise generating activity), whilst the effectiveness of others is not known (e.g. soft start procedures for fish). Limitations of existing mitigation guidelines and practises are not discussed in detail here as these have been reviewed previously[36][37] and were also summarised in the scientific synthesis prepared for the CBD Secretariat.[38]

Impulsive Noise Mitigation

A methodological guide to address impulsive noise sources in the marine environment that can have an impact on cetaceans in the ACCOBAMS region has recently been released.[39] Mitigation guidance is provided for offshore construction (predominantly pile-driving), military and civil sonar, seismic surveys and explosives. For each of these noise sources a mitigation framework is required that consists of three main stages; a planning phase, real-time mitigation and a post-activity phase (Table 1). Many of the mitigation measures are common to all four types of noise source (e.g. soft start and visual / acoustic monitoring protocols) while some measures are specifically recommended for one or two activities such as buffer zones for sonar use or the use of acoustic mitigation devices for offshore construction or the use of explosives.

Prior to the planning phase of the mitigation framework a comprehensive environmental impact assessment (EIA) should be conducted for the proposed activity. Although not always required by law, operators wishing to be regarded as adhering to the highest standards of environmental responsibility should make environmental impact assessment an intrinsic part of project planning.[40] A model EIA and consultation process for seismic surveys has recently been proposed.[41] This sets out in detail the requirements for a fully transparent process over three main stages: 1. developing a thorough EIA, 2. stakeholder consultation, and 3. ongoing stakeholder engagement. Ideally, baseline assessments and long-term monitoring of the affected area should be started as early as possible, preferably a number of years before the operation is planned. For example, industry-sponsored baseline assessments and long-term monitoring of cetaceans were initiated eight years before a specific hydrocarbon operation was planned to start in Angola, facilitating the development of mitigation measures and enabling the detection of behavioural changes in Humpback whales during seismic surveys.[42] For other marine taxa existing national or regional databases should be utilized, for example, datasets collected by the fishing industry or fisheries research organizations for commercial species.

Further detail for the ACCOBAMS guidelines are available as an Annex to ACCOBAMS Resolution 4.17 and are also provided with this document (Annex 1). These consist of general guidelines for any noise-generating activity and more specific guidance for each source type.[43] Using the general guidelines as a baseline we can develop a ’working list’ of best practise guidance for the mitigation of anthropogenic impulsive noise effects on marine biodiversity, with current emphasis on marine mammals:

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[36] Weir, C., Dolman, S.J., 2007. Comparative review of the regional marine mammal mitigation guidelines implemented during industrial seismic surveys, and guidance towards a worldwide standard. Journal of International Wildlife Law and Policy 10, 1–27

[37] Dolman, S. J., Weir, C.R., and Jasny, M. 2009. Comparative review of marine mammal guidance implemented during naval exercises. Marine Pollution Bulletin 58 pp. 465-477

[38] CBD Secretariat 2012. Scientific Synthesis on the impacts of underwater noise on marine and coastal biodiversity and habitats. 93 pp.

[39] ACCOBAMS 2013. Methodological Guide: Guidance on underwater noise mitigation measures. ACCOBAMS-MOPS/2013/Doc24

[40] Nowacek, D. et al., 2013. Responsible practises for minimizing and monitoring environmental impacts of marine seismic surveys with an emphasis on marine mammals. Aquatic Mammals 39: 356-377.

[41] Prideaux, G. and Prideaux, M. 2013. Seismic Seas: Understanding the impact of offshore seismic petroleum exploration surveys on marine species. Wild Migration technical and policy review #3. Wild Migration, Australia.

[42] Cherchio, S. et al., 2010. Humpback whale singing activity off northern Angola: An indication of the migratory cycle, breeding habitat and impact of seismic surveys on singer number in Breeding Stock B1. International Whaling Commission, Cambridge, UK.

[43] ACCOBAMS 2010. Resolution 4.17. Guidelines to Address the Impact of Anthropogenic noise on cetaceans in the ACCOBAMS area

Table 1. ACCOBAMS Mitigation Frameworks for Impulsive Noise Generating Activities

Stage	Action	Pile Driving, Drilling, Dredging	Seismic surveys	Military or Civil Sonar	Explosives
Planning Phase (expected outcomes of the EIA)	1. Review the presence of cetaceans in the candidate periods for the work and conduct or fund research where information is absent or inadequate	✓	✓	✓	✓
	2. Select periods with low biological sensitivity	✓	✓	✓	✓
	3. Define no-survey or exercise zones (biological reserves, protected areas etc.)		✓	✓	
	4. Define buffer zones			✓	
	5. Use sound propagation modelling results, verified in the field, to define the Exclusion Zone (EZ)	✓	✓	✓	✓
	6. Plan the lowest practicable source power or charge (explosive)	✓	✓		✓
	7. Consider alternative technologies	✓	✓		
	8. Plan noise mitigation technologies (if no alternatives are possible)	✓			
Real time mitigation	1. Use Acoustic Mitigation Devices prior to the beginning of the work	✓			✓
	2. Use noise mitigation technologies e.g. air bubble curtain, hydrosound damper net				✓
	3. Use a soft start protocol	✓	✓	✓	✓
	4. Use the visual monitoring protocol (MMO's)	✓	✓	✓	✓
	5. Use the acoustic monitoring protocol (PAM equipment)	✓	✓	✓	✓
Post Activity	1. Detailed reporting of real-time mitigation	✓	✓	✓	✓

General guidelines for Impulsive Noise Generating Operations in the Marine Environment (adapted from ACCOBAMS Resolution 4.17)

1. Consult databases of selected taxa spatial and seasonal distribution and habitats in order to plan and conduct activities at times and locations when animals are unlikely to be encountered whilst also avoiding critical habitats.
2. Collect information and, if required, organise field data collection (surveys or monitoring with fixed detectors) to assess the population densities in the areas selected for operation
3. Avoid marine taxa’s key habitats/periods of occurrence and protected areas, define appropriate buffer zones and consider the possible impact of long-range propagation
4. Consider cumulative impacts of noise and other anthropogenic stressors over time including seasonal and historical impacts from all other impulsive and continuous noise sources in the specific operational area and adjacent region. Develop GIS/databases that track the history of noise generating activities in the region for the selected taxa.
5. Model the generated sound field in relation to oceanographic features to define the area likely to be affected by the noise source
6. Determine safe / harmful exposure levels for various species, age classes, contexts that are precautionary enough to consider large levels of uncertainty.
7. Exclusion zones (EZ) should be determined on a scientific and precautionary basis rather than an arbitrary or static designation. EZ determination should be modelled on the source characteristics, the species in question and on local sound propagation features and verified in the field. Adopt the safest, most precautionary EZ option if there are multiple choices
8. Consider the establishment of a larger exclusion zone to reduce behavioural disruption, based on the latest scientific information for the selected taxa / species.
9. Real-time mitigation guidelines should be adopted and publicised by all operators
10. Use an automated system to record the acoustic source and document the amount of acoustic energy produced. Make this information available to noise regulators and the public
11. Mitigation should include monitoring and reporting protocols to document the implemented procedures and their effectiveness, and provide datasets to improve existing databases for marine taxa.
12. During operations, existing stranding networks in the area should be alerted and additional monitoring of the closest coasts and for deaths at sea should occur (mainly for marine mammals)
13. If required, organise post-operation field data collection to determine whether population changes or anomalous deaths occurred as a possible consequence of operations (requires pre-operation knowledge of the area)
14. If strandings occur, possibly related to operations, acoustic emissions should stop and maximum effort devoted to understanding the causes of death (mainly for marine mammals)
15. If abnormal behaviours are observed in animals close to operations, acoustic emissions should stop and maximum effort addressed to monitoring those animals
16. Trained and approved marine mammal observers (MMO) and bio-acousticians (e.g. PAM operators) should be employed for the monitoring and reporting programme including overseeing implemented mitigation rules
17. Observers and bio-acousticians must be qualified, dedicated and experienced, with suitable equipment.
18. Observers to report to the regulatory body using a standardized reporting protocol. Accurate reporting is required to verify the EIA hypothesis and the effectiveness of mitigation

19. Procedures and protocols should be based on a conservative approach that reflects levels of uncertainty and should include mechanisms that create an incentive for good practise

20. When uncertainties occur a precautionary approach needs to be taken and unexpected events or uncertainties referred to the regulatory body.

Responsible practises to minimise and monitor the environmental impacts of seismic surveys were recently published with an emphasis on marine mammals[44] but are also applicable to other marine taxa of concern such as teleost fish, marine turtles and seabirds. The overall general approach described for predicting, minimising and measuring impacts could also be applicable to other impulsive noise sources as mentioned in Table 1. A practical roadmap for planning, executing, evaluating and improving the design of an impulsive noise generating activity (in this case a marine seismic survey) is set out in Figure 1. The main aspects of planning and executing the operation are provided in Table 2.

National seismic survey guidelines for operations in Canadian waters are set out in a 'Statement of Canadian Practise with respect to the Mitigation of Seismic Sound in the Marine Environment[45]. This statement both formalises and standardises mitigation measures in Canada for seismic operations. It considers not only marine mammals, but also marine turtles and fish, and at the population-level any other marine species. At the planning stage seismic surveys must be planned to avoid:

- A significant adverse effect on individual marine mammals or sea turtles that are listed as endangered or threatened on Schedule 1 of the Species at Risk Act;
- A significant adverse population-level effect for any other marine species;
- Displacing individuals of endangered or threatened species of marine mammal or turtle from breeding, feeding or nursing;
- Diverting migrating individuals of endangered or threatened species of marine mammal or turtle from a known migration route or corridor;
- Dispersing aggregations of spawning fish from a known spawning area
- Displacing a group of breeding, feeding or nursing marine mammals, if it is known there are no alternate areas available to those marine mammals for those activities, or that if by using those alternate areas, those marine mammals would incur significant adverse effects, and
- Diverting aggregations of fish or groups of marine mammals from known migration routes or corridors if it is known there are no alternate routes or corridors, or if the fish aggregations or marine mammal groups incur significant adverse effects if they use an alternate migration route or corridor.

To avoid the seismic operation having any of the effects mentioned above will require extensive background knowledge of the area to be surveyed in terms of marine fauna distribution, migration and critical habitats and seasons for feeding, breeding / spawning and nursing. This emphasises the need to collect and analyse all available information prior to the proposed operation (Table 2). However, it can be very difficult in practice to detect population-level effects, particularly on cetaceans, and to know whether there are alternative areas for fish or marine mammals.

Once there is sufficient baseline information for an area of proposed activity it is possible to draw up a set of spatio-temporal restrictions so that the species or taxa of concern are not affected or that disturbance is kept to a minimum. Geographical and seasonal restrictions to avoid the ensonification of particular species and habitats are regarded as a highly successful mitigation measure.[46] The noise generating activity should be scheduled to avoid times or locations that the marine fauna of concern use for activities such as breeding / spawning, feeding, or migration. However in some cases complete

[44] Nowacek, D. et al., 2013. Responsible practises for minimizing and monitoring environmental impacts of marine seismic surveys with an emphasis on marine mammals. Aquatic Mammals 39: 356-377

[45] http://www.dfo-mpo.gc.ca/oceans/management-gestion/integratedmanagement-gestionintegree/seismic-sismique/statement-enonce-eng.asp

[46] OSPAR Commission. 2009. Overview of the impacts of anthropogenic underwater sound in the marine environment. London, UK: OSPAR Commission.

avoidance of an area during a particular temporal window may not be possible. For example, at high latitudes where sea ice occurs there can be an overlap between the time available for seismic surveys and the presence of sensitive species of marine mammals such as gray or bowhead whales.[47] In such situations there needs to be particular attention paid to planning, mitigation and monitoring and the analysis of potential effects. This more stringent and precautionary approach should be regarded as an indication of responsible practise by industry whether it is legally required or not.[48]

Noise mitigation procedures may also be considered for decommissioning offshore structures in the marine environment such as oil and gas platforms or wind turbines. The ACCOBAMS methodological guide[49] provides some guidance for the mitigation of explosives which can be used to decommission structures in some cases, although cutting is used more commonly.

A recent preliminary assessment of operational and economic constraints regarding the implementation of underwater noise mitigation measures by industry was conducted in France.[50] Consultations with both industry and the military were conducted to discuss constraints for the mitigation of underwater noise produced by wind farm construction, seismic surveys, naval sonar, marine traffic and dredging. The mitigation guidelines in question were those established by international bodies (ACCOBAMS, ASCOBANS and OSPAR) and the draft guidelines for shipping within the IMO.[51] For the oil and gas industry relatively few constraints were raised about implementing the guidelines for seismic surveys with two measures identified as expensive and difficult to implement; changing course during a survey and the use of low power sources. The shipping sector and the military regarded the use of many measures as problematic. Shipping authorities stated that implementing noise mitigation measures would be very expensive and the use of alternative or new designs was not favoured until independent research could verify their effectiveness. The renewable energy industry were generally in favour of using most recommended mitigation practises and procedures but were less interested in adopting mitigation technologies because of the high cost and operational issues. There were also concerns with stopping piling if a cetacean was detected during the exclusion zone and rescheduling work to avoid sensitive times as this would mean leaving potentially unstable piles and shifting activities to other times with possible increased costs.

It should also be noted that mitigation guidelines and procedures at the national level should be tailored to the national context and underpinned by legislation. Cultural values are an important aspect of national legislation, which should incorporate the use of best practice guidelines and the best available technology for noise mitigation procedures into national policies. Where legislation is weak with regard to noise mitigation, industry should follow best available practise and take a precautionary / risk-based approach.

Globally, legislators have responded to the issue of the risk of injury or disturbance to marine life in a number of ways. In many legislatures, marine mammals are protected specifically from injury while disturbance is included less often. In some cases, the law acts directly, while in others the law is coupled with guidance. In a few cases, acoustic thresholds have been set. The absence of scientific certainty has often led to precautionary approaches.

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[47] Nowacek, D. et al., 2013. Responsible practises for minimizing and monitoring environmental impacts of marine seismic surveys with an emphasis on marine mammals. Aquatic Mammals 39: 356-377

[48] Ibid

[49] ACCOBAMS 2013. Methodological Guide: Guidance on underwater noise mitigation measures. ACCOBAMS-MOPS/2013/Doc24

[50] Maglio, A. 2013. Implementation of underwater noise mitigation measures by industries: operational and economic constraints. Prepared for the Joint ACCOBAMS-ASCOBANS noise working group. Sinay, Caen, France

[51] Ibid

Figure 1: A practical roadmap for planning, executing, evaluating and improving the design of a marine seismic survey (after Nowacek et al., 2013)

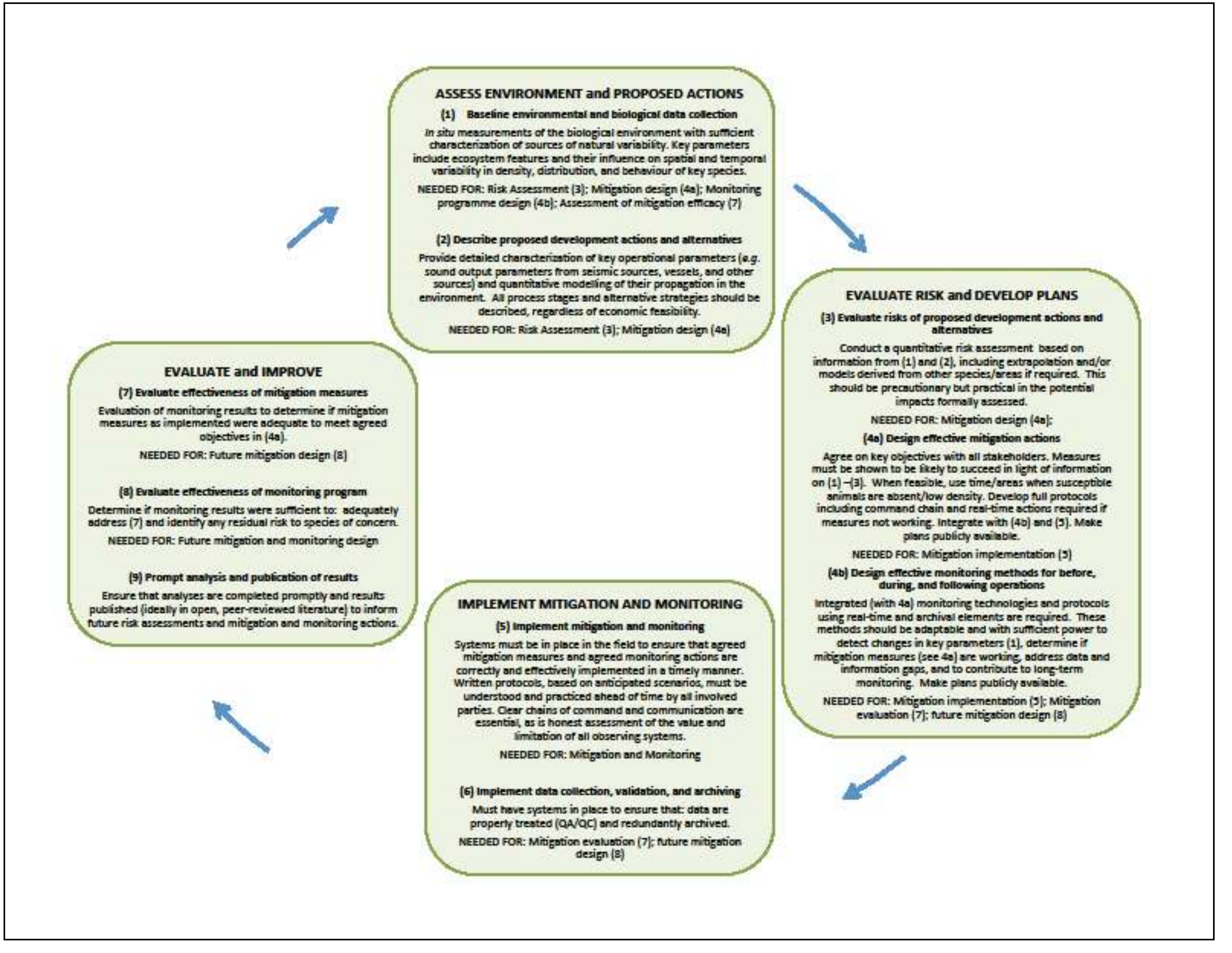

Table 2: Main elements for planning and conducting a marine seismic survey (adapted from Nowacek et al., 2013).

Primary Components	Notes
Assessment of background data with respect to species of concern (habitats, habits, life history) and environment (bathymetry, sound propagation)	• Identify multi-year data on general characteristics and natural variability of the relevant biological and ecological systems to understand environmental stochasticity and its influence on animal populations • Collate and evaluate information on species of concern to gain a thorough understanding of seasonal occurrence and density, behaviour, reproduction, foraging and habitat use • Collect and evaluate information on the areas physical properties (e.g. water temperature, currents, presence of sea ice) and how these influence the phenology and activities of the animals • Ensure that pre-operation assessments such as EIAs are openly available to the public and decision-makers
Spatial and/or temporal restrictions and requirements	• If possible ensure that operations occur when the species of concern is absent from the area • Co-ordinate the timing of operations (seismic surveys) when there are the fewest possible individuals of species of concern present in the area. • Ensure operations can commence at the beginning of any temporal windows of opportunity especially where these are seasonally restricted (e.g. high latitude areas) • Consider the potential effects of mitigation measures on ‘non-target’ organisms during the planning process
Generation of acceptable exposure criteria	• Key to the development of operational rules for seismic (or other impulsive) activities • Critical that any received-level thresholds to be used are derived in conditions similar to those of the proposed operation • Set criteria for the primary species or taxa of concern that consider both impulsive and continuous noise sources and also for both auditory and behavioural response thresholds • Important to utilise all pertinent data to derive the best possible estimates for criteria
Understanding the acoustic footprint of the survey: modelling of the acoustic source and the propagation environment	• Sound propagation model must be capable of reproducing all the relevant acoustic propagation properties of the region • Selected environmental parameters for modelling should be as close as possible to the prevailing local properties including the time of year. • Modelled noise source (e.g. seismic array) should produce the same volumetric far-field levels as those produced by the operational equipment, in this case, airguns. • Consider the use of pre-modelled acoustic footprints to increase the efficiency of response to changing environmental conditions

Pre-survey validation of source and propagation models	• If possible, conduct a site-specific validation of any acoustic modelling approach, preferably based on field measurements collected at or close to the location of the planned operation • Less specific validations can reveal the accuracy of certain aspects of the estimation but do not provide verification for both source and propagation modelling • Staging a limited trial of an activity similar to the planned one is the ideal scenario but may be logistically and economically unfeasible • Site-specific validations can substantially increase estimation confidence and should be part of standard mitigation and monitoring planning
Selection of appropriate techniques for implementing mitigation and monitoring elements (e.g. visual and/or acoustic survey methods)	• Consider all possible observation techniques during the planning phase • Select a tailored set of mitigation and monitoring measures that are included in a programme-specific mitigation and monitoring plan • Develop mitigation and monitoring plan as a collaboration between the operator, scientific experts, contactors, vessel owners and NGOs • Final plan should be science-based, precautionary and practical • For populations or individuals of particular concern (e.g. critical feeding, breeding areas or mother/calf pairs) active mitigation (operational shutdown) should occur at a behavioural threshold boundary • The use of telemetered systems for real-time acoustic monitoring during the most critical circumstances (i.e. for species and times of most concern) is strongly recommended to ensure behavioural thresholds are not exceeded
Creation of robust communication plan, including explicit chain of command	• Clear and robust communication protocols are essential during the operation to support efficient real-time decision making • A clearly defined chain of command is required to enable decision-making and the most effective and productive coordination of a project • All participants must have a thorough understanding of their roles and responsibilities, as well as those of the other parties involved and of the linkages between them • The decision-making process relative to the agreed operational protocols should be coherent and transparent • Consideration of communication issues caused by language differences is essential and the use of bilingual or multilingual participants is recommended • Communication plan should be reviewed during the operation, especially at the beginning to identify weaknesses, flaws and areas that need clarification
Post-survey assessment of mitigation measures	• Complete an initial assessment of mitigation and monitoring that documents the efficacy of mitigation protocols • Prepare and disseminate a preliminary report that provides a general overview of operations and major

	events and some initial data analysis
Publication of monitoring data to describe effects (or lack of), and to improve mitigation and monitoring of future surveys	• Regulators should insist that operators complete detailed analyses and rigorous, objective assessments of the efficacy of mitigation and monitoring measures • Operators should regard the full and open publication of results as a mark of corporate responsibility • Include funding for analysis and publication in project budgeting • Open access to data will help fill data gaps for marine taxa and provide useful information for future operations to improve management, reduce risk and minimise environmental effects.

Exposure Criteria

Exposure criteria or acoustic thresholds have been developed by the U.S. Government's National Oceanic and Atmospheric Administration (NOAA) for marine mammals and a few other taxa (marine fish and turtles) to predict the noise exposure levels above which adverse physical effects (i.e. injury) or behavioural harassment are expected. Initial scientific recommendations for marine mammals were published in 2007[52] and split the marine mammal taxa into five categories according to functional hearing abilities. Criteria suggestions were only provided for injurious exposure and not for behavioural responses of marine mammals although a qualitative, 10 step index for the severity of behavioural response was proposed. However, when the severity index was compared to reports of behavioural observations relative to the received sound level, the exposure sound level (e.g. dose-response approach) failed to reliably predict the probability of identified behavioural responses.[53][54] Current NOAA guidance on exposure levels for marine mammals does include acoustic thresholds for behavioural harassment but these are prone to the inaccuracies described previously. These thresholds are presented in the form of single received levels (RL) for particular source categories (e.g. impulsive, continuous or explosive).

NOAA recently released new draft guidance for assessing the effects of anthropogenic sound on marine mammals which proposes a revised set of acoustic threshold levels for the onset of permanent and temporary threshold shifts.[55] The guidance identifies the received levels above which individual marine mammals are predicted to experience changes in their hearing sensitivity (either temporary or permanent) for all underwater anthropogenic sound sources. The draft guidance includes:

- A protocol for estimating PTS and TTS onset levels for impulsive and non-impulsive sound sources;
- The formation of marine mammal functional hearing groups (a modified version of the groups recommended in 2007): low-, mid-, and high frequency cetaceans, otariid and phocid pinnipeds, and;
- The incorporation of marine mammal auditory weighting functions into the calculation of thresholds

The acoustic threshold levels are presented using both cumulative sound exposure level and peak sound pressure level. The cumulative sound exposure level (SEL_{cum}) is defined as the metric to account for accumulated exposure over the duration of the activity or for 24 hours (whichever is the shorter). However, this only accounts for the cumulative exposure to one particular noise source in the hearing range of an individual and does not consider the cumulative or aggregate effect of multiple noise sources, noting that there can be masking of one noise source by another. Advice is also provided in the draft guidance on how to combine multiple datasets and determine appropriate surrogates when little or no data exists.

The draft guidance is directed at marine mammals that reside or utilise marine waters under the jurisdiction of NOAA and so is U.S.-centric. An important point to note is that the updated thresholds are not supposed to represent the entirety of an impact assessment, but instead provide a tool to help evaluate the effects of a proposed action or activity on marine mammals[56]. Other aspects that should be considered within an overall assessment of risk include behavioural impact thresholds, auditory masking assessments and evaluations to help understand the ultimate effects of an impact on an individual's fitness and on populations.

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[52] Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene, C.R. Jr., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A., and Tyack, P. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals 33: 411-521

[53] Ibid

[54] Ellison, W.T., Southall, B.L., Clark, C.W. and Frankel, A.S. 2011. A new context-based approach to assess marine mammal behavioural responses to anthropogenic sounds. Conservation Biology

[55] NOAA, 2013. Draft guidance for assessing the effects of anthropogenic sound on marine mammals. Acoustic threshold levels for onset of permanent and temporary threshold shifts. Draft, 23 December 2013.

[56] Ibid

Interim exposure criteria for physical effects of pile driving on marine fish were developed on the west coast of the U.S. over a number of years by the fisheries hydroacoustic working group (FHWG) and published in 2008. Prior to this NOAA fisheries used peak sound pressure level (SPL) to assess the risk of injury to fishes, but this metric did not take into account the injury risk to non-auditory tissues in fishes with swim bladders.[57] The interim exposure criteria are the only known current criteria in use for the onset of physiological effects on fishes.[58] Although these criteria are in use they were strongly criticized before being released as not using the best available science at the time and that they were based on limited, incomplete experimental data.[59]

A revised version of suggested exposure guidelines for fishes and turtles from different noise sources has recently been published.[60] A working group initiated by NOAA divided possible effects into three categories: mortal and potentially mortal effects, impairment (including recoverable injury, TTS and masking) and behavioural changes. These sound exposure guidelines are based on the best scientific information at the time, and should be treated as interim.[61] Exposure guidelines for effects are based on five different ‘animal’ groups, defined by the way they detect sound:

1. Fishes without a swim bladder (only detect particle motion);
2. Fishes with a swim bladder (primarily detect particle motion, and probably also pressure);
3. Fishes with a swim bladder ‘connected’ to the ear;
4. Sea turtles, and;
5. Fish eggs and larvae.

Many fishes and invertebrates and perhaps turtles are sensitive to particle motion in terms of behavioural responses.[62] There is a need to consider particle motion in the monitoring and mitigation of underwater noise for these species. However little is known of particle motion detection by marine animals and the effects of elevated particle motion on their physiology and behaviour.

There are currently no exposure criteria developed for marine invertebrates.

Apart from the U.S. there are only a few other countries that specifically use exposure criteria in the regulation of anthropogenic noise production in the marine environment. One example is the mandatory use of a noise exposure criterion for marine mammals as part of the licence for pile driving in offshore waters within the German EEZ when constructing offshore wind turbines.[63] The dual criterion is defined as: emitted sounds have to be limited to a received level of 160 dB re 1µPa^{2}s SEL and a sound pressure level of 190 dB$_{peak\text{-}peak}$ re 1 µPa at a distance of 750 m. These levels were selected following the precautionary principle in order to account for multiple exposures of pile driving impulses and keep disturbance as low as possible. The mandatory regulation has, along with substantial government support, stimulated industrial research programmes to develop noise reduction techniques that aim to meet the required criterion.

There is increasing concern that the use of a received level (RL) dose-response approach for behavioural responses to underwater noise is inconsistent with current understanding, potentially

[57] Stadler, J.H. and Woodley, D.P. 2009. Assessing the effects to fishes from pile driving: Application of new hydroacoustic criteria. Inter-Noise 2009. Ottawa, Ontario, Canada. 8 pp.
[58] Normandeau Associates Inc. 2012. Effects of noise on fish, fisheries, and invertebrates in the U.S. Atlantic and Arctic from energy industry sound generating activities. A Literature Synthesis. Prepared for the U.S. Department of the Interior, Bureau of Ocean Energy Management. Contract # M11PC00031. 135 pp.
[59] Ibid
[60] Popper, A.N. et al., 2014. ASA S3/SC1.4 TR 2014 Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI..
[61] Ibid.
[62] Lucke, K. et al., 2013. Report of the workshop on international harmonisation of approaches to define underwater noise exposure criteria. Budapest, Hungary, 17 August 2013. IMARES, Wageningen UR, The Netherlands. Report number C197.13. 40 pp
[63] Ibid

misleading, and in some cases inaccurate.[64] Focussing on the amplitude of the received sound ignores a range of biological, environmental and operational factors (i.e. context) that can affect both the perception of received sounds and the complex behavioural responses invoked.[65] Research indicates that a variety of factors can influence how an animal responds to sound in terms of the form, extent and probability of a response. There is a need to account for these factors in underwater noise management approaches which is challenging given the limited understanding of behavioural responses for most species of marine animals. However, including context as part of behavioural-response assessment is recommended by the scientific community[66] and deemed necessary by federal government agencies in the United States that produce and regulate sound.[67] With this in mind a new context-based approach that accounts for both acute and chronic noise and cumulative effects on marine animals (in this case mammals) has been proposed.[68] The approach consists of three parts:

1. Measurement and evaluation of context-based behavioural responses of marine mammals exposed to various sounds;
2. New assessment metrics that emphasise the relative sound levels (e.g. ratio of signal to background noise and level above hearing threshold;
3. Considering the effects of both chronic and acute noise exposure.

These three aspects of sound exposure are recommended for integration into marine spatial planning and ecosystem-level management of human offshore activities.[69] However, there are some concerns that hearing thresholds may not be as useful for predicting impact as initially thought as many species respond to noise outside of their range of greatest hearing sensitivity, and that species with very similar audiograms can respond very differently. Some marine animals other than mammals can also detect sound in non-auditory ways, such as through their bodies or skin.

Real-time Mitigation Protocols

This section describes best practise for real-time mitigation protocols, namely soft start, visual and acoustic monitoring protocols used for industrial or military activities and highlights a number of examples. Succinct guidelines for noise generating activities that include real-time mitigation protocols have been developed by ACCOBAMS for cetaceans and are summarized in Table 3. Although developed for the ACCOBAMS agreement area (The Mediterranean) this general guidance could be used to develop or update guidance for cetaceans in other marine regions including those areas where no statutory guidelines are in place. As mentioned in Table 2, for maximum effectiveness real-time mitigation procedures should be a tailored set of mitigation and monitoring measures as part of a project-specific mitigation and monitoring plan that is science-based, precautionary and practical.[70]

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[64] Ellison, W.T., Southall, B.L., Clark, C.W. and Frankel, A.S. 2011. A new context-based approach to assess marine mammal behavioural responses to anthropogenic sounds. Conservation Biology
[65] Ibid
[66] Southall, B.L., et al. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals 33: 411-521
[67] Southall, B., et al. 2009. Addressing the Effects of Human-Generated Sound on Marine Life: An Integrated Research Plan for U.S. federal agencies. Interagency Task Force on Anthropogenic Sound and the Marine Environment of the Joint Subcommittee on Ocean Science and Technology. Washington, DC
[68] Ellison, W.T., Southall, B.L., Clark, C.W. and Frankel, A.S. 2011. A new context-based approach to assess marine mammal behavioural responses to anthropogenic sounds. Conservation Biology
[69] Ibid
[70] Nowacek, D. et al., 2013. Responsible practises for minimizing and monitoring environmental impacts of marine seismic surveys with an emphasis on marine mammals. Aquatic Mammals 39: 356-377.

Table 3: Real-time Mitigation Protocols to address the impact of noise generating operation on cetaceans (Adapted from ACCOBAMS guidelines)

Protocol	Guidance	Comments / Notes
Soft start / ramp up	Noise emissions should begin at low power, increasing gradually until full power is reached. The procedure should take a minimum of 20 minutes Soft start procedure should be delayed if cetaceans enter the Exclusion Zone (EZ)	The effectiveness of this procedure is still debateable as it is not always science-based and generic (but also see recent publications that support the use of the procedure[71][72])
Visual Monitoring	Marine Mammal Observers (MMOs) should watch the EZ for 30 minutes before the beginning of the soft start procedure (or 120 minutes for highly sensitive species) Continuous visual monitoring to be conducted for the entire duration of the noise emission At least two dedicated MMOs continuously on watch with shifts not exceeding two hours Activity should be stopped (or powered down) if cetaceans enter the EZ If noise activity is stopped, then a new 30 minute period is required without animals in the EZ before emissions are restarted (120 minutes for highly sensitive species)	Highly sensitive species include deep-diving beaked whales Ideally operations should not be conducted in areas that highly sensitive species are known to inhabit MMOs main tasks are: • Monitoring and implementing mitigation measures as per the visual monitoring protocol • Collection of abundance, distribution and behavioural data during operations (and in transit) • reporting
Acoustic Monitoring* (PAM)	Acoustic monitoring should be used to alert the MMOs to the presence of cetaceans Continuous acoustic monitoring to be conducted for the entire duration of the noise emission At least one acoustician on watch at any one time (unless proven automatic detection systems are available) Acoustic monitoring is mandatory for operations at night or in bad weather conditions In darkness or bad weather noise emissions should be stopped or powered down if cetaceans are detected acoustically.	Shut down of source(s) whenever aggregations of vulnerable species (e.g. beaked whales) are detected anywhere in the monitoring area. PAM may be inadequate mitigation at night if cetaceans are not vocal or easily heard Ideally high power sources should be prohibited at night, during periods of low visibility and during significant surface ducting conditions, since current mitigation techniques may be inadequate to detect and localise cetaceans

*: The pros and cons of passive and active acoustic monitoring tools are discussed in section 4.

A recent and best practise example of operational guidelines to minimise acoustic disturbance from seismic surveys is the New Zealand Government's Department of Conservation 2013 Code of Conduct.[73] This code of conduct provides detailed guidance for operators on their legal requirements to minimise noise levels and the potential for disturbance to marine mammals in New Zealand waters. The code splits seismic surveys into three main types based on the air gun capacity:

[71] OGP 2011. Model based assessment of underwater noise from an airgun array soft-start operation. International Association of Oil and Gas Producers. Report No. 451. February 2011. 98 pp.
[72] Stone, C.J. (in press). Marine mammal observations during seismic surveys from 1994-2010. JNCC report No. 463
[73] http://www.doc.govt.nz/conservation/marine-and-coastal/seismic-surveys-code-of-conduct/

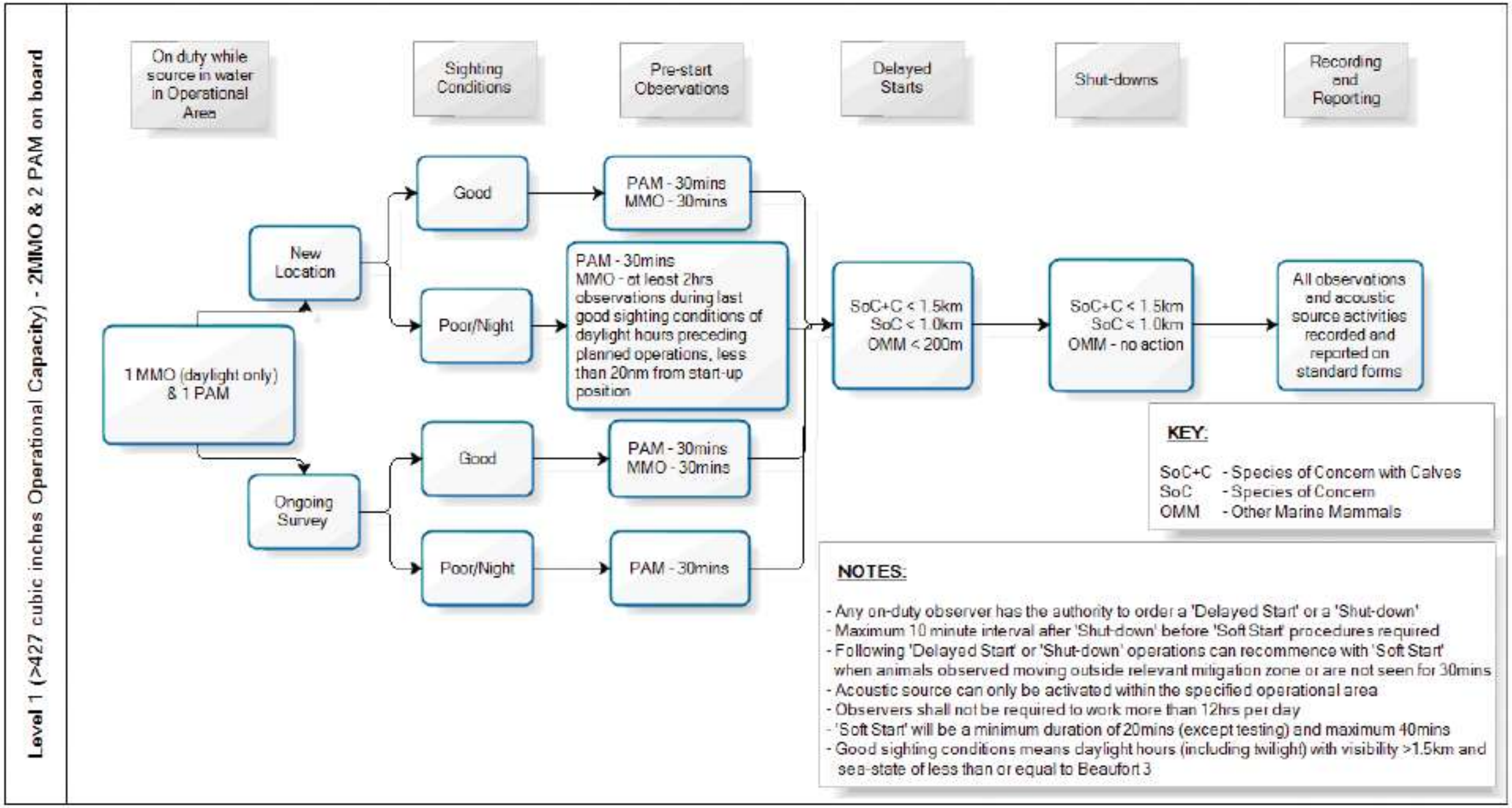
- Level 1 (>427 cubic inches) – large-scale geophysical investigations with dedicated seismic survey vessels or other studies with high powered acoustic sources. This level has the most stringent requirements for marine mammal protection;
- Level 2 (151-426 cubic inches) – lower scale seismic investigations often associated with scientific research. Smaller platforms using moderate power or smaller source arrays with less risk and therefore less stringent mitigation measures;
- Level 3 (<150 cubic inches) - all other small scale survey technologies that are considered to be of such low impact and risk that they are not subject to the provisions of the code

Level 1 mitigation meets, and in some cases exceeds, all the measures listed in Table 3. The code also provides clear instructions on the specific roles and responsibilities of MMOs and PAM operators during operations and sets out procedures in the form of operation flowcharts that are practical and easy to use (Figure 2). The code of conduct was produced by the New Zealand Department of Conservation in consultation with a broad range of stakeholders in marine seismic survey operations in the country, including international and domestic stakeholders representing industry, operators, observers, and marine scientists. The overall aim is to provide effective, practical mitigation measures for minimising acoustic disturbance of marine mammals during seismic surveys and the code has been endorsed as industry best practice by the Petroleum Exploration and Production Association of New Zealand (PEPANZ).

The real-time mitigation protocols described previously have been specifically designed for marine mammals and cetaceans in particular. Although there is considerably less information available on the effects of underwater noise on marine fish, turtles and invertebrates than for marine mammals, the non-mammal taxa are beginning to receive more attention from the scientific community and regulatory bodies and agreements in the last decade. The development or adaptation of real-time mitigation and monitoring procedures and measures for these taxa should be encouraged as more information becomes available. Whether measures such as soft starts are effective mitigation for fish or turtles and more mobile invertebrates such as squid is not currently known. It is important to determine whether soft starts are effective in moving fish, turtles or selected invertebrates from an area prior to operation. As some fishes and invertebrates occupy home ranges they may be reluctant to move, while others can move only slowly.[74] Visual observation during operations will not be valid for marine fish or invertebrates but may be used for marine turtles.

[74] Normandeau Associates Inc. 2012. Effects of noise on fish, fisheries, and invertebrates in the U.S. Atlantic and Arctic from energy industry sound generating activities. A Literature Synthesis. Prepared for the U.S. Department of the Interior, Bureau of Ocean Energy Management. Contract # M11PC00031. 135 pp.

Figure 2: Operation Flowchart for Level 1 Seismic Surveys in New Zealand waters (Source: NZ Department of Conservation 2013 Code of Conduct).



One of the main sources of information used[75] for the following sections on noise quietening and limitation technologies was compiled as an information synthesis background document for a recent workshop on quieting technologies for seismic surveying and pile driving, organised by the U.S. Government's Bureau of Ocean Energy Management (BOEM).[76] The final report describing the corrections to the background document, discussions, conclusions and recommendations of this workshop has recently been published. The main conclusions of this BOEM workshop are provided below for seismic surveys and pile driving:

At the present time the primary potential but still emerging alternative airguns is marine vibreosis (MV). A number of types of MV units are under development but at least one system may be close to commercial use for certain applications, notably in shallow water, sensitive habitats, and near vulnerable biological resources. However, MV is not likely to be implemented on a wider scale until its economic feasibility is proven and its potential for environmental impacts is tested.

There are a number of commercially available alternatives for pile driving but none have been fully field tested and research into alternative pile driving methods continues. The commercially available alternatives to impact pile driving include drilling, vibratory, gravity base and floating piles. New pile designs have been developed (double-walled pile and lower radial expansion pile), but further research and development is required. Mitigation measures for quieting the pile driving process include bubble curtains, cofferdams and noodle nets but none of these technologies have been sufficiently tested to determine their true field performance. There is no one-type-fits-all solution to pile driving noise, particularly regarding through sediment transmission of sound and other site-specific issues such as water depth, currents and substrate type. Projects may therefore require an individual analysis to determine the most effective and suitable noise reduction method.

Alternative Noise Quietening Technologies

A summary of alternative noise quietening technologies for impulsive noise generating activities, notably seismic surveys and offshore construction, are summarised in Table 4 with information provided on their known effectiveness and current state of development. Information was mainly derived from two recent reviews[77][78] where considerable further detail can be found on the technologies, and also from the ACCOBAMS methodological summary.[79]

Alternative acoustic source technologies are those that have the potential to replace existing commonly used technologies in certain conditions. Many of the alternative technologies are in various stages of development and are currently not commercially available for use, although considerable progress has been made in recent years, especially in the development of alternatives to pile driving for offshore wind turbines[80] (Table 4a). There are a number of alternative foundation types in existence or currently being developed including vibratory pile driving, foundation drilling, floating wind turbines and gravity-based or bucket foundations. Underwater noise measurements during installation are only available for a few of these technologies but many significantly reduce or completely eliminate the emission of impulsive sound generated by pile driving. Instead, continuous sound is emitted during installation generated by activities such as drilling, suction dredging and support ship movements, which can contribute to the overall level of background noise in an area.

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[75] CSA Ocean Sciences Inc., 2014. Quieting Technologies for reducing noise during seismic surveying and pile driving. Information Synthesis. BOEM. 53 pp

[76] Quieting technologies for reducing noise during seismic surveying and pile driving workshop. 25-27 February 2013. Silver Spring, Maryland. Bureau of Ocean Energy Management (BOEM).

[77] CSA Ocean Sciences Inc., 2014. Quieting Technologies for reducing noise during seismic surveying and pile driving. Information Synthesis. BOEM. 53 pp.

[78] Koschinski, S. and Lüdemann, K. 2013. Development of noise mitigation measures in offshore wind farm construction. Federal Agency for Nature Conservation / Bundesamdt für Naturschutz (BfN). 97 pp.

[79] ACCOBAMS 2013. Methodological Guide: Guidance on underwater noise mitigation measures. ACCOBAMS-MOPS/2013/Doc24. 18 pp.

[80] Koschinski, S. and Lüdemann, K. 2013. Development of noise mitigation measures in offshore wind farm construction. Federal Agency for Nature Conservation / Bundesamdt für Naturschutz (BfN). 97 pp.

Alternative technologies for seismic surveys to replace airguns have been under development for decades and include marine vibroseis, the low level acoustic combination source (LACS) and a low impact seismic array (LISA) (Table 4b). Many of these technologies are under development and in many cases testing has shown there to be a number of technical issues that mean they do not improve on seismic surveys as a tool to image sub-surface geology. Marine Vibroseis (MV) is regarded as the most promising replacement for airguns. This controlled source is around 32 dB quieter and could convert to a substantial, reduction in the presumed area of impact immediately around the seismic survey[81]. In an environmental assessment report funded by the International Association of Oil and Gas Producers, a MV survey was estimated to expose roughly 80-99% fewer whales and dolphins to high noise levels compared to an airgun survey, based on modelling studies[82]. MV can lower the environmental impact compared with airguns mainly by strongly suppressing the unwanted, high-frequency components of the MV signal--unused by the oil and gas industry and thus wasted energy--and by eliminating the rapid rise time, which can be biologically damaging. The signal would contain the same energy as an airgun's because the duration would be longer, which may increase the potential for masking. This could be counteracted by using a frequency modulated, narrowband signal. If MV is shown to be better tolerated by marine life, mitigation measures for MV may be less restrictive than for airguns, and MV surveys may be allowed in situations where airgun surveys are not. Mitigation for MV could be more straightforward and cost-effective for seismic operators given shutdown zones would be dramatically smaller. Pressure and funding from regulators and decision-makers could hasten development of MV.[83][84]

Complementary Technologies for Seismic Surveys

As well as developing alternatives to airguns to conduct seismic surveys there is some potential to reduce the amount of seismic survey activity required through the use of existing complementary technologies or methods to investigate subsurface geology.[85] These include low-frequency passive seismic methods, electromagnetic surveys, gravity and gravity gradiometry surveys, and the use of fibre optic receivers. However many of these technologies have issues that currently prevent their wide uptake by industry and require further development or testing.

Low-frequency passive seismic methods use natural sounds (natural seismicity, ocean waves and microseism surface waves) to image the subsurface and are currently being studied in academia and industry as a means to identify and delineate hydrocarbon reservoirs.[86] Of the three natural sounds that are recorded, the use of microseism surface waves is still at an early stage of development, the ocean waves method requires further testing and measuring natural seismicity takes longer to collect

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[81] Weilgart, L. 2013. Alternative quieter technologies to seismic airguns for collecting geophysical data. In: von Nordheim, H., Maschner, K., and Wollny-Goerke, K. (Eds.) Proceedings of the 3rd International Conference on Progress in Marine Conservation in Europe 2012. BfN-Skripten 339: 127-134.

[82] LGL and MAI. 2011. Environmental Assessment of Marine Vibroseis. LGL Rep. TA4604-1; JIP contract 22 07-12. Rep. from LGL Ltd., environ. res. assoc., King City, Ont., Canada, and Marine Acoustics Inc., Arlington, VA, U.S.A., for Joint Industry Programme, E&P Sound and Marine Life, Intern. Assoc. of Oil & Gas Producers, London, U.K. 207 p.

[83] Weilgart, L. 2012. Are there technological alternatives to air guns for oil and gas exploration to reduce potential noise impacts on cetaceans? In: Popper, A.N., and A. Hawkins (Eds.). The Effects of Noise on Aquatic Life, Advances in Experimental Medicine and Biology 730: 605-607, New York: Springer Press.

[84] Weilgart, L. 2013. Alternative quieter technologies to seismic airguns for collecting geophysical data. In: von Nordheim, H., Maschner, K., and Wollny-Goerke, K. (Eds.) Proceedings of the 3rd International Conference on Progress in Marine Conservation in Europe 2012. BfN-Skripten 339: 127-134.

[85] CSA Ocean Sciences Inc., 2013. Quieting Technologies for reducing noise during seismic surveying and pile driving. Information Synthesis. BOEM. 53 pp.

[86] Habiger, 2010. Low frequency passive seismic for oil and gas exploration and development: a new technology utilising ambient seismic energy sources. In: Weilgart, L.S (ed.), 2010. Report of the workshop on alternative technologies to seismic airgun surveys for oil and gas exploration and their potential for reducing impacts on marine mammals. Monterey, California, 2009. Okeanos –Foundation for the Sea. 29+iii pp.

sufficient data to produce results than the other two.[87] However all three ways are regarded as promising and worthy of further investigation and development.

Electromagnetic (EM) surveys are often used in conjunction with seismic surveys and there are currently two techniques that have been used as an exploration tool in the last decade: controlled source electromagnetic (CSEM) and magnetotelluric (MT) surveys. The CSEM technique involves the transmission of very low frequency (< 1 Hz) EM signals into the upper layer of the seafloor. The environmental impacts of CSEM are expected to be negligible as the CSEM source uses extremely low spatial and temporal frequencies with a small region of potential influence to marine life[88]. MT surveys are a passive measurement of the Earth's EM fields by detecting the natural electrical and magnetic fields present.[89] Both methods are often used in combination for subsurface mapping. At the present time these methods do not have the resolution or penetration to replace seismic surveys but broader application of EM methods does have the potential to reduce the level of 3D seismic surveying required.[90] The technology is underutilised by industry due to a lack of understanding and adoption.[91]

Gravity and gravity gradiometry surveys are passive remote-sensing methods that measure variations in the naturally occurring gravity field. Both technologies are fairly well developed and have been used by mining and petrochemical industries for decades.[92] Gravity gradiometry involves measuring the Earth's gravity gradient and provides better resolution than gravity surveys but also requires more complex and expensive equipment. The techniques are not applicable in all geological settings but have some potential to reduce the amount of seismic survey effort required.[93]

Fibre optic receivers are sensors that incorporate optical fibres to transmit the received acoustic signal as light[94]. They are mainly used for seismic permanent reservoir monitoring but the technology is not currently available for towed streamer surveys. However, several key characteristics have been identified that could lead to noise reduction during airgun surveys:[95]

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[87] CSA Ocean Sciences Inc., 2014. Quieting Technologies for reducing noise during seismic surveying and pile driving. Information Synthesis. BOEM. 53 pp.

[88] Ridyard, D. 2010. Potential application of 3D EM methods to reduce effects of seismic exploration on marine life. In: Weilgart, L.S (ed.), 2010. Report of the workshop on alternative technologies to seismic airgun surveys for oil and gas exploration and their potential for reducing impacts on marine mammals. Monterey, California, 2009. Okeanos –Foundation for the Sea. 29+iii pp.

[89] CSA Ocean Sciences Inc., 2014. Quieting Technologies for reducing noise during seismic surveying and pile driving. Information Synthesis. BOEM. 53 pp.

[90] Ridyard, D. 2010. Potential application of 3D EM methods to reduce effects of seismic exploration on marine life. In: Weilgart, L.S (ed.), 2010. Report of the workshop on alternative technologies to seismic airgun surveys for oil and gas exploration and their potential for reducing impacts on marine mammals. Monterey, California, 2009. Okeanos –Foundation for the Sea. 29+iii pp.

[91] Ibid

[92] Bate, D. 2010. Gravity gradiometry. In: Weilgart, L.S (ed.), 2010. Report of the workshop on alternative technologies to seismic airgun surveys for oil and gas exploration and their potential for reducing impacts on marine mammals. Monterey, California, 2009. Okeanos –Foundation for the Sea. 29+iii pp.

[93] Ibid

[94] CSA Ocean Sciences Inc., 2014. Quieting Technologies for reducing noise during seismic surveying and pile driving. Information Synthesis. BOEM. 53 pp

[95] Nash, P. and Strudley, A.V. 2010. Fibre optic receivers and their effect on source requirements. In: Weilgart, L.S (ed.), 2010. Report of the workshop on alternative technologies to seismic airgun surveys for oil and gas exploration and their potential for reducing impacts on marine mammals. Monterey, California, 2009. Okeanos –Foundation for the Sea. 29+iii pp.

Table 4: Summary of Alternative Quieting Technologies available for pile driving (4a) and seismic surveys (4b) and their development status

4a: Marine Construction – Pile Driving (Sources; Koschinki and Lüdemann, 2013; CSA Ocean Sciences Inc., 2014, and references therein)

Technology	Description	Emissions	Development Status / Comments
Vibratory pile driving	Vertical oscillation of the pile at a specific low frequency (10-60 Hz) by the use of rotating weights. Often used in combination with impact pile driving	Lower peak pressure levels than impact driving, 15-20 dB. Some broadband sound emitted at higher frequencies between 500 Hz and several KHz.	Proven technology. Routinely used on smaller piles. Total energy imparted can be comparable to impact pile driving as more time is required for installation. Technology for larger piles and deeper water recently developed, but driving would still be required at the start/end of the process (and most installation barges poorly adapted to carry two driving technologies)
Vibrio-drilling	Combination of a vibrator tandem PVE and a drill head in one unit. Pile is driven into the seabed by vibration, drilling is applied when there is resistance to vibration	<130 dB @ 750 m (estimated, not field tested)	Development stage not known
Vertical drilling (and cast-in-place concrete piles)	Drill head is clamped to the pile base and drills a cavity into which the pile sinks. Various technologies currently being developed. Used in combination with impact driving for particular circumstances	In shallow water emitted sound levels are much lower than impact pile driving and continuous levels are lower than those from large vessels	Proven technology for a number of offshore deep foundation applications but some technologies still under development. Sound levels have not been fully documented in offshore conditions.
Press-in-piles	Use of hydraulic rams to push piles into the ground. Self-contained units that use static forces to install piles. Designed for urban areas but also used in shallow waters	Underwater noise measurements not available but sound levels are expected to be very low	Not known for offshore developments
Gravity-based Foundations	Steel-reinforced concrete structures held in place by their weight and supplementary ballast. Excavation of the seabed required by suction hopper dredging for most designs.	No specific sound measurements available but impact pile driving / impulsive noise is eliminated. Main emissions are ship noise and dredging	Proven technology in shallow waters (< 20 m depth). Very limited use in deeper waters but developments are planned for up to 45 m. Generally not competitive with other types of structures beyond depths of 10 metres at the present time. One design, the cranefree gravity foundation is self-installing and does not require dredging or levelling of the seabed. This currently needs testing at the full-scale prototype stage.

Floating Foundations	Three main types: spar, tension leg platform and barge floater. Aimed at expanding wind farms into greater depths. Can involve pile driving to fix anchor points or use gravity base or suction anchors	No specific sound measurements available but no reduction in emissions expected if pile driving is used for anchor installation. For other anchoring systems emissions from gravity base and suction anchors are expected to be similar to gravity and bucket foundation installation respectively.	Currently the least used and least proven method. Mainly at the concept or prototype stage but often based on proven technology from the oil and gas industry
Bucket or suction-based foundations	A large steel caisson that is embedded into the seabed by suction pumps. Water is pumped out of the cavity underneath the caisson – the vacuum in combination with the hydrostatic pressure enables the caisson to penetrate the seabed	No specific sound measurements available but noise levels thought to be negligible as impact pile driving / impulsive noise is eliminated. Noise sources are support ships and the suction pump	A proven technology in the oil and gas industry. Designs for wind farms are currently at the full-scale prototype and demonstration project stage. Suction methods can be used in deep and shallow waters

4b: Seismic Surveys (Sources: CSA Ocean Sciences Inc., 2014 and references therein)

Technology	Description	Emissions	Development Status / Comments
Marine Vibroseis	Hydraulic and electromechanical MV's can be towed in the same configuration as airgun arrays or operated in a stationary mode. MV's have lower source signal rise times, lower peak pressures and less energy above 100 Hz. Electromechanical systems have a number of technical and logistical advantages over hydraulic ones.	Source level: 203 dB re 1µPa; 6-100 Hz. Auditory masking is likely to be more of a problem than with using airguns as signals are for a longer duration and will have a higher duty cycle (% time 'on'). Frequency modulation signals could ameliorate masking.	Electromechanical system licenced for shallow water projected to be available in 2014 depending on recent field tests. Previous hydraulic systems successfully field tested but not cost-effective over the short-term due to expense to retrofit vessels. Proposed 'seavibe' prototype may be reliable and more efficient than airguns. Joint Industry Programme is currently testing and evaluating three different technologies over the next 18 months. Commercial systems are to be built from these three technologies which is anticipated to be completed by 2016
Low Level Acoustic Combination Source (LACS)	The LACS system is a combustion engine producing long sequences of acoustic pulses at a rate of 11 shots/second with low intensity at non-seismic (>100 Hz) frequencies.	Source level: 218 dB re 1µPa at 1 m (peak to peak)	One system is market available and suitable for shallow penetration, towed streamer seismic surveys or vertical seismic profiling. Second system for deeper penetration is under development and needs field testing once built. However, the project is currently on hold and it would take a minimum of 18

			months to build and field test one of these systems
Deep-towed Acoustics/Geophysics System (DTAGS)	Current model uses a Helmholtz resonator source to generate a broadband signal greater than two octaves. Source is extremely flexible enabling changes in waveform and a decrease in sound level to suit specific requirements. Towed 100 m above the seabed at depths down to 6000 m with a sediment penetration of 1 km.	Source level of 200 dB re 1µPa at 1 m. Proximity to the seafloor ensures that impulsive sound levels are minimised in the above water column.	Recent field trials for the single DTAGS in existence. Number of technical and operational disadvantages compared to airguns – mainly less sediment penetration and slower towing speed. Effect on marine fauna in shallow waters thought to be minimal
Low Impact Seismic Array (LISA)	Large array of small, powerful electromagnetic projectors that use a low frequency electromagnetic transducer system. Signal can be well controlled for frequency and directionality	Source level of 223 dB re 1µPa at 1 m possible for a small array according to initial testing	Thought to be suitable for environmentally sensitive areas as there is little or no collateral environmental impact. Development stage not known
Underwater Tunable Organ-Pipe	Pipe is driven by an electro-mechanical piston source to create a tunable Helmholtz resonator capable of large acoustic amplitudes at a single frequency	Not available	Can be deployed to depths of 5000 m. Early prototype stage and only used with frequencies above 200 Hz. (i.e. not suitable for seismic surveys)

- Reduced amplitude – fibre optic receivers on the seafloor have greater sensitivity and achieve a better signal-to-noise ratio than towed conventional sensors which are subject to additional noise in the water column;
- Reduced airgun volume – fibre optic receivers have better low-frequency performance meaning that the requirement for large airgun volumes may be reduced;
- Reduced survey duration – as the receivers are permanently deployed, total survey time is reduced compared to towed streamer surveys because no infill is needed and weather downtime is minimised.

The technology is particularly suited to future use with alternative seismic sources that produce less high frequency output. To accommodate conventional airgun sources the sensors require a large dynamic range at higher frequencies to avoid sensor saturation[96] and these sensors are currently expensive. Combining fibre optic receivers with techniques that emit less high-frequency sound such as marine vibroseis will eliminate the need to use the more expensive sensors.[97]

Noise Limitation Technologies

A number of mitigation techniques have been developed to attenuate noise from activities that generate impulsive sound in the marine environment (Table 5). This section focusses on techniques designed to reduce noise levels from marine construction activities, particularly pile driving (Table 5a) and from seismic surveys (Table 5b). Information sources used to compile the tables were primarily two recent reviews of noise mitigation techniques produced by the U.S.[98] and German[99] Governments, with additional information accessed from recent documents produced by two regional bodies, ACCOBAMS[100] and OSPAR.[101] It should be noted that the information provided here is an overview of existing and developing noise reduction techniques and the information sources mentioned above should be consulted for more detailed information. **Techniques to reduce noise from pile driving** mainly consist of placing a barrier around the pile to attenuate sound from hammering. The barrier can be a solid casing that is drained or filled with a layer of bubbles or other absorptive materials, or a curtain of bubbles. There has been considerable progress in the development of a range of methods to mitigate pile driving noise in recent years. The most commonly used techniques are cofferdams and bubble curtains. Techniques that alter the duration of the noise pulse and the design of the piling hammer are also at the early stages of development (Table 5a).

There have been numerous studies of the effectiveness of bubble curtains for wind turbine foundations, docks and other coastal construction projects and pile driving activities (See CSA Ocean Sciences Inc., 2013[102] for a list of published studies). Big bubble curtains are currently regarded as the best-tested and most proven noise mitigation technique for the foundations of offshore wind farms,[103]

[96] CSA Ocean Sciences Inc., 2013. Quieting Technologies for reducing noise during seismic surveying and pile driving. Information Synthesis. BOEM. 53 pp

[97] Nash, P. and Strudley, A.V. 2010. Fibre optic receivers and their effect on source requirements. In: Weilgart, L.S (ed.), 2010. Report of the workshop on alternative technologies to seismic airgun surveys for oil and gas exploration and their potential for reducing impacts on marine mammals. Monterey, California, 2009. Okeanos –Foundation for the Sea. 29+iii pp

[98] CSA Ocean Sciences Inc., 2013. Quieting Technologies for reducing noise during seismic surveying and pile driving. Information Synthesis. BOEM. 53 pp

[99] Koschinski, S. and Lüdemann, K. 2013. Development of noise mitigation measures in offshore wind farm construction. Federal Agency for Nature Conservation / Bundesamdt für Naturschutz (BfN). 97 pp.

[100]ACCOBAMS 2013. Methodological Guide: Guidance on underwater noise mitigation measures. ACCOBAMS-MOPS/2013/Doc24

[101] OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic. 2014. Draft Inventory of noise mitigation measures for pile driving. Meeting of the Intersessional Correspondence Group on noise (ICG Noise), Gothenburg (Sweden): 29-30 January 2014. ICG Noise 14/6/2-E.

[102] CSA Ocean Sciences Inc., 2013. Quieting Technologies for reducing noise during seismic surveying and pile driving. Information Synthesis. BOEM. 53 pp

[103] Koschinski, S. and Lüdemann, K. 2013. Development of noise mitigation measures in offshore wind farm construction. Federal Agency for Nature Conservation / Bundesamdt für Naturschutz (BfN). 97 pp.

Their suitability has been shown through modelling, field testing and practical application. Additionally, using a double layer of bubbles can be considerably more effective for noise mitigation than a single bubble curtain, Little bubble curtains also have considerable potential and more recent designs of using a ring of vertical hoses or casings are able to prevent bubble drift in tidal currents.[104] Of the three designs mentioned (Table 5a) the curtain of vertical hoses is at the most advanced stage of development. Little bubble curtains have the potential to be applied in commercial offshore settings once the components are adapted to offshore conditions.[105] Modelling of bubble curtain effects has been shown to result in noise reductions that can meet objectives including meeting regulatory noise criteria[106], likely reducing behavioural disturbance of marine mammals[107] and avoiding fish kills.[108]

A variation on the bubble curtain is the Hydro Sound Damper (HSD) which uses a net embedded with small elastic, gas filled balloons and foam to enclose the pile. By varying the balloon size the HSD can be adjusted to achieve maximum noise reduction at particular frequencies. Other advantages over bubble curtains are that the HSD system is very flexible in terms of assembly design to suit different applications, does not rely on compressed air and is less affected by currents or tides.[109]

The known effectiveness and current development status of two recent designs for complex isolation casings (IHC Noise Mitigation System and BEKA Shells) are summarised in Table 5a. These combine the effects of a reflective casing and confined bubble curtains with the principle of cofferdams to reduce noise by absorption, scattering and dissipation.[110] Both systems have been designed primarily for offshore developments and in theory will achieve greater noise reduction than bubble curtains or cofferdams individually. However both systems require further testing in an offshore setting to provide actual emission reduction data that can confirm the modelling predictions.

The potential for technical noise mitigation from pile driving is currently limited by the multipath transmission of the emitted sound waves. Modelling of the relative contribution of propagation pathways (air, water and seismic paths) indicates that the water path propagates the greatest amount of noise and mitigation techniques have therefore focussed on reducing the sound radiation into the water.[111] However, the seismic contribution through the seabed is usually the limiting factor for the effectiveness of mitigating the water path[112] as a considerable amount of sound energy can re-enter the water column via the seismic path. The seismic contribution to overall sound transmission in water is 10-30 dB less than the three paths combined.[113] Therefore the maximum achievable noise reduction for current mitigation techniques is limited to 30 dB unless the seismic path is also attenuated.[114]

[104] Ibid

[105] Ibid

[106] Wilke, F., Kloske, K. and Bellman, M. 2012. ESRa – Evaluation von Systemen zur Rammschallminderung an einem Offshore-Testpfahl. May 2012 (In German with extended abstract in English)

[107] Nehls, G. 2012. Impacts of pile driving on harbour porpoises and options for noise mitigation. In: Symposium on protecting the Dutch whale, Amsterdam, 18 October 2012.

[108] Reyff, J.A. 2009. Reducing underwater sounds with air bubble curtains. TR News 262. P. 31-33.

[109] CSA Ocean Sciences Inc., 2013. Quieting Technologies for reducing noise during seismic surveying and pile driving. Information Synthesis. BOEM. 53 pp

[110] Nehls, G., Betke, K, Eckelmann, S. and Ros, M. 2007. Assessments and costs of potential engineering solutions for the mitigation of the impacts of underwater noise arising from construction of offshore wind farms. BioConsult SH report, Husum, Germany.

[111] OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic. 2014. Draft Inventory of noise mitigation measures for pile driving. Meeting of the Intersessional Correspondence Group on noise (ICG Noise), Gothenburg (Sweden): 29-30 January 2014. ICG Noise 14/6/2-E.

[112] Applied Physical Sciences. 2010. Mitigation of underwater pile driving noise during offshore construction. Final report. Report No. M09PC00019-8

[113] Ibid

[114] Koschinski, S. and Lüdemann, K. 2013. Development of noise mitigation measures in offshore wind farm construction. Federal Agency for Nature Conservation / Bundesamdt für Naturschutz (BfN). 97 pp.

Table 5: **Summary of Noise Limitation Techniques for pile driving (5a) and seismic surveys (5b) and their development status**

5a. Pile driving and associated marine construction activities (dredging and drilling)

Mitigation Technology	**Description**	**Emission Reduction**	**Development Status[1] / Comments**
Big air bubble curtain	A large bubble curtain that usually consists of a pipe with drilled holes placed on the seabed around the whole foundation or structure. Compressed air escaping from the holes forms the bubble screen, shielding the environment from the noise source.	Single bubble curtain: 11-15 dB (SEL), 8-14 dB (peak) [2] Double bubble curtain: 17 dB (SEL), 21 dB (peak)	Proven technology and potential for optimization in terms of handling and system effectiveness (air supply, bubble sizes and distance from source) Double screens reduce emissions more than single ones and are most effective when two separate bubble curtains form Seismic path propagation may be reduced due to the large diameter of the system
Little air bubble curtain (several variations)	More customised smaller curtain that is placed around the noise source in a close fit. Can consist of a rigid frame placed around the source but several designs are possible: Layered ring system – multiple layers of perforated pipes that surround the source in a ring-shaped arrangement Confined bubble curtain – additional casing around the area of rising bubbles. Casing can consist of plastic, fabric or a rigid pipe and does not affect the mitigating properties of the system Little bubble curtain of vertical hoses – vertical arrangement of a number of perforated pipes or hoses around the source	Layered ring system: 11-15 dB (SEL), 14 dB (peak) Confined little bubble curtain: 4-5 dB (SEL) Little bubble curtain with vertical hoses: 14 dB (SEL), 20 dB (peak)	Pilot stage with full-scale tests completed Practical application possible Tidal currents can cause bubble drift and sound leakage but effect can be minimised in more recent designs. Confined bubble curtains initially designed for shallow waters with strong tidal flow All designs do not affect seismic path propagation Vertical hose design prevents sound leakages as there are no horizontal gaps between the hoses
Hydro Sound Damper (HSD)	HSD consists of fishing nets embedded with small latex balloons filled with gas and foam that surround the source. The resonance frequency of the balloons is adjustable, even to low-frequency ranges	4-14 dB (SEL); 17-35 dB (SEL)	Independent of compressed air and not influenced by currents. Easily adaptable to different applications Pilot stage but also commercially applied at one North Sea offshore wind farm

			Further development – additional dampers and net layers; tests to reduce seismic propagation
‘encapsulated bubbles’	Same principle as HSD - balloons of 6-12 cm diameter used to reduce low-frequency components of pile driving noise	Up to 18 dB (singular third octave bands)	Currently under development with a few ‘proof of concept’ field experiments completed
Cofferdam	Rigid steel tube that surrounds the pile from seabed to surface, with the water pumped out between the tube and pile. The air space between the pile and the water column attenuates sound – acoustic decoupling of noise of the pile driving noise within the cofferdam.	Up to 22 dB (SEL), 18 dB (peak) Generally expected to match bubble curtains in terms of noise mitigation	Practical application in many commercial projects in shallow waters (<15 m). Currently at the pilot stage for deeper offshore waters and proposed for depths of at least 45 m. Further developments for offshore underway (e.g. free standing system, telescopic system). Installation likely to require more time than lined barriers or bubble curtains and specialist equipment is needed for offshore developments.
Pile-in-Pipe Piling	Particular type of cofferdam where the cofferdams are the four legs of a foundation. Pile driving occurs above the sea level so that acoustic decoupling is enabled by the construction itself. Requires considerably more material than conventional cofferdams	27 - 43 dB (SEL) – modelled High noise reduction expected	Validated concept stage but is a variation on a proven technique Complete dewatering of cofferdams will be crucial Cofferdams are not reusable as they are part of the foundation
IHC Noise Mitigation System (NMS)	Double layered screen filled with air and a multi-level and multi size confined bubble curtain between the pile and the screen.	5-17 dB (SEL)[2] Noise reduction by NMS predicted to exceed that of a bubble curtain	Bubble curtain is fully adjustable. Proven technology to 23 m depth. Tested in a commercial offshore project but insufficient data available to make reliable conclusions for mitigation performance.
BEKA Shells	Double steel casing with a polymer filling combined with an inner and outer bubble curtain and acoustic decoupling (vibration absorber). Multiple layers create shielding, reflection and absorption effects	6-8 dB (SEL)* Predicted to have the highest noise reduction potential of all techniques presented	Lower end penetrates the seabed to decouple sound transmission along the seismic path. *Available emission reduction data collected in specific problematic circumstances (ESRa Project) Pilot stage completed. Requires full-scale testing in offshore field conditions
Prolongation of pulse	Prolonging the pulse duration of a pile strike will	Models: 4-11 dB (SEL), 7-13 dB	Modelling and experimental stage for large pile

duration	reduce the corresponding sound emission which in principle can be achieved by having an elastic piling cushion between the hammer and pile Disadvantage of a loss of piling force with the use of cushions increasing the total number of strikes	(peak)[2] Piling cushions (various materials): 4-8 dB (SEL)[2]	diameters but proven technology for small pile diameters. In tests micarta (bakelite) was identified as the best option for piling cushion material
Modification of piling hammer	Not specified	Not available	Experimental stage – research results pending

1. With regard to North Sea offshore conditions and water depths to 40 m.

2. Data from several developments or field tests combined

5b. **Seismic surveys** (Source: CSA Ocean Sciences Inc., 2014 and references therein)

Technology	**Description**	**Emission Reduction**	**Development Status / Comments**
Bubble curtains	Evaluation of deploying towed air bubble hoses to reduce lateral noise propagation (BOEM sponsored study)	Initial evaluation; at least 20 dB Second evaluation: bubble curtains were not able to produce the required noise reduction	Desk-based evaluation - advise in 2010 was to not investigate further as little noise, if any, would be attenuated Not practical for deep water and does not block sound when there is a direct line of sight to the source
Parabolic reflectors	Evaluation of the potential to make airgun arrays more vertically directional by towing a parabolic reflector over the array	Potential for large reductions in sound, especially at vertical angles > 70°.	Not recommended for further investigation in 2009 due to a number of limitations (elevated risk in towing and deployment, not effective in shallow water because of bottom reflections)
Airgun silencer	Consists of acoustically absorptive foam rubber on metal plates mounted radially around the airgun	Tests: 0-6 dB (SPL) above 700 Hz but overall increase in SPL of 3 dB due to an increase in sound near 100 Hz	Modest reduction achieved in tests but thought to have potential to improve Regarded as a 'proof of concept' that would require further development in 2007 but later, in 2009, as 'impractical'.
Modification of airguns	Possibility of redesigning airguns to reduce high-frequency sound considered E-source airgun – reduces high-frequency output	Not available Not available	Initially regarded as unfeasible as would require development and testing of a completely new product E-source airgun currently under development

Damping of the seismic path from the embedded section of the pile is currently difficult[115] but needs to be considered if noise mitigation systems are to be improved further[116]. The application of big bubble curtains may enable noise reduction from the seismic path as the large diameter of the mitigation system can extend beyond the distance where seismic path noise re-enters the water column. BEKA shells are also designed to mitigate the noise propagated through the seismic path by penetrating into the seabed and decoupling the sound transmission via this route[117].

A key logistical challenge is minimising the installation time for the noise mitigation system so that the application of such a system is economically feasible[118]. As not all of the available systems have been routinely applied yet it is difficult to predict the length of the installation process with certainty, particularly in offshore settings. Further work is currently aiming to efficiently integrate noise mitigation into the operations[119].

Noise mitigation techniques for seismic surveys have been recently reviewed by the U.S. Government's Bureau of Ocean Energy Management (BOEM)[120]. A number of techniques to reduce lateral noise emissions from airguns have been investigated including the use of bubble curtains and parabolic reflectors, and the development of an airgun silencer or re-designed quieter airguns (Table 5b). However, none of the techniques have been taken much further than the early developmental stages and some have been discontinued. Both bubble curtains and parabolic reflectors were regarded as impractical and ineffective after initial evaluation. Airgun silencers were first thought to have potential as modest levels of noise reduction were measured during tests[121] but then were also later considered to be impractical[122]. Efforts to re-design airguns for the reduction of high-frequency emissions have made more progress than other noise mitigation technique but are still under development. The E-source airgun is currently being developed by Bolt Technology Corporation and WesternGeco[123] but there is no information publicly available to report on current progress[124].

Continuous Sound Mitigation

Long-term measurements of ocean ambient sound have indicated that low frequency anthropogenic noise has been increasing, at least in some parts of the ocean, and this has been primarily attributed to commercial shipping[125][126]. The global merchant fleet is thought to be the greatest contributor to the doubling in background noise levels in the marine environment in every decade over the last 50

[115] Ibid
[116] OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic. 2014. Draft Inventory of noise mitigation measures for pile driving. Meeting of the Intersessional Correspondence Group on noise (ICG Noise), Gothenburg (Sweden): 29-30 January 2014. ICG Noise 14/6/2-E.
[117] Koschinski, S. and Lüdemann, K. 2013. Development of noise mitigation measures in offshore wind farm construction. Federal Agency for Nature Conservation / Bundesamdt für Naturschutz (BfN). 97 pp.
[118] Ibid
[119] Ibid
[120] CSA Ocean Sciences Inc., 2013. Quieting Technologies for reducing noise during seismic surveying and pile driving. Information Synthesis. BOEM. 53 pp
[121] Nedwell, J. and Edwards, B.E. 2005. Initial tests of an airgun silencer for reducing environmental impact. Subacoustech report reference: 644 R 0108. Submitted to Exploration and Production Technology Group, BP Exploration.
[122] Spence, J. 2009. Seismic survey noise under examination. Offshore Magazine 69. Vol. 5.
[123] Weilgart, 2012. Alternative quieter technologies to seismic airguns for collecting geophysical data. In: Abstracts, 3rd International Conference on Progress in Marine Conservation in Europe 2012. Straslund, Germany. Pp. 17-18
[124] CSA Ocean Sciences Inc., 2013. Quieting Technologies for reducing noise during seismic surveying and pile driving. Information Synthesis. BOEM. 53 pp
[125] Andrew RK, Howe BM, Mercer JA, Dzieciuch MA (2002) Ocean ambient sound: comparing the 1960s with the 1990s for a receiver off the California coast. Acoust Res Lett Online 3:65–70
[126] McDonald MA, Hildebrand JA, Wiggins SM, Ross D (2008) A fifty year comparison of ambient ocean noise near San Clemente Island: a bathymetrically complex coastal region off southern California. J Acoust Soc Am 124:1985–1992

years[127]. In some areas there is clear evidence that shipping noise is increasing as the level of ship traffic increases[128].

The main noise sources from ships are those caused by the propeller, by machinery including sea-connected systems (e.g. pumps) and the noise caused by the movement of the hull through the water[129130]. Propeller cavitation is usually the dominant source for large commercial vessels.

Reducing noise production by ships can be achieved through design or operational solutions and a wide range of these are available[131132]. Design alterations are briefly summarised below (Table 6), and considerable further detail for these can be found in the source references. Many of the alterations are designed to improve the propulsive efficiency of the ship. It is thought that existing technology can be used to quieten the noisiest ships which are also currently operating at sub-optimal efficiencies[133] although this is likely to be costly. The main techniques available are improving propeller design to reduce cavitation and match actual operating conditions, and improving the wake flow into the propeller for existing ships or for new-builds. The latter is achievable with relatively little additional cost to the overall price of a vessel[134] and may result in reduced running costs once operational[135]. Retro-fitting existing ships to improve wake flow is also relatively cheap compared to other more substantial design changes. A flow chart that sets out the activities required to reduce underwater noise from commercial shipping[136] is provided in Figure 2.

There are also quieter alternatives to conventional propulsion systems which are not a solution for existing vessels but can be considered when designing new ships for particular uses[137]. Examples are drop thrusters, Z-drives and podded propulsion systems (azipods), waterjets, rim drive propulsion and Voith-Schneider systems[138]. However, there may be other environmental or economic implications in the use of these alternative propulsion systems (e.g. lower fuel efficiency) that should be taken into consideration.

[127] Wright, A.J. (ed.) 2008. International Workshop on Shipping Noise and Marine Mammals, Hamburg, Germany, 21st-24th April 2008. Okeanos - Foundation for the Sea, Auf der Marienhohe 15, D-64297 Darmstadt. 33+v p

[128] Frisk, G.V. 2012. Noiseonomics: The relationship between ambient noise levels in the sea and global economic trends. Sci. Rep. 2:437. doi: 10.1038/srep00437

[129] Leaper, R. and Renilson, M. 2012. A review of practical methods for reducing underwater noise pollution from large commercial vessels. International Journal of Maritime Engineering 154: A79-A88. doi:10.3940/rina.ijme.2012.a2.227?

[130] CSA Ocean Sciences Inc., 2013. Quieting Technologies for reducing noise during seismic surveying and pile driving. Information Synthesis. BOEM. 53 pp.

[131] Wright, A.J. (ed.) 2008. International Workshop on Shipping Noise and Marine Mammals, Hamburg, Germany, 21st-24th April 2008. Okeanos - Foundation for the Sea, Auf der Marienhohe 15, D-64297 Darmstadt. 33+v p

[132] CSA Ocean Sciences Inc., 2013. Quieting Technologies for reducing noise during seismic surveying and pile driving. Information Synthesis. BOEM. 53 pp.

[133] [133] Leaper, R. and Renilson, M. 2012. A review of practical methods for reducing underwater noise pollution from large commercial vessels. International Journal of Maritime Engineering 154: A79-A88. doi:10.3940/rina.ijme.2012.a2.227?

[134] Wright, A.J. 2014. Reducing impacts of human ocean noise on cetaceans: Knowledge gap analysis and recommendations. WWF International, Gland, Switzerland

[135] Leaper, R. and Renilson, M. 2012. A review of practical methods for reducing underwater noise pollution from large commercial vessels. International Journal of Maritime Engineering 154: A79-A88. doi:10.3940/rina.ijme.2012.a2.227?

[136] Ibid

[137] CSA Ocean Sciences Inc., 2013. Quieting Technologies for reducing noise during seismic surveying and pile driving. Information Synthesis. BOEM. 53 pp.

[138] Ibid

Many of the technologies available to reduce noise from the engine and associated machinery are not currently scalable to the sizes needed for commercial shipping. Research programmes are needed to resolve this issue, which has been regarded as a priority for investment.[139]

Table 6. A Summary of Design Noise Reduction Methods for Commercial Ships (after CSA Ocean Sciences Inc. 2013; Leaper and Renilson, 2012)

Source	Technique	Notes
Propeller	Reduced vessel speed	Simple method to reduce the ship's acoustic footprint, but may result in sub-optimal propeller performance –see below
	Modify propeller to match actual use	Most propellers are designed for modelled and not actual, variable operating conditions
	Foul release coating – non-toxic, antifouling coating that improves efficiency	Mixed evidence that there is noise reduction
	Routine maintenance	Repair minor damage / remove marine growth to maintain efficiency and minimise cavitation
	Specially designed propellers and thrusters	Delay and reduce cavitation but effects not independently verified for all designs
	Wake inflow devices and ducted propellers	Improve the wake to reduce cavitation and improve the flow into the propeller
	Propeller hub caps	Reduce hub vortex cavitation and hydroacoustic noise, and improve propeller efficiency
	Altering propeller/rudder interactions	Propeller/rudder interaction has a significant impact on propulsive efficiency. Various concepts
	Anti-singing edge	Modify the propellers trailing edge
	Twin-screw ships – better working conditions for propellers	Reduce propeller cavitation
Machinery	Resilient isolation of equipment	Reduce vibration
	Isolated deck / larger structure	Resiliently mount equipment on one floating deck
	Damping tiles / Spray-on damping	Reduce vibration energy in structures
	Ballast-Crete – pre-blended commercial ballast material	Provides additional damping of structures in contact
	Decoupling materials (e.g. foam rubber or similar)	Applied to hull exterior to reduce radiation efficiency
	Selection of low-noise equipment	Variation between manufacturers
Hull	Well-designed hull form	Good designs require less power for a given speed and provide a more uniform flow into the propeller, increasing its efficiency and improving wake flow
	Asymmetrical afterbody	Improves flow into single screw propellers
	Air bubble system (curtain) along a portion of the hull	Blocks sound transmission from hull (but also from propeller or machinery)

[139] Wright, A.J. 2014. Reducing impacts of human ocean noise on cetaceans: Knowledge gap analysis and recommendations. WWF International, Gland, Switzerland.

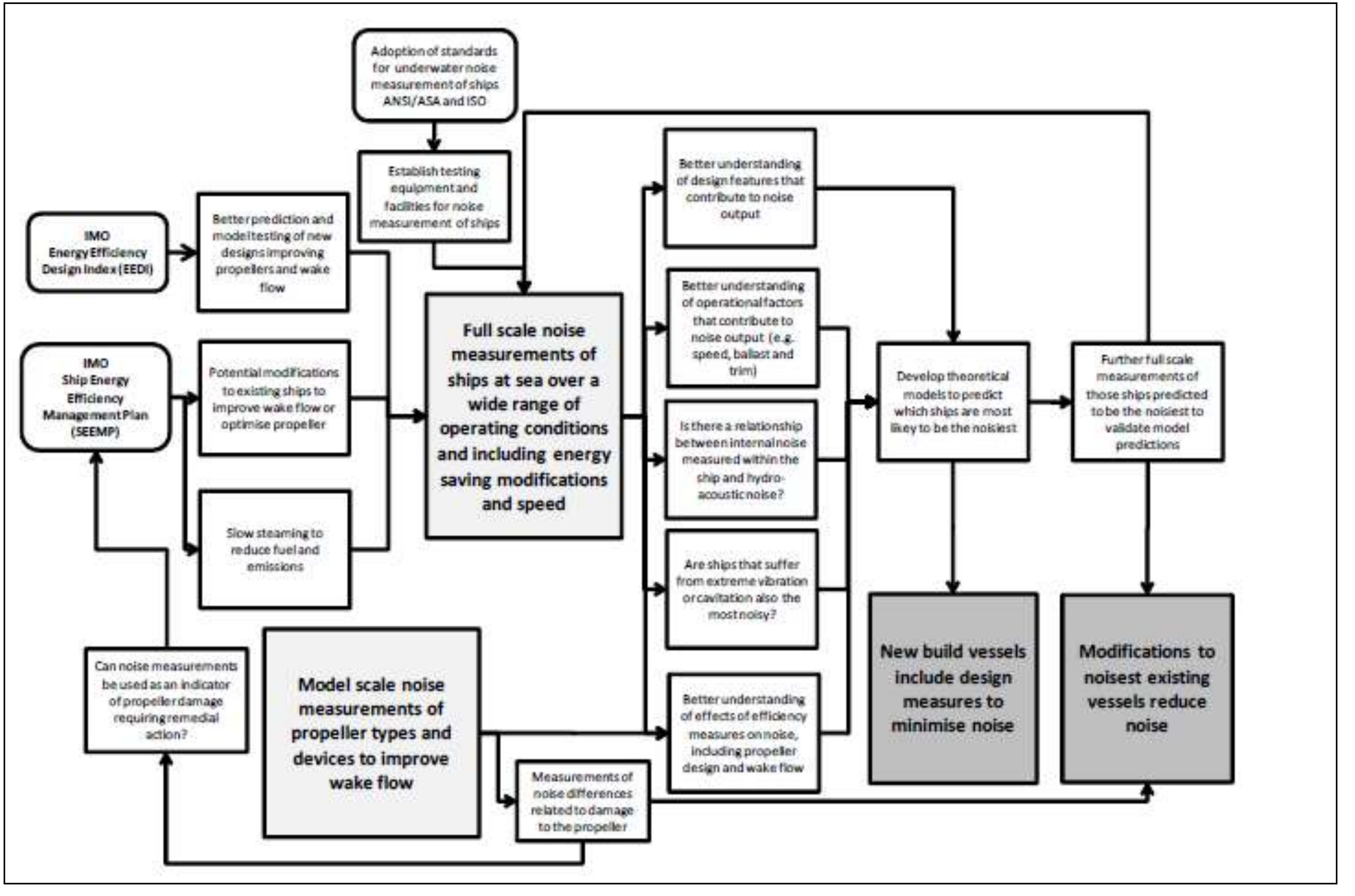

Figure 2. Flow chart of activities required to reduce underwater noise emissions from conventional merchant ships (Leaper and Renilson, 2012)

Operational procedures to reduce noise emissions are mainly concerned with travelling at slower/optimal speeds or ensuring there is routine maintenance of equipment such as propellers. Although slower steaming may require more ships to be operated to carry the same amount of cargo there should be a large reduction in total acoustic emissions associated with slow steaming for most propeller types.[140] Slow steaming can also reduce fuel costs for individual vessels but may mean that ships spend more time in sensitive habitats.

Regulating vessel routing and scheduling[141] may also achieve reductions in ambient noise levels by reducing the density of shipping traffic in certain areas and/or times, such as sensitive habitats or seasons for marine taxa.[142] Re-routing vessels has been suggested to avoid operation in environments that favour long-range transmission[143] such as locations where sound will propagate into the deep sound channel.[144] These locations are where the sound channel intersects bathymetric features such as the continental slope or at high latitudes where it is very close to the surface.[145] Avoiding such areas can be achieved by vessels moving further offshore in some cases (off the continental shelf) but such re-routing will need careful consideration if there is an associated increase in speed or distance travelled[146] (and fuel usage).

Guidelines for minimising underwater noise from commercial ships have been developed by the International Maritime Organization's (IMO) Design and Equipment Subcommittee[147] (annex II). The guidelines mainly focus on considering noise in the design of propellers and hulls, and in the selection of on-board machinery. They also encourage model testing during the design phase and maintenance during operation. The guidelines were adopted by the IMO's Marine Environment Protection Committee at its 66th session, which was held 31 March to 4 April 2014. The guidelines are voluntary and are intended to provide general advice about the reduction of underwater noise to designers, shipbuilders and ship operators. It has been suggested that the adoption of these guidelines will represent acknowledgement of the severity of the issue and represent a substantial step forward in reducing ship noise.[148]

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140 Leaper, R. and Renilson, M. 2012. A review of practical methods for reducing underwater noise pollution from large commercial vessels. International Journal of Maritime Engineering 154: A79-A88. doi:10.3940/rina.ijme.2012.a2.227?

141 Southall, B.L. and Scholik-Schlomer, A. 2008. Final report of the NOAA International Conference: 'Potential application of vessel-quieting technology on large commercial vessels.' 1-2 May, 2007, Silver Spring, MD.

142 CSA Ocean Sciences Inc., 2013. Quieting Technologies for reducing noise during seismic surveying and pile driving. Information Synthesis. BOEM. 53 pp

143 Southall, B.L. and Scholik-Schlomer, A. 2008. Final report of the NOAA International Conference: 'Potential application of vessel-quieting technology on large commercial vessels.' 1-2 May, 2007, Silver Spring, MD.

144 Leaper, R. and Renilson, M. 2012. A review of practical methods for reducing underwater noise pollution from large commercial vessels. International Journal of Maritime Engineering 154: A79-A88. doi:10.3940/rina.ijme.2012.a2.227?

145 McDonald, M.A., Hildebrand, J.A. and Wiggins, S.M. 2006. Increases in deep ambient noise in the Northeast Pacific west of San Nicholas Island, California. J. Acoust. Soc. Am. 120:711-718.

146 Leaper, R. and Renilson, M. 2012. A review of practical methods for reducing underwater noise pollution from large commercial vessels. International Journal of Maritime Engineering 154: A79-A88. doi:10.3940/rina.ijme.2012.a2.227?

147 International Maritime Organisation. 2013. Report to the Maritime Safety Committee and the Marine Environment Protection Committee. DE 57/25/Add.1. Sub-committee on Ship Design and Equipment. Annex 14: Draft MEPC circular on guidelines for the reduction of underwater noise from commercial shipping.

148 Wright, A.J. 2014. Reducing impacts of human ocean noise on cetaceans: Knowledge gap analysis and recommendations. WWF International, Gland, Switzerland

3. Monitoring and Mapping Tools

This section outlines the monitoring and mapping tools currently available or in development to enable the production of acoustic and marine species population maps for a given area. Data needs and the current availability of acoustic and mapping tools are discussed. Monitoring tools include passive acoustic monitoring (PAM), habitat models for marine mammals and real-time marine mammal detection. New monitoring techniques such as the use of thermal imaging are also highlighted.

Acoustic monitoring and modelling is an essential element of noise mitigation for the marine environment both for the assessment of impulsive and continuous sound levels in an area but also for predicting and determining the presence of some marine species in the vicinity of noise generating activities.

Acoustic and Species Distribution Mapping

The development of acoustic mapping tools has made considerable progress in recent years, with a number of tools currently being developed by researchers, mainly for government agencies. These tools are being put together to describe average human-induced noise fields over extended periods of time or over large areas of coastline or open ocean. They can provide powerful visualizations of low frequency contributions from anthropogenic sources and their extent, and also begin to address the scales at which many marine animals actually operate. In combination with tools to characterize the distribution and density of marine animals as well as important management jurisdictions, they can provide important information for risk assessment and for understanding what tools are available to address those risks.[149] However, there is some debate regarding the validity of average noise fields for assessing risk to marine fauna, with further research and development of these tools called for.

Two important tools that are currently being developed in the United States are 'SoundMap' and 'CetSound' by working groups convened by NOAA: the underwater sound-field mapping working group and the cetacean density and distribution mapping working group. SoundMap aims to create mapping methods to depict the temporal, spatial and spectral characteristics of underwater noise. The specific objective of CetMap is to create regional cetacean density maps that are time- and species-specific for U.S. waters using survey and models that estimate density using predictive environmental factors. CetMap is also identifying known areas of specific importance for cetaceans such as feeding and reproductive areas, migratory corridors, and areas in which small or residential populations are concentrated. The SoundMap product will enable predicted chronic noise levels to be mapped for an area over a specific timeframe and facilitate the management of cumulative noise impacts for cetaceans and other taxa. Mapping of more transient and localised noise events from acute sources such as military sonar or seismic surveys can also be undertaken.

Both tools were presented to a range of stakeholders from government and industry as well as research scientists, environmental consultancies and conservation advocacy groups at a symposium in 2012.[150] Discussions at the meeting provided feedback for the working groups on the utility of the products to support planning and management, and also suggested ways to improve the tools such as integrating them with other mapping products to assess risk from multiple stressors and determine cumulative impacts. The use of equivalent, unweighted sound pressures levels (L_{eq}) which are averages of aggregated sound levels was also questioned in that it does not provide sufficient detail to

[149] Leila Hatch pers. comm.
[150] National Ocean and Atmospheric Administration. 2012. Mapping Cetaceans and Sound: Modern Tools for Ocean Management. Final Symposium Report of a Technical Workshop held May 23-24 in Washington, D.C. 83 pp.

show the acoustic conditions experienced by individual animals.[151] It is also not clear whether this is a useful indicator of noise impacts on cetaceans (or other marine fauna) . However it was generally agreed that the products were a useful first step in developing practical tools to map both noise and cetaceans in the marine environment and have great potential as they are further improved. Regular updates of the products are also required to keep them up to date and usable.

There are a number of acoustic propagation modelling tools available for assessing and planning the mitigation of underwater noise impacts in coastal waters, which are regularly used in environmental impact assessments. Two examples in current use in European waters are the Hydro-Acoustic Model for mitigation and Ecological Response (HAMMER)[152] and the Impulse Noise Sound Propagation and Impact Range Estimator (INSPIRE).[153] These tools have been developed primarily for noise generating activities of the marine renewable industry. The HAMMER modelling tool combines a predictive acoustic propagation model with behavioural response models for individual marine species. The INSPIRE tool was developed to specifically model the propagation of impulsive broadband underwater noise in shallow waters. A third modelling tool, the Simple Propagation Estimator and Ranking (SPEAR) model has been developed to rank a number of activities that cause underwater noise in order of their significance, to determine those activities that are likely to have the greatest impact for a particular species.

Another product that is in development is the Subsea Environmental Acoustic Noise Assessment Tool (SEANAT) which provides a range of tools for modelling sound fields associated with underwater noise sources.[154] SEANET has been developed by the Centre for Marine Science and Technology at Curtin University for use in the German Economic Exclusion Zone (EEZ) waters. The product can configure model scenarios, run underwater sound propagation models in realistic acoustic environments, compute received levels and visualise the resulting sound fields. Sound propagation modelling uses two models, RAMGeo, a modified version of the Range-dependent Acoustic Model (RAM) for lower frequencies up to 2 kHz. For higher frequencies (>2 kHz) the Bellhop model is used.

Habitat modelling of cetaceans can also help to inform marine spatial management and planning. Cetacean modelling has considerably advanced in the last decade[155] and near real-time forecasts of distribution[156] are now possible providing highly useful information that can assist in the planning of anthropogenic noise generating activities. Cetacean habitat modelling techniques are also able to predict cetacean densities at fine spatial scales to match the size of operational areas.[157] Densities are estimated as continuous functions of habitat variables such as sea surface temperature, seafloor depth, distance from shore or prey density.[158] Model results have also been collaboratively incorporated into an online mapping portal that uses OBIS-SEAMAP geo-datasets and a spatial decision support system (SDSS) that allows for easy navigation of models by taxon, region or season.[159] The SDSS displays model outputs as colour-coded maps of cetacean density for an area of interest along with a table of densities and measures of precision. The user-friendly online system is designed to enable the application of these habitat models to real world conservation and management issues,[160] although further verification of modelling predictions by ground-truthing is also required.

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[151] Ibid

[152] http://www.hrwallingford.com/projects/predicting-the-impact-of-underwater-noise-on-marine-life

[153] http://www.subacoustech.com/modelling/inspire/

[154] Subsea Environmental Acoustic Noise Assessment Tool (SEANAT) V3-Draft. 2014. SEANAT Manual. 4 January 2014.

[155] Gregr, E.J, Baumgartner, M.F., Laidre, K.L. and Palacios, D.M. 2013. Marine mammal habitat models come of age: the emergence of ecological and management relevance. Endangered Species Research 22: 205-212.

[156] Becker, E.A. and others. 2012. Forecasting cetacean abundance patterns to enhance management decisions. Endangered Species Research 16: 97-112.

[157] Forney, K.A. and others. 2012. Habitat-based spatial models of cetacean density in the eastern Pacific Ocean. Endangered Species Research 16: 113-133.

[158] Redfern, J.V. and others. 2006. Techniques for cetacean-habitat modelling. Marine Ecology Progress Series 310: 271-295.

[159] Best, B.D. and others. 2012. Online cetacean habitat modelling system for the U.S. east coast and Gulf of Mexico. Endangered Species Research 18: 1-15.

[160] Ibid

There are also considerations to develop confirmatory or mechanistic models that will provide more robust and accurate predictions of species distributions that are based on greater ecological understanding[161]. However, mechanistic models do currently have a number of limitations[162] and an incremental iterative process from simple to complex formulations is recommended before spatially explicit models of marine mammal population dynamics incorporating prey abundance and environmental variability can be successfully built.[163]

Mapping the distributions of marine mammals other than cetaceans is required as well as important species from other taxa such as fish, turtles and invertebrates. Scientific fish stock survey data (or reliable fisheries data) are a key source of information to produce species distribution and habitat maps for many marine fishes. These data should be combined with products such as SoundMap to enable spatio-temporal risk assessments that can feed into the marine spatial planning process. Ecosystem-level modelling frameworks for the marine environment that permit the inclusion of human activities should also be considered.[164]

Recent studies in the Mediterranean Sea of Cuvier's beaked whale distribution indicate that modelling tools can be employed for a preliminary risk assessment of 'unsurveyed' areas[165]. *A priori* predictions of beaked whale presence in the Alboran Sea were evaluated using models developed in the Ligurian Sea that use bathymetric and chlorophyll features as predictors. The accuracy of predictions was found to be adequate suggesting that the habitat model was transferable for use in an area different from the calibration site.[166] This study indicates that initial risk assessments may be feasible in data-poor areas if a regional habitat model for a particular species is available for transfer into the 'unsurveyed' site.

Continuous noise pollution has the potential to mask the vocalizations or hearing of marine animals during important activities such as navigating, feeding or breeding.[167] These chronic effects may be more substantial than short-term acute effects over the spatial and temporal extents relevant to marine animals that rely on acoustic communication.[168] There is increasing recognition that sub-lethal impacts such as communication masking or behavioural responses from chronic exposure to sounds are perhaps one of the most important considerations for populations.[169] Communication masking is particularly an issue for baleen whales that rely on low-frequency sounds for major life functions as their communication frequencies overlap with most chronic noise producing activities, particularly from large commercial vessels. It is therefore important to be able to measure continuous noise levels and determine the extent of communication masking for marine fauna such as baleen whales. It should be noted that masking by conspecifics for baleen whales may have been greater prior to commercial whaling when these whales made significant contributions to basin-wide ocean noise levels.[170]

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[161] Palacios, D.M., Baumgartner, M.F., Laidre, K.L. and Gregr, E.J. 2013. Beyond correlation: integrating environmentally and behaviourally mediated processes in models of marine mammal distributions. Endangered Species Research 22: 191-203.
[162] Ibid
[163] International Whaling Commission 2013. Report of the scientific committee. Annex K1: Report of the working group on ecosystems modelling. J. Cetacean Res Manag. 14(Suppl.): 268-272.
[164] Plaganyi, É.E. and others. 2012. Multispecies fisheries management and conservation: tactical applications using models of intermediate complexity. Fish Fish, doi: 10.1111/j.1467-2979.2012.00488.x .
[165] Azzellino, A. et al., 2011. Risk mapping for sensitive species to underwater anthropogenic sound emissions: Model development and validation in two Mediterranean areas. Marine Pollution Bulletin 63: 56-70.
[166] Ibid
[167] See previous information document for a review: CBD Secretariat 2012. Scientific Synthesis on the impacts of underwater noise on marine and coastal biodiversity and habitats. 93 pp.
[168] Hatch, L. T., et al. 2012. Quantifying Loss of Acoustic Communication Space for Right Whales in and around a U.S. National Marine Sanctuary. Conservation Biology 26: 983-994
[169] Normandeau Associates Inc. 2012. Effects of noise on fish, fisheries, and invertebrates in the U.S. Atlantic and Arctic from energy industry sound generating activities. Literature Synthesis. Prepared for the U.S. Department of the Interior, Bureau of Ocean Energy Management
[170] http://ocr.org/pdfs/papers/Stocker_Reuterdahl_Historic_Ocean_noise_levels_Draft.pdf

Tools have been developed to measure communication masking in the marine environment. One example is the assessment of communication space and masking for the endangered North Atlantic right whales in an ecologically relevant area during their peak feeding season on the east coast of the United States.[171][172] Modelling techniques were used to predict received sound levels from vessel and whale sound sources for the area within the frequency band that contains most of the sound energy in whale contact calls. As well as providing techniques to measure and predict the degree of communication masking the tools can be used to support the development of management guidelines, as they provide a method for integrating different quantitative evaluations into a management framework.

Further development of tools to assess masking in other marine taxa such as fish is required. The potential for communication masking in marine fish is considerable[173] with most communication signals in fish falling within a frequency band between 100 Hz and 1 kHz,[174] which overlaps with low frequency shipping noise. It would be useful to develop techniques to translate the effects of masking on ecosystem services[175] for marine taxa, especially marine mammals and fishes. Integration of masking effects into assessments of cumulative impacts from multiple stressors is also required.

Passive and Active Acoustic Monitoring

Passive acoustic monitoring (PAM) can be an effective tool for cetacean detection if used properly and should be included in mitigation procedures during operations, alongside other techniques. PAM is also a useful tool for the collection of baseline data before a project starts and once operations have been completed to monitor long-term patterns of cetacean distribution in the project area. The ability to conduct detailed real-time mitigation and monitoring has improved considerably in recent years with the availability of GIS-based data collection tools such as PAMGUARD[176], SEAPRO and PAM Workstation,[177] LOGGER[178] and WILD.[179] Further information for these PAM tools has been recently summarized in a report by the ACCOBAMS/ASCOBANS joint noise working group (Table 19).[180] Most PAM systems still require human operators to assess incoming sounds although automated detection systems are becoming increasingly viable for some species.[181] However PAM does have a number of limitations,[182][183] although some of these can be addressed.[184] Specifically PAM is unable to:

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[171] Clark, C.W., Ellison, W.T., Southall, B.L., Hatch L., van Parijs, S.M., Frankel, A. and Ponirakis, D. 2009. Acoustic masking in marine ecosystems: intuitions, analyses, and implication. Marine Ecology Progress Series, 395: 201 – 222

[172] Hatch, L. T., et al. 2012. Quantifying Loss of Acoustic Communication Space for Right Whales in and around a U.S. National Marine Sanctuary. Conservation Biology 26: 983-994

[173] CBD Secretariat 2012. Scientific Synthesis on the impacts of underwater noise on marine and coastal biodiversity and habitats. 93 pp.

[174] Popper, A.N. and Hastings, M.C. 2009a. The effects of anthropogenic sources of sound on fish. Journal of Fish Biology, 75: 455 – 489.

[175] Hatch, L. T., et al. 2012. Quantifying Loss of Acoustic Communication Space for Right Whales in and around a U.S. National Marine Sanctuary. Conservation Biology 26: 983-994

[176] PAMGUARD. 2006. PAMGUARD: Open-sourced software for passive acoustic monitoring. www.pamguard.org.

[177] http://www-3.unipv.it/cibra/seapro.html

[178] International Fund for Animal Welfare (IFAW). 2000. Logger: Field data logging software (Version 2000). http://www.marineconservationresearch.co.uk/downloads/logger-2000-rainbowclick-software-downloads.

[179] D'Amico, A., Kyburg, C. and Carlson, R. 2010. Software tools for visual and acoustic real-time tracking of marine mammals. The Journal of the Acoustical Society of America, 128 (4), 237.

[180] Maglio, A. 2013. Anthropogenic noise and marine mammals. Review of the effort in addressing the impact of anthropogenic underwater noise in the ACCOBAMS and ASCOBANS areas. Prepared for the Joint ACCOBAMS-ASCOBANS noise working group. Sinay, Caen, France.

[181] Wright, A.J. 2014. Reducing impacts of human ocean noise on cetaceans: Knowledge gap analysis and recommendations. WWF International, Gland, Switzerland.

[182] Bingham, G. 2011. Status and applications of acoustic mitigation and monitoring systems for marine mammals: Workshop Proceedings; November 17-19, 2009, Boston, Massachusetts. U.S. Dept. of the Interior,

- Accurately measure animal abundance as passive acoustics cannot independently verify the number of animals from which vocalizations originate. Several techniques have been used by field-based researchers to accommodate for this;
- Identify to the species level in some cases – especially for odontocetes. This can be overcome by collecting simultaneous visual observations;
- Determine whether a lack of acoustic communication is associated with the absence of animals that might otherwise be vocalising. Visual observers can confirm the presence of marine mammals in favourable conditions. At night or in adverse weather conditions, marine mammal presence may be detected by thermal imaging of blows.[185]

In addition, subtle variations in marine mammal sounds produced between different populations of the same species can reduce the accuracy of automated detection systems.[186] The orientation of the sound-producing animal in relation to the PAM system can also influence the levels received and therefore the estimated distance to the animal.[187] Although there are issues with using PAM the technology is developing rapidly and becoming a more efficient tool for use in mitigation.

The correct use of PAM is important so that acoustic detection is as accurate and effective as possible. In the past there has been a lack of guidance for PAM implementation and a lack of training programmes for its use.[188] As PAM use becomes more widespread the development and delivery of accredited training programmes across industry is advisable. There are currently no standard qualifications for PAM operators.[189] To be a certified PAM operator, candidates should have sufficient experience of using PAM at sea, as there is no substitute for field experience.[190] A minimum of 20 weeks of PAM use at sea has been suggested.[191] Detailed guidance on the qualifications, training standards and conduct of PAM operators and MMOs are available as a series of Marine Mammal Observer Association (MMOA) position statements.[192]

The use of PAM to detect non-mammal marine fauna is questionable as vocalizations by fish and invertebrates are quieter than those of marine mammals. Specific PAM systems used in noise

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Bureau of Energy Management, Regulation, and Enforcement, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEMRE 2011-002. 384 pp.

[183] Gill, A. et al. 2012. Marine Mammal Observer Association: Position Statements. The key issues that should be addressed when developing mitigation plans to minimise the effects of anthropogenic sound on species of concern. Version 1 (Consultation document). 32 pp. Marine Mammal Observer Association, London, U.K. http://www.mmo-association.org/position-statements

[184] Carduner, J. 2013. Best Practises for baseline passive acoustic monitoring of offshore wind energy development. Research Thesis. Duke University. 41 pp.

[185] Zitterbart, D.P., Kindermann, L., Burkhardt, E. and Boebel, O. 2013. Automatic round-the-clock detection of whales for mitigation from underwater noise impacts. PLoS ONE 8(8): e71217. doi: 10.1371/journal.pone.0071217. 6 pp.

[186] Wright, A.J. 2014. Reducing impacts of human ocean noise on cetaceans: Knowledge gap analysis and recommendations. WWF International, Gland, Switzerland.

[187] Ibid

[188] Weir, C. R. and Dolman, S.J. 2007. Comparative review of the regional marine mammal mitigation guidelines implemented during industrial seismic surveys, and guidance towards a worldwide standard. Journal of International Wildlife Law and Policy. 10: 1-27.

[189] Bingham, G. 2011. Status and applications of acoustic mitigation and monitoring systems for marine mammals: Workshop Proceedings; November 17-19, 2009, Boston, Massachusetts. U.S. Dept. of the Interior, Bureau of Energy Management, Regulation, and Enforcement, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEMRE 2011-002. 384 pp.

[190] Ibid

[191] Gill, A. et al. 2012. Marine Mammal Observer Association: Position Statements. The key issues that should be addressed when developing mitigation plans to minimise the effects of anthropogenic sound on species of concern. Version 1 (Consultation document). 32 pp. Marine Mammal Observer Association, London, U.K.

[192] Ibid

mitigation procedures that can detect the presence of fishes have not yet been developed[193] although the use of passive acoustics for fisheries monitoring and assessment is an active and growing research field.[194][195]

Active acoustic monitoring (AAM) techniques are more applicable for non-vocalising marine fauna such as fish, turtles and invertebrates and also for non-vocalising marine mammals. However, AAM systems can often only detect animals at closer ranges than passive monitoring but are able to estimate the range of targets more easily. The use of active acoustic systems will, however, add sound energy to the marine environment which, unless the frequency used is above the range perceived by a species, may have behavioural effects on some taxa, particularly marine mammals, and increase the occurrence of stress and masking responses. The use of AAM is not recommended for marine mammals, except in the case of mitigating single loud sounds such as explosives where they can be used simultaneously as an alarming device.[196] The potential effects of AAM on other marine taxa also need to be investigated.

Real-time Automated Monitoring

Large-scale real-time passive monitoring of the marine acoustic environment can provide information on both continuous and impulsive noise production as well as detecting the presence and location of vocalising marine taxa such as marine mammals. 'Listening to the Deep Ocean Environment' (LIDO) is an international project that can monitor marine ambient noise in real-time over large spatial and temporal scales.[197] Acoustic information is collected at cabled deep sea platforms and moored stations in multiple sites associated with national or regional observatories. The software has several dedicated modules for noise assessment, detection, classification and localization.[198] Data is processed to produce outputs that can characterise an acoustic event as well as spectrograms for quick visualisation and compressed audio. The outputs are publicly available via a website[199] and can be viewed with a specific application.

The main approach used for LIDO is to divide the recording bandwidth into frequency bands that cover the acoustic niche of most cetacean species and apply a set of detectors and classifiers. This information is then used by localisation and tracking algorithms to monitor the presence and activity of cetaceans. This acoustic detection, classification and localization (DCL) system has the potential to be used as a mitigation tool for some offshore noise generating activities and has the advantages of being a fully automated system that can operate in all conditions (sea state, day/night) with no specialist operators required. However it is not currently being used to its full potential and requires further development to increase spatial coverage and facilitate uptake by industry.

4 Management Frameworks and International Agreements

This section provides information on a range of management frameworks currently in use or proposed to manage underwater noise pollution. These include the use of spatio-temporal restrictions (STRs) to protect marine fauna from noise pollution as part of a wider marine spatial planning approach and the use of impact or risk assessment frameworks. The recent progress made by various management or

[193] Normandeau Associates Inc. 2012. Effects of noise on fish, fisheries, and invertebrates in the U.S. Atlantic and Arctic from energy industry sound generating activities. Workshop Report. Prepared for the U.S. Department of the Interior, Bureau of Ocean Energy Management

[194] Gannon, D.P. 2008. Passive acoustic techniques in fisheries science: a review and prospectus. Transactions of the American Fisheries Society 137: 638-656.

[195] Luczkovich, J.J., Mann, D.A. and Rountree, R.A. 2008. Passive acoustics as a tool in fisheries science. Transactions of the American Fisheries Society 137: 533-541

[196] Wright, A.J. 2014. Reducing impacts of human ocean noise on cetaceans: Knowledge gap analysis and recommendations. WWF International, Gland, Switzerland.

[197] Andre, M., ven der Schaar, M., Zaugg, S., Houegnigan, L., Sanchez, A.M. and Castell, J.V. 2011. Listening to the Deep: live monitoring of ocean noise and cetacean acoustic signals. Mar Poll Bull 63:18-26

[198] Ibid

[199] http://listentothedeep.com/acoustics/index.html

regulatory frameworks at the regional and international level that are non-statutory (e.g. ACCOBAMS/ASCOBANS/CMS, OSPAR, HELCOM), or legally-binding (e.g. EU MSFD, IMO) to address underwater noise pollution is also summarized.

Spatio-temporal restrictions, including marine protected areas, are regarded by some as one of the most effective ways of protecting cetaceans and their habitat from the cumulative and synergistic effects of noise and other anthropogenic stressors.[200][201][202] Avoiding sound production when vulnerable marine fishes or invertebrates are present has also been recommended.[203] The use of spatio-temporal restrictions (STRs) to protect marine mammals and other taxa from noise pollution and other stressors has been strongly endorsed with the proposal of a conceptual framework for STR implementation.[204] However, the size of marine areas to be protected from noise is a major concern as sound can propagate great distances in the marine environment, especially at low frequencies.[205] For example, for intense mid-frequency sounds to be excluded from areas tens of kilometres away from critical cetacean habitats would require an STR of 100-1000 km^2 while protection from intense low frequency sounds could require distances of hundreds of kilometres and STR areas of at least 10 000 to 100 000 km^2.[206] The use of noise-based STRs as part of marine spatial planning frameworks requires that managers have a certain level of background information for the species of concern and their preferred habitats for activities such as breeding / spawning or feeding. Information on the timing, location, type and intensity of proposed noise generating activities is also needed to evaluate the level of risk to marine fauna in the region if spatial restrictions are not permanent.

Modelling, in combination with field research, is required to further support the identification of particular concentrations of noise sensitive species[207] and their critical habitats. In cases where important habitat is still relatively quiet, acoustic refuges have been suggested to prevent noisy activities affecting those areas. The use of chronic ocean noise or masking metrics within marine spatial planning frameworks has been suggested to help prioritise the protection of important habitats for noise sensitive species, particularly quieter locations.[208] These quiet areas include, for example, areas within fjords on the west coast of Canada, which are important habitat for noise-sensitive cetaceans. [209] Increased knowledge of the presence of small, range-limited populations is also recommended, along with the closure of identified areas to activities that generate high levels of noise.[210] Setting population- or environmental-level targets for minimizing the effect of noise as part

[200] Weilgart, L.S. 2006. Managing Noise through Marine Protected Areas around Global Hot Spots. IWC Scientific Committee (SC/58/E25).

[201] Dolman, S.J. 2007. Spatio-Temporal Restrictions as Best Practise Precautionary Response to Ocean Noise. J. Int. Wildlife Law & Policy 10.3: 219-224.

[202] Agardy, T., Aguilar, N., Cañadas, A., Engel, M., Frantzis, A., Hatch, L., Hoyt, E., Kaschner, K., LaBrecque, E., Martin, V., Notarbartolo di Sciara, G., Pavan, G., Servidio, A., Smith, B., Wang, J., Weilgart, L., Wintle, B. and Wright, A. 2007. A Global Scientific Workshop on Spatio-Temporal Management of Noise. Report of the Scientific Workshop. 44 pages.

[203] Normandeau Associates Inc. 2012. Effects of noise on fish, fisheries, and invertebrates in the U.S. Atlantic and Arctic from energy industry sound generating activities. Literature Synthesis. Prepared for the U.S. Department of the Interior, Bureau of Ocean Energy Management

[204] Agardy, T., et al., 2007. A Global Scientific Workshop on Spatio-Temporal Management of Noise. Report of the Scientific Workshop. 44 pages

[205] Wright, A.J. 2014. Reducing impacts of human ocean noise on cetaceans: Knowledge gap analysis and recommendations. WWF International, Gland, Switzerland

[206] Agardy, T., et al.,. 2007. A Global Scientific Workshop on Spatio-Temporal Management of Noise. Report of the Scientific Workshop. 44 pages

[207] Simmonds, M.P. et al., 2014. Marine Noise Pollution – Increasing recognition but need for more practical action. Journal of Ocean Technology 9.1: 70-90.

[208] Williams, R. et al., 2013. Acoustic quality of critical habitats for three threatened whale populations. Animal Conservation Print ISSN 1367-9430

[209] Ibid

[210] Simmonds, M.P. et al., 2014. Marine Noise Pollution – Increasing recognition but need for more practical action. Journal of Ocean Technology 9.1: 70-90.

of spatial prioritization approaches could act as an incentive to reduce noise levels in critical habitats for acoustically sensitive species.[211]

An example of a STR to manage underwater noise in combination with other stressors for a threatened, resident and sensitive species of beaked whale is the Gully MPA, a submarine canyon, off Nova Scotia on the east coast of Canada. The Gully MPA Management Plan describes four priority conservation issues, one of which is the protection of whales from the impact of human activities, with fisheries and hydrocarbon exploration identified as important stressors that required more focussed management attention.[212] The regulations for the Gully MPA also include a ‘vicinity clause’ that addresses concerns that harmful impacts could be caused by transboundary stressors and may therefore be a powerful legal tool to prevent potential threats of activities adjacent to the protected area.

Management Frameworks

Management frameworks for the marine environment include underwater noise management and mitigation as part of a broader approach to control the impacts of anthropogenic stressors on marine biodiversity, often within an ecosystem-based management approach. These frameworks include marine spatial planning approaches and assessments of the level of risk or impact for species as part of broader strategic environmental assessments (SEAs) or environmental impacts assessments (EIAs). Risk and impact assessments are usually estimating effects on species at the population level rather than the individual level.

A framework for the systematic prioritization of noise mitigation for cetaceans was developed and proposed during the global scientific workshop on spatio-temporal management of noise[213] (Table 7). The framework consists of six steps and draws heavily on the general principles identified in the conservation planning and adaptive management literature.[214] Although published in 2007 it is still valid for use in noise mitigation today and contains some similar recommendations for mitigation practises provided in recent publications.[215] The six step process could also be tailored to suit other marine taxa such as vulnerable species of fish, turtle or invertebrate.

Table 7: A Framework for systematic prioritization of noise mitigation (for cetaceans) (adapted from Agardy et al., 2007)

Step	Notes
1. Define the goal(s), constraints and geographic scope of the planning process	Key requirements of the goal on which prioritization can be structured are: clear geographic scope, a measurable conservation target, the desired degree of confidence, and a measure of social opportunity costs. Crucial to the transparency of the project and helps engage all stakeholders
2. Identify relevant data and data gaps	Spatial information on species habitat distributions, threats (e.g. areas of seismic exploration) and socio-economic information (e.g. current jurisdictional boundaries). Sufficient data is seldom available for all species and all social aspects) Urgent data collection may be needed but usually preferable to proceed with

[211] Williams, R. et al., 2013. Acoustic quality of critical habitats for three threatened whale populations. Animal Conservation Print ISSN 1367-9430
[212] VanderZwaag, D.L. and Macnab, P. 2011. Marine Protected Areas: Legal Framework for the Gully off the coast of Nova Scotia (Canada). IUCN-EPLP No. 81 26 pp.
[213] Agardy, T., et al.,. 2007. A Global Scientific Workshop on Spatio-Temporal Management of Noise. Report of the Scientific Workshop. 44 pages
[214] Ibid
[215] Nowacek, D. et al., 2013. Responsible practises for minimizing and monitoring environmental impacts of marine seismic surveys with an emphasis on marine mammals. Aquatic Mammals 39: 356-377.

	data that is available and use expertise and modelling to make decisions
3. Synthesise habitat and threat data to generate exposure ranking maps	Identify areas of overlap between biodiversity value and threats to those values e.g. Threat maps may be species-specific or general. Weighting of particular species of concern or interest can be applied.
4. Generate map of mitigation priority areas	Integrate exposure maps from 3. With spatial data on existing opportunities and impediments, opportunity costs and any other relevant spatial information. Commonly associated with systematic conservation planning algorithms that can be used to produce an 'optimal' solution e.g. the most effective protection for a species or habitat for the least cost. Committee processes (Delphi methods) can be used instead of algorithms for less complicated situations
5. Identify and prioritise actions for priority conservation zones	Action prioritization is necessary as conservation budgets are finite. Use a coherent and transparent approach with a respected prioritization protocol that incorporates the concepts of conservation benefit, feasibility and cost efficiency, to prioritise actions
6. Implement and monitor	Ensure that monitoring data is integrated back into the decision making process to enable adaptive management. This requires good coordination between managers and scientists Monitoring is central to the success of the adaptive prioritization framework Design monitoring programme in advance to allow monitoring prior to implementation

In the United States a national policy[216] was signed in 2010 to strengthen ocean governance and coordination, establish guiding principles for ocean management and adopt a flexible framework for effective coastal and marine spatial planning (CMSP) to address conservation, economic activity, user conflict and sustainable use of the marine environment in U.S. waters.[217] The National Ocean Policy recommends the development of regional assessments that include descriptions of the existing biological, chemical, physical and historic characteristics; identification of sensitive habitats and areas; identification of areas of human activities; analyses of ecosystem conditions, and assessments, forecasts and modelling of cumulative impacts.[218]

To inform marine spatial planning and other processes such as environmental impact assessments, several national-scale systems were developed including Ocean.Data.Gov and the NOAA CMSP Data Registry. The Ocean.Data.Gov system is dedicated to coastal and marine scientific data and aims to build capacity in the development of spatial data, data standards, mapping products and decision support tools. These information platforms feed into NOAA's Integrated Ecosystem Assessment (IEA) framework which is regarded as a promising approach to ecosystem-based management and a leading example of a comprehensive ecosystem-based assessment.[219] The IEA framework consists of five components: 1. Scoping, 2. Identifying indicators and reference levels, 3. Performing risk analyses, 4. Evaluating management strategies and, 5. Monitoring and evaluating progress towards

[216] National Policy for the Stewardship of the Oceans, Coasts and Great Lakes.
[217] National Ocean and Atmospheric Administration. 2012. Mapping Cetaceans and Sound: Modern Tools for Ocean Management. Final Symposium Report of a Technical Workshop held May 23-24 in Washington, D.C. 83 pp.
[218] Interagency Ocean Policy Task Force. 2010. Final recommendations of the Interagency Ocean Policy Task Force. White House Council on Environmental Quality.
[219] Foley et al., 2013. Improving ocean management through the use of ecological principles and integrated ecosystem assessments. BioScience 63:619-631.

management goals. The framework has been widely implemented in U.S. waters[220] and also in the North Sea.[221]

Undertaking risk or impact assessments is a key part of ecosystem-based management and conservation planning. Quantitative risk assessment techniques that could be applicable for the assessment of underwater noise effects in combination with other impacts include the use of population viability analysis (PVA). This technique is commonly used to quantify the probability that a species will decline to an unacceptably low population size within a particular timeframe.[222] To date PVA has not been widely used to assess noise impacts and the viability of populations of marine fauna under a range of management scenarios.

A framework to assess risk to indicator species in coastal ecosystems has been tested in Puget Sound, WA, USA.[223] The framework can identify land- or sea-based activities that pose the greatest risk to key species of marine ecosystems, including marine mammals, fishes and invertebrates. Ecosystem-based risk is scored according to two main factors: the exposure of a population to an activity and the sensitivity of the population to that activity, given a particular level of exposure. The framework is scalable, transparent and repeatable and can be used to facilitate the implementation of EBM, including integrated ecosystem assessments and coastal and marine spatial planning.[224] In the Puget Sound case study the combined effects of four human activities – coastal development, industry, fishing and residential land use – were assessed for seven indicator species: two marine mammals, four fish and one invertebrate. The framework offers a rigorous yet straightforward way to describe how the exposure of marine species to human stressors interacts with their potential to respond under current and future management scenarios.[225] The applicability of this framework to assess the risk of noise effects for marine species requires consideration.

A risk assessment framework specifically addressing underwater noise impacts for marine mammals is also available[226] and could be adapted for other marine taxa. The framework consists of a four-step analytical process: 1. Hazard Identification, 2. Dose-response assessment, 3. Exposure assessment, and 4. Risk characterization. A fifth step, risk management, involves the design and application of mitigation measures to reduce, eliminate or rectify risks.[227] A decision flow and information pathway for the framework is presented in Figure 3. The decision pathway contains a feedback loop involving mitigation when the risk exceeds the trigger level indicating that an adaptive approach to managing risk is taken.

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[220] www.noaa.gov.iea

[221] International Council for the Exploration of the Sea. 2011. Report of the working group on integrated assessments of the North Sea (WGINOSE). ICES Report no. ICES CM 2011/SSGRSP:02.

[222] Burgman, M.A., Ferson, S. and Akçakaya, H.R. 1993 Risk assessment in conservation biology. Chapman and Hall, London.

[223] Samhouri, J.F. and Levin, P.S. 2012. Linking land- and sea-based activities to risk in coastal ecosystems. Biological Conservation. 145: 118-129

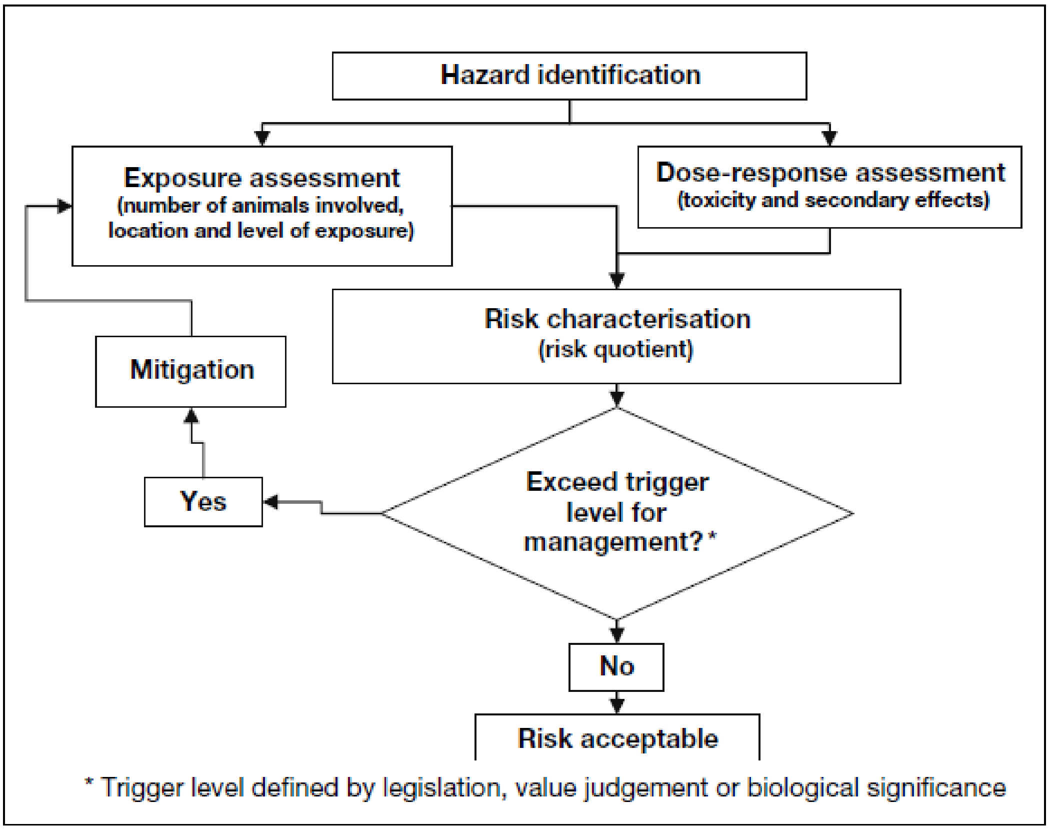
[224] Ibid.

[225] Ibid

[226] Boyd, I., 2008. The effects of anthropogenic sound on marine mammals. A draft research strategy. Report Produced from the Joint Marine Board-ESF and National Science Foundation (US) Workshop at Tubney House on October 4–8, 2005.

[227] Ibid.

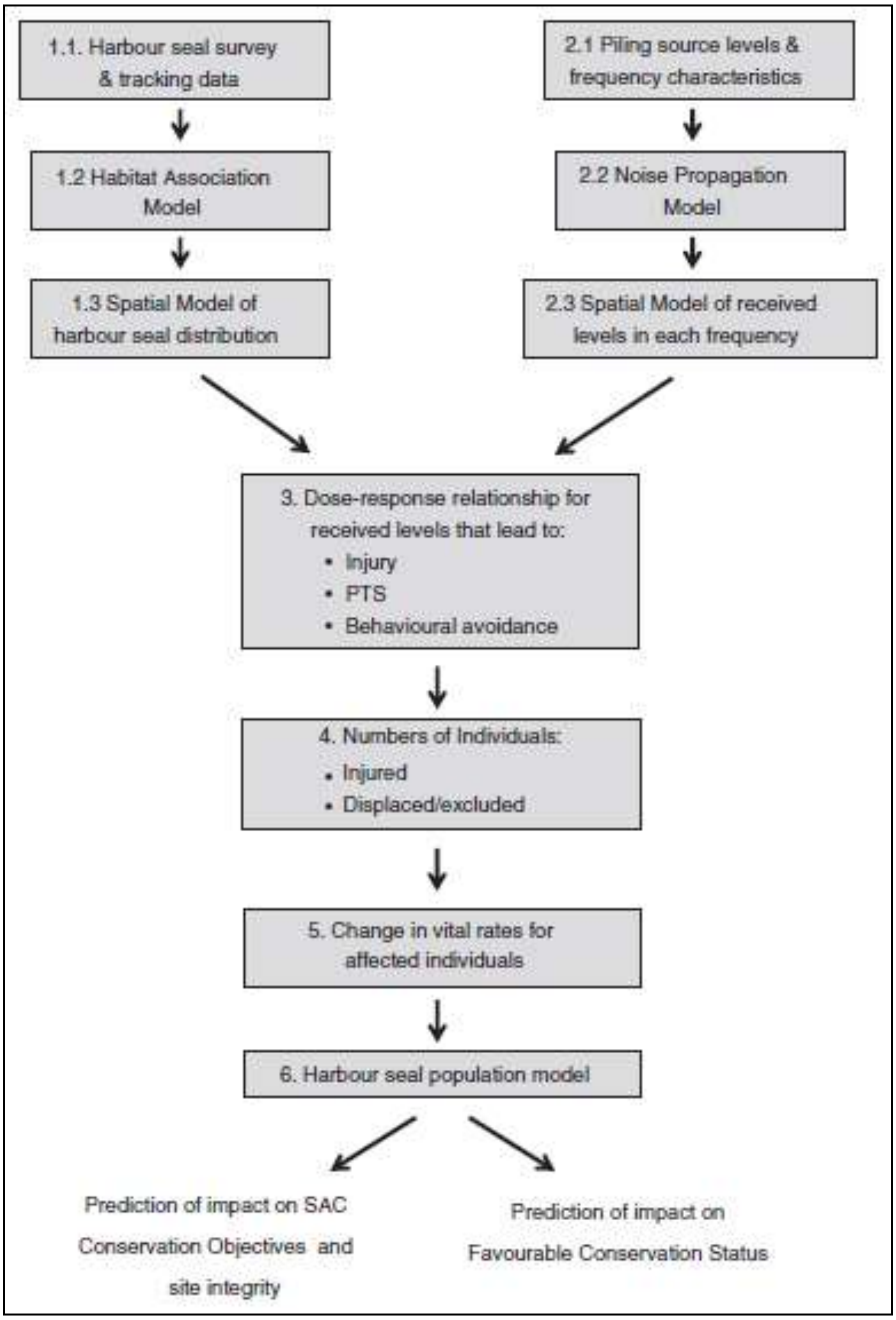
Figure 3. Illustration of the information flow and decision pathway for a risk assessment process (Boyd et al., 2008).



A current best practise example of an assessment framework to explore the long-term impact of a noise generating activity on a marine mammal has recently been published.[228] In this case it is the impact of pile-driving from wind farm construction on a harbour seal population within a Special Area of Conservation (SAC) under the European Community's Habitats Directive. Spatial patterns of seal distribution and received noise levels were integrated with available data on the potential impacts of noise to predict the number of individuals that would be displaced or experience auditory injury. Then expert judgement was used to link these impacts to changes in vital rates (fecundity and survival) and applied to population models that compare population changes under baseline and construction scenarios over a 25 year period.[229] A schematic of the approach taken is provided below (Figure 4):

[228] Thompson, P.M. et al., 2013. Framework for assessing the impacts of pile-driving noise from offshore wind farm construction on a harbour seal population. Environmental Impact Assessment Review 43: 73-85.
[229] Ibid.

Figure 4. Schematic of the approach used to assess the impact of wind farm construction on the harbour seal in a Special Area of Conservation (SAC) and with Favourable Conservation Status (FCS). (after Thompson et al., 2013)



The framework can be used to provide preliminary guidance on how developers should assess the population consequences of acoustic disturbance from construction activities in the marine environment. There was considerable uncertainty for some parts of the analysis, particularly for the number of animals that were displaced from the area or experienced Permanent Threshold Shift (PTS) and how this affected individual fitness.[230] The latter was completely dependent on expert judgement. It was deemed most appropriate to use expert judgement in the short-term for certain parameters, but in the long-term use of the Population Consequences of Acoustic Disturbance (PCAD) framework[231]

[230] Ibid
[231] NRC, 2003. Ocean Noise and Marine Mammals. Washington, DC. National Academies, 2003.

is recommended as more information becomes available and uncertainty is reduced. Development of the framework relied heavily on the availability of detailed information on harbour seal populations in the locality which also makes the case study a suitable opportunity to develop detailed PCAD studies in the future.[232]

The modelling framework could also suitable for use on other less studied harbour seal populations, although it may be necessary to 'borrow' data such as fecundity estimates from better studied populations or possibly other seal species.[233] It is important to recognise that, due to the level of uncertainty and the use of conservative estimates for some individual parameters, this assessment framework is assessing worst-case impacts. Conservatism accumulates through the framework leading to more significant short-term impacts than is thought to be likely.[234] However, the framework does offer an alternative interim approach that can provide regulators with confidence that proposed developments will not significantly affect the long-term integrity of marine mammal populations, in this case the harbour seal.

The use of mitigation and management frameworks over the whole lifetime of a proposed noise generating activity has been highlighted in Section 1.

Regional and International Agreements

This section provides a brief overview of the current progress regarding the regulation, mitigation and management of underwater noise under the jurisdiction of regional and international agreements.

EU MSFD

The European Union Marine Strategy Framework Directive (EU MSFD) is the most developed legal response to underwater noise to date. The MSFD is a legally-binding large-scale monitoring framework for the marine environment of EU Member States with set indicators and targets. The MSFD requires that Member States put in place the necessary management measures to achieve Good Environmental Status (GES)[235] in their marine waters by 2020. GES is described by 11 high –level descriptors, with Descriptor 11[236] covering underwater noise. Member States are required to apply an ecosystem-based approach to the management of human activities to ensure that the capacity of the marine ecosystem to respond to human-induced changes is not compromised. For ambient underwater noise the current recommendations are to monitor two 1/3-octave frequency bands (63 and 125 Hz) targeting areas of intensive shipping activity.[237] A proposed register of high amplitude impulsive noise (e.g. pile driving, seismic surveys) can act as a proxy indicator of high-amplitude acoustic disturbance.[238] However, there are some concerns that many marine mammal habitats may not be included in monitoring programmes and that there is no specific requirement for long-term monitoring of the acoustic impact of activities on marine mammal populations.[239] Focussing on high shipping

[232] Thompson, P.M. et al., 2013. Framework for assessing the impacts of pile-driving noise from offshore wind farm construction on a harbour seal population. Environmental Impact Assessment Review 43: 73-85.

[233] Caswell, H., Brault, S., Read, A.J. and Smith, T.D. 1998. Harbor porpoise and fisheries: an uncertainty analysis of incidental mortality. Ecol. Appl. 8: 1226-1238.

[234] Thompson, P.M. et al., 2013. Framework for assessing the impacts of pile-driving noise from offshore wind farm construction on a harbour seal population. Environmental Impact Assessment Review 43: 73-85.

[235] Good Environmental Status means the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations (MSFD 2008/56/EC Article 3(5)).

[236] Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.

[237] Van der Graaf, A. et al., 2012. European Marine Strategy Framework Directive – Good Environmental Status (MSFD GES): Report of the Technical Subgroup on Underwater Noise and other forms of energy.

[238] Ibid.

[239] Merchant, N.D., et al., 2014. Monitoring ship noise to assess the impact of coastal developments on marine mammals. Marine Pollution Bulletin 78: 85-95

density areas may mean that significant changes to the marine acoustic environment in less polluted areas, which could contain critical habitats, are overlooked.[240]

There have been several pieces of relevant work conducted in the context of the EU Marine Strategy Framework Directive (Dir. 2008/56/EC):

1. Report on Underwater noise and other forms of energy (April 2010)[241]

This document takes stock of the (limited) knowledge on the effects of underwater energy, particularly noise, and especially at any scale greater than the individual/group level. The report contains much scientific background information and has suggestions for possible indicators for noise, as well as on the assessment of the effects of electromagnetic fields and heat on the marine environment.

2. Report of the Technical Subgroup on Underwater Noise and other forms of energy (February 2012)[242]

This is the report of an expert group (TSG Noise) established to help EU Member States implement relevant indicators. The Group focussed on clarifying the purpose, use and limitation of these indicators and on the description of a methodology that would be unambiguous, effective and practicable.

3. Monitoring guidance for underwater noise in European Seas (November 2013) [243]

This document provides guidance on how to monitor loud impulsive noise and ambient noise on a regional seas basis in European waters. The report consists of three parts: Part 1, Executive summary and Recommendations; Part 2, Monitoring Guidance Specifications; and Part 3, Background Information and Annexes.

The monitoring guidance for impulsive noise provides details on the requirements to meet EU MSFD indicator 11.1.1 to determine the spatio-temporal distribution of loud, low and mid frequency impulsive sounds. This involves setting up a register of the occurrence of impulsive sounds to establish the current level and trends at a Regional Sea level. The indicator is designed to address the cumulative impact of sound generating activities and possible associated displacement that is ‘considerable’[244] and may lead to population effects. All sources that have the potential to cause a significant population level effect are to be included in the register, including explosives and military activities. A series of minimum thresholds were derived for each of the sound generating activities over which the sound emission must be recorded in the register (except for pile driving where all activities are recorded). The register will provide member states with a quantified assessment of the spatial and temporal distribution of impulsive noise sources, throughout the year in regional seas. This will enable States to establish baselines for current levels and then use the register to help manage impulsive noise levels, assist in marine spatial planning and mitigation requirements to minimise displacement.

The monitoring of ambient noise is covered by indicator 11.2.1 which requires the monitoring of trends in ambient noise in two 1/3 octave bands centred at 63 and 125 Hz or whichever frequencies are appropriate to a member state’s area. Levels and trends will be derived from a combined use of measurements, models and sound maps to enable cost-effective and reliable trend estimation. Guidance is also provided to member states on monitoring strategy and for the reporting of results.

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[240] Ibid.

[241] Tasker, M.L, M. Amundin, M. Andre, A. Hawkins, W. Lang, T. Merck, A. Scholik-Schlomer, J. Teilmann, F. Thomsen, S. Werner & M. Zakharia. 2010 Marine Strategy Framework Directive. Task Group 11. Report Underwater noise and other forms of energy.

[242] Van der Graaf, S. et al. 2012. European Marine Strategy Framework Directive – Good Environmental Status (MSFD GES): Report of the Technical Subgroup on Underwater Noise and other forms of energy

[243] Monitoring Guidance for Underwater Noise in European Seas – Executive Summary. 2nd Report of the Technical Subgroup on Underwater Noise (TSG Noise) November 2013

[244] Displacement of a significant proportion of individuals for a relevant period and at a relevant spatial scale

Relevant work also emerges from the context of EU conservation law, in particular the Habitats Directive (Dir. 92/43/EEC). In this context, Guidelines for the establishment of the Natura 2000 network in the marine environment have been developed which, inter alia, address the issue of noise pollution (pp. 94-96) in relation to provisions in Articles 6 and 12 of the Directive.

There are also several on-going EU-funded research projects that are addressing issues relevant to underwater noise:

- Baltic Sea Information on the Acoustic Soundscape (BIAS);[245]
- Environmental Impact of Noise, Vibrations and Electromagnetic Emissions from Marine Renewables (MaRVEN);[246][247]
- Impacts of noise and use of propagation models to predict the recipient side of noise. This study was commissioned by DG Environment and results should become available in the second half of 2014;[248]
- In the Science for Environment Policy series, the Commission recently published an issue on underwater noise which takes stock of relevant research.[249]

IMO

In 2008 following a submission on 'the development of non-mandatory technical guidelines to minimize the introduction of incidental noise from commercial shipping operations into the marine environment to reduce potential adverse impacts on marine life' to the Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO) it was suggested that the issues should be discussed by the IMO. Given this suggestion, the MEPC agreed to commence the work programme on "Noise from commercial shipping and its adverse impacts on marine life" and to establish an intersessional correspondence group with a view to identifying and addressing ways to minimize the introduction of incidental noise into the marine environment from commercial shipping to reduce the potential adverse impact on marine life. More in particular, the MEPC agreed to develop voluntary technical guidelines for lower noise technologies as well as potential navigation and operational practices.

After thorough discussions, the guidelines were adopted by the IMO's Marine Environment Protection Committee at its 66th session, which was held 31 March to 4 April 2014.

OSPAR

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the OSPAR Convention) has set up an Intersessional Correspondence Group on Noise (ICG Noise) under the OSPAR Committee of the Environmental Impact of Human Activities (EIHA). The ICG Noise initially focussed on the monitoring of impulsive and ambient noise but also on primary and secondary noise mitigation measures. For the latter the group is currently developing an inventory of noise mitigation measures with priority given to pile driving, seismic activities and explosions. Other sources and activities that will be considered within the inventory are high frequency impulsive noise from echosounders, dredging activities, sonar and shipping. The inventory will provide an overview of the effectiveness and feasibility of mitigation options and help to support OSPAR EU member states in establishing programmes of measures in relation to underwater noise under the European Marine Strategy Framework Directive (MSFD).

OSPAR recently had a meeting of the Intersessional Correspondence Group on Underwater Noise in Gothenburg, Sweden, on 29-30 January 2014 where mitigation was on the agenda. A draft document on mitigation of pile driving noise was presented and discussed, which will be part of the OSPAR

[245] http://biasproject.wordpress.com/
[246] http://www.dhigroup.com/News/2014/01/15/DHILedConsortiumWinsFlagshipEuropeanProjectOnUnderwaterNoise.aspx (short description)
[247] http://cordis.europa.eu/projects/%0bhome_en.html (pending)
[248] http://ec.europa.eu/environment/marine/
[249] http://ec.europa.eu/environment/integration/research/newsalert/pdf/FB7.pdf

Inventory of noise mitigation strategies. The draft inventory of noise mitigation measures for pile driving is based upon a longer report compiled by Germany.[250] Outcomes of the meeting will be made available on the OSPAR website.[251] Work on other areas of noise mitigation to be included in the inventory is being developed in 2014.

HELCOM

The Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention or HELCOM) stipulates (under Regulation 2 of Annex VI) that parties must use the best available technology and best environmental practise to prevent and eliminate pollution, including noise, from offshore activities.

At the HELCOM Ministerial Meeting in Moscow in 2010, the parties agreed to "develop common methodologies and appropriate indicators, to facilitate national and coordinated monitoring of noise and identification of sources of noise and to further investigate the potential harmful impacts to wildlife from noise".[252]

In its capacity as the coordinating platform for the regional implementation of the EU MSFD in the Baltic Sea for those Contracting Parties that are also EU members, HELCOM initiated work to develop HELCOM core indicators which are harmonized with MSFD Descriptors under the HELCOM-CORESET project.

In October 2013, at the HELCOM Ministerial Meeting in Copenhagen[253] the parties agreed that "the level of ambient and distribution of impulsive sounds in the Baltic Sea should not have negative impact on marine life and that human activities that are assessed to result in negative impacts on marine life should be carried out only if relevant mitigation measures are in place, and accordingly as soon as possible and by the end of 2016, using mainly already on-going activities, to:

- Establish a set of indicators including technical standards which may be used for monitoring ambient and impulsive underwater noise in the Baltic Sea;
- Encourage research on the cause and effects of underwater noise on biota;
- map the levels of ambient underwater noise across the Baltic Sea;
- Set up a register of the occurrence of impulsive sounds;
- Consider regular monitoring on ambient and impulsive underwater noise as well as possible options for mitigation measures related to noise taking into account the on-going work in IMO on non-mandatory draft guidelines for reducing underwater noise from commercial ships and in CBD context."

At the meeting of the HELCOM Monitoring and Assessment Group in November 2013, the parties shared information about their national activities and projects dealing with underwater noise. There was discussion about how to carry out further regional work on development of an underwater noise indicator and monitoring and it was agreed that as a first step for establishing a foundation for monitoring of noise, HELCOM should make use of the outcomes of the Baltic Sea Information on Acoustic Soundscape project (BIAS), in which several HELCOM countries are involved. An intercessional activity has been initiated with the view that there will be a thematic session on underwater noise (based on preparations by and material from the intercessional activity) at the next meeting of the HELCOM Monitoring and Assessment Group (to be held in Oslo, Norway on 8-10 April 2014).

BIAS is an EU LIFE+ funded project with the ultimate goal to secure that the introduction of underwater noise is at levels that do not adversely affect the marine environment of the Baltic Sea.

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[250] Koschinski, S. and Lüdemann, K. 2013. Development of noise mitigation measures in offshore wind farm construction. Federal Agency for Nature Conservation / Bundesamdt für Naturschutz (BfN). 97 pp.
[251] http://www.ospar.org/v_meetings
[252] HELCOM 2010 Moscow Ministerial Declaration
[253] HELCOM Copenhagen Ministerial Declaration

BIAS will work towards this goal by bridging the gap between the MSFD descriptor 11 and actual management of human-induced underwater noise. Objectives of the project include:

- Demonstration of national and regional advantages of a transnational approach for management of underwater noise
- Initial assessment of underwater noise in the Baltic Sea
- Implementation of a planning tool for straightforward management of intermittent underwater noise sources
- Establishment of draft Baltic Sea standards and tools for management of underwater noise

Underwater noise is regarded as a priority on the HELCOM agenda although the work is still at an early stage.

CMS/ASCOBANS/ACCOBAMS – Joint Noise Working Group

The Joint CMS/ASCOBANS/ACCOBAMS Noise Working Group (Joint NWG) consists of members and observers of the scientific and advisory bodies of the Convention on Migratory Species (CMS), the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS) and Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS). External experts also participate in the Joint NWG to ensure the best possible advice can be generated for Parties.

The Joint NWG presents reports on progress and new information to each meeting of the CMS Scientific Council, ACCOBAMS Scientific Committee and ASCOBANS Advisory Committee. It addresses the mandates of relevant resolutions for all three organizations including CMS Res 9.19, CMS Res. 10.24, ACCOBAMS Res 3.10, ACCOBAMS Res. 4.17, ASCOBANS Res. 6.2 and ASCOBANS Res 7.2 and any new relevant resolutions not yet passed.

In 2013 the Joint NWG produced three main reports to present recent activities of its work programme:

1. Anthropogenic noise and marine mammals. Review of the effort in addressing the impact of underwater noise in the European Union

This document presents reviews of the political effort from international bodies (resolutions, regional agreements etc.), existing guidelines from these bodies and implementation by countries, and existing mitigation technologies. Future actions to strengthen the effectiveness of mitigation measures are also provided.

2. Implementation of underwater noise mitigation measures by industries: operational and economical constraints

This is a report on consultations with industries and military authorities within the French Maritime Cluster which involved discussions on five main topics: marine renewable energies, sonar and seismic, marine traffic and dredging, fisheries, and marine protected areas. The consultations provided a better understanding of the mitigation procedures that are actually implemented and which measures have technical and economic constraints.

3. Guidance on Underwater Noise Mitigation Measures

This is a working document that provides guidance to industries and country authorities on the application of noise mitigation measures. It outlines noise mitigation practises and technologies that should be used for dealing with major sources of impulsive noise as identified by the European Commission's Technical Subgroup on underwater noise (TSG Noise)[254].

[254] Van der Graaf, S. et al. 2012. European Marine Strategy Framework Directive – Good Environmental Status (MSFD GES): Report of the Technical Subgroup on Underwater Noise and other forms of energy.

The Joint NWG has recently been addressing the development of guidance for the whole duration of impulsive noise generating operations (pre-operation assessment and planning, implementation and post-operation evaluation) with an emphasis on seismic surveys and the need for a more rigorous assessment stage as part of EIAs or SEAs.

5. Setting Standards and Guidelines for measurement of underwater noise

This section provides information on the current status of efforts to set global standards (ISO) for acoustic measurements of anthropogenic noise in the marine environment. The need for standards, limits and guidelines for a range of noise-related procedures that concern the marine environment is also highlighted. These include the setting of standards for environmental impact assessments (EIAs) and for mitigation procedures undertaken by Government and/or Industry regarding noise generating activities such as seismic surveys or naval sonar. International harmonization of ways to define underwater noise exposure criteria is also included.

National and International Standards

The development of standards for the measurement and assessment of underwater noise only began quite recently. Previously measurements were made by a number of organizations using different techniques and with different methods of extrapolation to determine the source level.[255] In 2009 a voluntary consensus standard for the measurement of underwater noise from ships was developed by the American National Standards Institute (ANSI) and the Acoustical Society of America (ASA). The standard describes measurement procedures and data analysis methods to quantify the underwater radiated noise level from a vessel referenced to a normalised distance of 1m. Three different standards are specified according to the level of precision needed.

In December 2011 The International Standards Organisation's (ISO) Technical Management Board established a new subcommittee: TC 43/SC 3, underwater acoustics. The Secretariat of the subcommittee is provided by the ASA acting on behalf of the ANSI. The scope of the subcommittee is:

'*Standardization in the field of underwater acoustics (including natural, biological, and anthropogenic sound), including methods of measurement and assessment of the generation, propagation and reception of underwater sound and its reflection and scattering in the underwater environment including the seabed, sea surface and biological organisms, and also including all aspects of the effects of underwater sound on the underwater environment, humans and aquatic life'*.

ISO standards are of a voluntary nature for use by industry as appropriate, and developed based on the demand of industry. The ISO underwater acoustics subcommittee contains three working groups (WG) that are predominantly working on the following subjects:

WG1 Measurement of noise from ships

WG2 Underwater acoustic terminology

WG3 Measurement of radiated noise from marine pile driving

Under a separate subcommittee ISO TC8/SC2, Marine Environment Protection, the standard ISO 16554 – Ship and marine technology – Measurement and reporting of underwater sound radiated from merchant ships – deep-water measurement, was published in 2013. The standard provides shipyards, ship owners and ship surveyors with an easy to use and technically sound measurement method for underwater sound radiated from merchant ships for use at the final delivery stage of ships. The measurement method should be carried out in a short duration (within a few hours) possibly during

[255] Leaper, R. and Renilson, M. 2012. A review of practical methods for reducing underwater noise pollution from large commercial vessels. International Journal of Maritime Engineering 154: A79-A88. doi:10.3940/rina.ijme.2012.a2.227?

the official sea trial of the target ship after the completion of construction and before delivery. Classification societies may issue a notation on the underwater sound level radiated from the ship under survey using the measurement results conducted according to ISO 16554.

A 'sister' standard, ISO 16554-2 Ship and marine technology – Measurement and reporting of underwater sound radiated from merchant ships – shallow-water measurement, is currently under development.

The ISO underwater acoustics subcommittee has also developed the standard ISO/PAS 17208-1:2012, Acoustics – Quantities and procedures for description and measurement of underwater sound from ships – Part 1: General requirements for measurements in deep water

ISO/PAS 17208-1:2012 describes the general measurement systems, procedures and methodologies to be used to measure underwater sound pressure levels from ships at a prescribed operating condition. It presents a methodology for the reporting of one-third-octave band sound pressure levels. The resulting quantities are the sound pressure levels normalized to a distance of 1 m. The underwater sound pressure level measurements are performed in the geometric far field and then adjusted to the 1 m normalized distance for use in comparison with appropriate underwater noise criteria.

Other standards that are under the direct responsibility of the acoustics subcommittee are ISO/CD 18405, Underwater acoustics – Terminology and ISO/CD 18406, Underwater acoustics – Measurement of radiated noise from marine impact pile driving. Both standards are currently at the committee stage.

A number of other subjects have been discussed by the acoustics subcommittee including a standard for measuring ambient noise, measurement standards for explosions or air gun pulses, and other potential future work items including the measurement of underwater sound from active sonars, underwater sound propagation modelling, measurement of the underwater sound field and underwater noise mapping.

Work on the development of acoustic standards is also being carried out in Europe with a focus on acoustic monitoring in relation to the environmental impact of offshore wind farms in the North Sea. European countries that border this sea are collaborating to develop standards and definitions of quantities and units related to underwater sound.[256] These metrics were then used for the development of standardised measurement and reporting procedures, aimed specifically at acquiring the relevant acoustic data for assessing the impact of the construction, operation and decommissioning of offshore wind farms on marine life.[257]

Setting other forms of standards for the mitigation and management of underwater noise has been proposed. These include the:

- Mandatory use of comprehensive Environmental Impact Assessments[258] (or Strategic Environmental Assessments) for any proposed impulsive noise generating activity in the marine environment;
- Setting of measurement standards for particle motion, of sound in the near field, and of ground transmission of sound;[259]
- Standardization of the design of behavioural data collection to make results comparable[260]

[256] Anon. 2011. Ainslie, M.A. (ed.). The Hague: TNO report TNO-DV 2011 C235. Standard for measurement and monitoring of underwater noise, Part I: Physical Quantities and their units. 67 pp.

[257] de Jong, C.A.F., et al. 2011. The Hague: TNO report TNO-DV 2011 C251. Standard for measurement and monitoring of underwater noise, Part II: Procedures for measuring underwater noise in connection with offshore wind farm licensing. 56 pp.

[258] Prideaux, G. and Prideaux, M. 2013. Seismic Seas: Understanding the impact of offshore seismic petroleum exploration surveys on marine species. Wild Migration technical and policy review #3. Wild Migration, Australia.

[259] Lucke, K. et al. 2013. Report of the Workshop on International Harmonization of Approaches to Define Underwater Noise Exposure Criteria. Budapest, Hungary, August 2013. IMARES –Institute for Marine Resources and Ecosystem Studies. Report No. C197.13

- Standardisation of monitoring data formats to improve data quality and robustness for use in research and evaluation;[261]
- Generic standardisation of the main phases of impulsive noise generating activities – pre-operation planning and assessment, implementation and mitigation, post-operation evaluation and reporting;
- International standardisation of mitigation procedures and measures for naval exercises using active sonar;[262]
- Use of training standards for operational activities e.g. MMOs or PAM operators;[263]
- Setting of regional standards for cumulative noise mapping and marine spatial planning;[264]
- Uptake of transparency and accountability standards by noise generating operators to ensure best practise is followed and information that is not commercially sensitive is made available to inform management;[265]
- Setting of data sharing standards for online data banks of acoustic, environmental and ecological information.[266]

6. Conclusions and Recommendations

Considerable progress has been made in the last decade to mitigate the effects of underwater noise produced by industry, particularly for seismic surveys and offshore construction techniques such as pile driving. Detailed mitigation measures and procedures have been developed for use by these industries, which are on the whole designed for marine mammals. Particular examples of best practise are the mitigation and monitoring plans and procedures implemented to protect gray whales from the effects of seismic surveys[267] and the use of mandatory exposure levels for pile driving in Germany which catalysed the production of new mitigation technologies by the offshore energy industry.[268]

However, although best practise exists it is often non-mandatory and not used to a standard level by industry or the military. For example, although mitigation measures for active sonar are taken during non-strategic exercises by navies, in some cases, no measures apart from MMO and PAM protocols are taken in strategic exercises.[269] The debate between national security needs versus the welfare and

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[260] Ibid.
[261] Ibid.
[262] Dolman, S. J., Weir, C.R., and Jasny, M. 2009. Comparative review of marine mammal guidance implemented during naval exercises. Marine Pollution Bulletin 58 pp. 465-477
[263] Gill, A. et al. 2012. Marine Mammal Observer Association: Position Statements. The key issues that should be addressed when developing mitigation plans to minimise the effects of anthropogenic sound on species of concern. Version 1 (Consultation document). 32 pp. Marine Mammal Observer Association, London, U.K.
[264] Lucke, K. et al. 2013. Report of the Workshop on International Harmonization of Approaches to Define Underwater Noise Exposure Criteria. Budapest, Hungary, August 2013. IMARES –Institute for Marine Resources and Ecosystem Studies. Report No. C197.13
[265] Prideaux, G. and Prideaux, M. 2013. Seismic Seas: Understanding the impact of offshore seismic petroleum exploration surveys on marine species. Wild Migration technical and policy review #3. Wild Migration, Australia.
[266] Lucke, K. et al. 2013. Report of the Workshop on International Harmonization of Approaches to Define Underwater Noise Exposure Criteria. Budapest, Hungary, August 2013. IMARES –Institute for Marine Resources and Ecosystem Studies. Report No. C197.13
[267] Nowacek, D. et al., 2013. Responsible practises for minimizing and monitoring environmental impacts of marine seismic surveys with an emphasis on marine mammals. Aquatic Mammals 39: 356-377.
[268] Koschinski, S. and Lüdemann, K. 2013. Development of noise mitigation measures in offshore wind farm construction. Federal Agency for Nature Conservation / Bundesamdt für Naturschutz (BfN). 97 pp
[269] Maglio, A. 2013. Implementation of underwater noise mitigation measures by industries: operational and economic constraints. Prepared for the Joint ACCOBAMS-ASCOBANS noise working group. Sinay, Caen, France.

security of vulnerable marine fauna continues. A minimum level of mitigation by navies on all military exercises that can be verified by independent observers is desirable. It is important to note that depth finding sonar is a form of active sonar, and that its use is pervasive, widespread and largely unregulated.

Noise exposure thresholds and management measures are beginning to move away from a reliance on received level (RL) thresholds to a broader ecosystem-level assessment of the cumulative and synergistic impacts of both multiple impulsive noise sources and increased levels of ambient noise. However, it has been suggested that, at the present time, most mitigation measures are not very effective in reducing the aggregate impact of underwater noise on marine mammals,[270] let alone on other marine taxa. It is not currently possible to demonstrate that existing measures are effective in mitigating cumulative and multiple impacts. Considerable further development of techniques to assess cumulative impacts of underwater noise is required and this 'overall noise impact' also needs to be considered alongside other multiple stressors affecting marine taxa.

There have been some advances made in considering how noise affects animal behaviour and whether a proposed noise generating activity will have an impact on a population. Researchers, working together with regulators and industry, are developing and testing new monitoring and mitigation practises that take into consideration some of the more obvious behavioural effects on marine mammals such as displacement.[271] These assessment frameworks are still at a relatively early stage and have to rely on a number of assumptions to determine behavioural effects as there are often insufficient data available for populations to use more quantitative techniques. Considerable data gathering is needed, particularly for the measurement and recognition of behavioural effects on marine taxa and the determination of noise impacts at the population level. In particular a far greater understanding of the more subtle behavioural effects (e.g. communication masking, stress responses, cognitive bias, fear conditioning, and attention and distraction) on marine taxa and how these influence populations is needed.[272] Such knowledge can then feed into the development of improved mitigation practises to minimise or prevent chronic impacts on marine fauna at the population level.

Improvements in technology and processing capacity have enabled substantial advances in real-time mitigation and monitoring procedures for impulsive noise generating activities, mainly for marine mammals although this has also highlighted the need for meticulous planning and implementation of mitigation practises facilitated by clear and practical communication protocols. Mapping tools to show acoustic characteristics of a particular area or the presence and distribution of species of concern are becoming more available to assist in marine spatial planning and the development of mitigation frameworks.

Spatio-temporal management of underwater noise at the regional level should focus on eliminating harmful levels of anthropogenic sound from locations and times that are critically important to sensitive marine fauna such as feeding, spawning and nursery grounds. If a noise generating activity is permitted within range of a sensitive area then mitigation practises of the highest standard[273] are required to ensure disturbance to the species of concern is prevented or kept to an acceptable level. As well, risk assessments can also inform the development of appropriate and proportional responses to the threat.

Wildlife protection laws and species recovery plans can be useful tools for protecting species against the threat of underwater noise. For example, under Canada's Species at Risk Act (SC 2002, c 2), acoustic habitat of two threatened populations of resident killer whales must be protected as a result of court decisions. The Federal Court of Appeal decision expressly endorsed the finding that critical

[270] Wright, A.J. 2014. Reducing impacts of human ocean noise on cetaceans: Knowledge gap analysis and recommendations. WWF International, Gland, Switzerland
[271] Thompson, P.M. et al., 2013. Framework for assessing the impacts of pile-driving noise from offshore wind farm construction on a harbour seal population. Environmental Impact Assessment Review 43: 73-85.
[272] Wright, A.J. 2014. Reducing impacts of human ocean noise on cetaceans: Knowledge gap analysis and recommendations. WWF International, Gland, Switzerland
[273] Nowacek, D. et al., 2013. Responsible practises for minimizing and monitoring environmental impacts of marine seismic surveys with an emphasis on marine mammals. Aquatic Mammals 39: 356-377

habitat is not just a geophysical area but also a set of attributes that includes acoustics, water quality, and availability of prey. Subsequent protection statements or protection orders must offer non-discretionary legal protection to all of those elements and attributes of critical habitat.

For many of the advances highlighted above for improving noise mitigation there has been an ongoing focus on a limited number of marine taxa, notably marine mammals and particularly cetaceans. This can be justified to a certain extent given their often vulnerable conservation status and high sensitivity. However, considerably less is known about noise impacts on other taxa such as marine fishes, reptiles and many invertebrate groups. These all require greater attention in terms of fundamental research on noise effects on individuals and populations and the development of specific mitigation measures and procedures for non-mammalian marine fauna. This is especially required for keystone species within marine ecosystems and for those that significantly contribute to providing ecosystem services. Identifying key species that are sensitive and vulnerable to underwater noise and developing best practise to mitigate the impacts of noise for these taxa should be prioritised. Noise impacts on non-mammal marine fauna are beginning to receive greater attention in terms of research and general recognition but at the present time there are still more questions than answers.[274]

The development of internationally accepted standards for the measurement of underwater noise produced by anthropogenic activities started relatively recently. Although progress is slow and considered, it is being made and should be encouraged. A range of standards will be required to cover noise emissions for the various anthropogenic activities in the marine environment.

A recent review of noise mitigation for cetaceans provides a range of recommendations for both the main activities that produce unwanted sound emissions and for regulatory bodies responsible for managing the marine environment.[275] These are summarised in Table 8 and their applicability to other marine taxa is also highlighted. Numerous recommendations were also made in a recent report by the ACCOBAMS / ASCOBANS joint noise working group[276] and these have also been incorporated into Table 8.

The recommendations include specific mitigation measures for the main noise generating activities in the marine environment, acoustic and biological research priorities and measures to improve the sharing of information to facilitate best practise for mitigation planning and implementation. The vast majority of the recommendations are applicable to marine taxa other than mammals. However in some cases there is insufficient knowledge to effectively implement a particular measure even though it is likely to reduce noise levels for species of marine fish or invertebrates. Further research, risk analysis and debate are required to determine acceptable levels for many non-mammal species for both impulsive and continuous noise. It should be noted that these recommendations may not be applicable to all jurisdictions, according to current national legally-binding measures for underwater noise management and mitigation.

More long-term strategic recommendations have also recently been made regarding underwater noise mitigation.[277] These include the reduction of the underlying demand for noise producing activities including through improved energy efficiency and the development and increased use of alternative technology.

Secondly, increasingly strict noise level standards for all noise producing activities should be phased in by regulatory bodies in order to drive innovation to reduce noise at the source. This has been evident in Germany where mandatory noise exposure standards for wind farm installation have

[274] Normandeau Associates Inc. 2012. Effects of noise on fish, fisheries, and invertebrates in the U.S. Atlantic and Arctic from energy industry sound generating activities. Literature Synthesis. Prepared for the U.S. Department of the Interior, Bureau of Ocean Energy Management

[275] Wright, A.J. 2014. Reducing impacts of human ocean noise on cetaceans: Knowledge gap analysis and recommendations. WWF International, Gland, Switzerland.

[276] Maglio, A. 2013. Anthropogenic noise and marine mammals. Review of the effort in addressing the impact of anthropogenic underwater noise in the ACCOBAMS and ASCOBANS areas. Prepared for the Joint ACCOBAMS-ASCOBANS noise working group. Sinay, Caen, France.

[277] Wright, A.J. 2014. Reducing impacts of human ocean noise on cetaceans: Knowledge gap analysis and recommendations. WWF International, Gland, Switzerland.

fuelled technical innovation and the development of mitigation techniques to attempt to meet the standard.[278] Setting lower noise level standards will help to address behavioural and other non-injurious effects of noise on marine fauna both in proximity to acute sources and at greater distances. Other ways and means to drive innovation should also be explored such as the use of incentives to implement the use of new quieter technologies by industry.[279] Continuing the dialogue between industry, regulators, the scientific community and non-governmental organisations can help to identify appropriate incentives and facilitate change to improve noise management.

[278] Koschinski, S. and Lüdemann, K. 2013. Development of noise mitigation measures in offshore wind farm construction. Federal Agency for Nature Conservation / Bundesamdt für Naturschutz (BfN). 97 pp

[279] CSA Ocean Sciences Inc. 2014. Quieting Technologies for Reducing Noise during Seismic Surveying and Pile Driving Workshop. Summary Report for the US Dept. of the Interior, Bureau of Ocean Energy Management BOEM 2014-061. Contract Number M12PC00008. 70 pp. + apps.

Table 8. Recommendations to improve the mitigation and management of underwater noise for marine mammals, but also relevant for other marine taxa (adapted from Wright, 2014; Maglio, 2013).

Domain	Recommendation / Action	Applicable to Non-Mammal taxa?
General	Implement proactive area-based management efforts where sufficient data are available (e.g. time-area closures, MPA establishment)	Yes
	Include environmental considerations at the very early stages of project planning	Yes
	Prioritise the collection of necessary biological data to support area-based determinations in data-deficient regions.	Yes
	Noise generating activities in data-deficient areas are to be undertaken with caution	Yes
	Consider the implementation of buffer zones around established protected areas to ensure noise levels with these areas do not go beyond acceptable levels	Yes
	Address cumulative and synergistic impacts from multiple stressors through appropriate cumulative impact assessment and management	Yes
	Adopt protocols that encourage cooperation within industry in the preparation of cumulative impact assessments so that all potential impacts are known in advance	Yes
	Identify ways to limit the combined impacts of human activity on marine mammal populations to prevent population decline	Yes
	Incorporate the level of uncertainty into any established legal noise thresholds	Yes
	Identify and quantify understudied noise sources such as high powered active transducers (Echosounders, various sonars)	Yes
	Improve knowledge of acoustic biology and of the distribution, abundance and life history of marine mammal species, especially endangered and data-deficient species	Yes
	Quantify noise effects on marine mammals at the population level	Yes
	Establish or enhance direct linkages between the scientific community, the private sector and regulators to exchange information on best available practises and technologies and also the effectiveness of mitigation measures during operations	Yes -
Oil and Gas Industry (seismic surveys and other	Implement technology-forcing, scientifically based noise limits for all types of oil and gas activities (e.g. exploration, extraction and decommissioning) that can be phased in over a period of not more than 10 years. Set noise limits according to area characteristics e.g. lower limits for biologically sensitive areas	Yes
	Further study the effectiveness of soft start / ramp-up procedures for marine mammal species in ‘real world’ conditions	Yes
	Conduct research into the long-term effects of exposure to seismic activity on marine mammals, such as non-injurious impacts that	Yes

activities)	may occur outside the prescribed safety zone	
	Assess the noise-related impacts of other aspects of the industry – drilling rigs, drill ships, offshore terminals etc. – and conduct research to reduce the noise levels from these aspects	Yes
	Use risk assessment software tools to improve mitigation measures during an operation	Yes – if available
	Promote the use of national, regional or global public web platforms to industry that contain data / maps on species presence/abundance and distribution and the location of maritime protection zones, biologically important areas etc.	Yes
Shipping	Encourage Port Authorities to develop regional port partnerships and adopt noise-related certification standards for low noise propulsion technologies and/or operational mitigation measures	Yes
	'Green' Certification programmes to include noise-related criteria in their standards	Yes
	Governments to actively support the efforts of the International Maritime Organisation to address noise from ships	Yes
	Regulators to mandate and incentivise compliance with the pending IMO guidelines	Yes
	Assess the feasibility of operational measures for shipping such as route and speed management	Yes
	Develop indicators for quantifying ship noise and use on-board monitoring systems to indicate the need for maintenance or repair	Yes
Pile driving and other coastal offshore operations	Determine acoustic emissions during the installation of gravity-based or suction foundations and of vibratory pile drivers	Yes
	Encourage the adaptation of screw pile technology for use in offshore settings (low noise emissions) where applicable	Yes
	Recognise the limitations of noise mitigating measures for pile driving and gradually introduce more restrictive standards	Yes
	Include a shutdown safety zone appropriate to the noise source which is monitored by visual observers and/or PAM	Yes- turtles (visual)
	Improve the knowledge and understanding of cumulative impacts of noise generated by construction activities	Yes
	Further test the effectiveness of source-based and target-based technologies	Yes (source-based)
Naval activities	Take efforts to refine military sonars to produce signals that are less damaging to marine mammals	Yes
	Encourage the use of risk assessment software by all Navies	Yes
	Encourage the use of national, regional or global public web platforms by Navies, that contain data / maps on species presence/abundance and distribution and the location of maritime protection zones, biologically important areas etc.	Yes – if available
	Avoid conducting sonar exercises in locations with topographical characteristics thought to be important in leading to strandings	No
	Use of pre-survey scans, safety zones, ramp-ups and the lowest possible source levels	Yes (lowest source)

	Include lower-level pings between sonar pulses if modelling shows that there is time for animals to approach too close to the source	No
	Restrict sonar exercises to daylight hours and use experienced MMOs instead of lookouts	No

Annexes

Annex 1: Guidelines to address the impact of anthropogenic noise on cetaceans in the ACCOBAMS area[280]

General guidelines

Mitigation procedures should be practical in that they should use data that can be readily collected by cetacean observers, account for operating conditions and constraints, and, as far as possible, minimize disruption of operations while maximizing environmental protection.

Besides procedures for specific activities, the following guidelines and concepts should be taken into account for any activity:

a) Consult databases of cetacean spatial and seasonal distribution and habitat databases so that activities can be planned and conducted to avoid critical habitats and when and where animals are unlikely to be encountered

b) Collect information and, if required, organize surveys (shipboard and/or aerial) or monitoring with fixed detectors (buoys, bottom recorders, etc.) to assess the population density in the areas chosen for operation

c) Avoid cetaceans' key habitats and marine protected areas, and define appropriate buffer zones around them; consider the possible impact of long-range propagation

d) Closed areas should be avoided and surrounded by appropriate buffer zones

e) Consider cumulative impacts not just of noise but of all anthropogenic threats over time; consider effects modeling; include consideration of seasonal and historical impacts from other activities (shipping, military, industrial, other seismic) in the specific survey area and nearby region. For these purposes, databases/GIS that track the history of sonar/seismic and other industrial activities and anthropogenic threats should be developed

f) Model the generated sound field in relation with oceanographic features (depth/temperature profile, sound channels, water depth, and seafloor characteristics) to assess the area possibly affected by relevant impacts

g) Determine safe / harmful exposure levels for various species, age classes, contexts, etc. This must be precautionary enough to handle large levels of uncertainty. When making extrapolations from other species, measures of uncertainty should quantify the chances of coming up with a wrong, and dangerous conclusion

h) There should be a scientific and precautionary basis for the exclusion zone (EZ) rather than an arbitrary and/or static designation; exclusion zones should be dynamically modeled based on the characteristic of the source (power and directionality), on the expected species, and on the local propagation features (cylindrical vs. spherical spreading, depth and type of sea bottom, local propagation paths related to thermal stratification). These EZ should be verified in the field

i) In the case of multiple EZ choices, the safest, most precautionary option should be adopted

j) Consider establishment of an expanded exclusion zone aimed at reducing behavioral disruption. This should be based on received levels much lower than those supposed to produce physiological and physical damage. Whenever possible, consider an expanded exclusion zone where exposure could be limited by reducing the emitted power (power-down) whilst maintaining acceptable operative capabilities

[280] As contained in the Annex to ACCOBAMS Resolution 4.17: Guidelines to Address the Impact of Anthropogenic Noise on Cetaceans in the ACCOBAMS Area

k) Cetacean mitigation guidelines should be adopted and publicized by all operators, whether military, industrial or academic

l) A system of automated logging of acoustic source use should be developed to document the amount of acoustic energy produced, and this information should be available to noise regulators and to the public

m) Mitigation should include monitoring and reporting protocols to provide information on the implemented procedures, on their effectiveness, and to provide datasets to be used for improving existing cetacean databases

n) During operations, existing stranding networks in the area should be alerted; if required, additional monitoring of the closest coasts and for deaths at sea should be organized

o) If required, organize post cruise survey to verify if changes in the population density or anomalous deaths occurred as a possible consequence of operations (this requires a knowledge of the area before any operation has occurred – see points a & b)

p) In the case of strandings possibly related with the operations, any acoustic emission should be stopped and maximum effort devoted to understanding the causes of the deaths

q) In the case of abnormal behaviors observed in animals close to the operations, any acoustic emission should be stopped and maximum effort addressed at monitoring those animals

r) Trained and approved Cetaceans Observers (visual observers and/or acoustic monitors where appropriate) should be employed for the monitoring and reporting programme including overseeing implemented mitigation rules

s) Cetacean observers and bio-acousticians in charge of the monitoring programme must be qualified, dedicated and experienced, with suitable equipment

t) Marine mammal observers should report to the National Focal Point that will inform the ACCOBAMS Secretariat using a standardized reporting protocol. Any unexpected condition and/or change in applied protocols should be discussed with the Secretariat in collaboration with the Scientific Committee.

u) Accurate reporting is required to verify the EIA hypotheses and the effectiveness of mitigation

v) Procedures and protocols should be based on a conservative approach that reflects levels of uncertainty. They should include mechanisms that create an incentive for good practice.

w) Take a precautionary approach every time uncertainties emerge; in the case of unexpected events or uncertainties refer to the National Focal Point.

Guidelines for (military sonar and civil) high power sonar

For sonar operations the following guidelines and key concepts should apply in addition to the general guidelines:

a) Sonar surveys should be planned so as to avoid key cetacean habitat and areas of cetacean density, so that entire habitats or migration paths are not blocked, so that cumulative sonar sound is limited within any particular area, and so that multiple vessels operating in the same or nearby areas at the same time are prohibited

b) Use of the lowest practicable source power

c) Adapt the sequencing of sonar lines to account for any predictable movements of animals across the survey area and avoid blocking escape routes

d) Continuous visual and passive acoustic monitoring (PAM) with a specialized team of cetaceans observers and bio-acousticians to ensure that cetaceans are not in the "exclusion zone" before turning on the acoustic sources and while sources are active.

e) Equipment for visual monitoring should include suitable binoculars, including big eyes, to be used according to the monitoring protocol

f) High power sources should be restricted at night, during other periods of low visibility, and during significant surface-ducting conditions, since current mitigation techniques may be inadequate to detect and localize cetaceans. Because of the impact of adverse weather conditions on the visual detection of mammals, emission during unfavorable conditions should be restricted as well

g) Passive acoustic monitoring (PAM) (towed array technology or other suitable technologies with enough bandwidth to be sensitive to the whole frequency range of cetaceans expected in the area) should be used to improve detection capabilities. PAM should be mandatory for night operations or when visibility is poor. However, PAM may be inadequate mitigation for night operations if cetaceans in the area are not vocal or easily heard.

h) At least two dedicated Cetacean Observers should be on watch at every time on every operative ship; organize shifts to allow enough rotation and resting periods to MMOs. In case of acoustic monitoring, at least one operator should be on watch and shifts should be organized to allow 24/24h operation, unless automatic detection/alerting systems with proven effectiveness are available

i) Before beginning any emission there should be a dedicated watch of at least 30 minutes to ensure no animals are within the EZ

j) Extra mitigation measures should be applied in deep water areas if beaked whales have been seen diving on the vessel trackline or if habitats suitable for beaked whales are approached: in such cases, the watch should be prolonged to 120 minutes to increase the probability that deep-diving species are detected (e.g. Cuvier's beaked whales). Ideally, however, sonar exercises should not be done in areas that beaked whales are known to inhabit.

k) Every time sources are turned on, there should be a slow increase of acoustic power (ramp-up or soft start) to allow cetaceans sufficient opportunity to leave the ensonified area in the event that visual and passive searches are unsuccessful. Ramp-up should be at least 30 minutes (the effectiveness of this procedure is still debatable)

l) The beginning of emissions should be delayed if cetacean species are observed within the exclusion zone (EZ) or approaching it. Ramp-up may not begin until 30 minutes after the animals are seen to leave the EZ or 30 minutes after they are last seen (120 minutes in case of beaked whales)

m) Avoid exposing animals to harmful acoustic levels by preventing them from entering into the EZ, by changing the ship course, if applicable, or by reducing (power-down) or ceasing (shut-down) the acoustic emissions

n) Shut-down of source(s) whenever a cetacean is seen to enter the EZ and whenever aggregations of vulnerable species (such as beaked whales and sperm whales) are detected anywhere within the monitoring area

<u>Guidelines for seismic surveys and airgun uses</u>

Guidelines for mitigating the effects of seismic surveys have been experimented with mostly in the context of academic seismic surveys conducted under NMFS permits. Most of the following guidelines are equivalent to those required for sonar operations and should apply in addition to general guidelines:

a) Seismic surveys should be planned so as to avoid key cetacean habitat and areas of cetacean density, so that entire habitats or migration paths are not blocked, so that cumulative seismic noise is limited within any particular area, and so that multiple vessels operating in the same or nearby areas at the same time are specifically regulated or prohibited.

b) Use of the lowest practicable source power

c) Limit horizontal propagation by adopting suitable array configurations and pulse synchronization and eliminating unnecessary high frequencies.

d) Adapt the sequencing of seismic lines to account for any predictable movements of animals across the survey area and avoid blocking escape routes

e) Modeling of the generated sound field in relation with oceanographic features (depth/temperature profile, water depth, seafloor characteristics) to dynamically set the Exclusion Zone. Confirm models by EZ tests in the field.

f) Mitigation procedures should be practical in that they should use data that can be readily collected by cetacean observers during offshore operations, account for operating conditions and constraints of seismic surveys and, as far as possible, minimize disruption of surveys while maximizing environmental protection

g) Continuous visual and passive acoustic monitoring (PAM) with a specialized team of cetacean observers and bioacousticians to ensure that cetaceans are not in the Exclusion Zone before turning on the acoustic sources and while sources are active.

h) Equipment for visual monitoring should include suitable binoculars and big eyes to be used according to the monitoring protocol

i) Ideally, high power airgun configurations should be prohibited at night, during other periods of low visibility, and during significant surface-ducting conditions, since current mitigation techniques may be inadequate to detect and localize cetaceans. Because of the impact of adverse weather conditions on the visual detection of mammals, emissions during unfavourable conditions should be restricted as well

j) Passive acoustic monitoring (PAM) (towed array technology or other suitable technologies with enough bandwidth to be sensitive to the whole frequency range of cetaceans expected in the area) should be used to improve detection capabilities. PAM should be mandatory for night operations or when visibility is scarce. However, PAM may be inadequate mitigation for night operations if cetaceans in the area are not vocal or easily heard.

k) At least two dedicated Cetacean Observers should be on watch at one time on every operative ship; shifts should be organized to allow enough rotation and resting periods to MMOs. In the case of acoustic monitoring, at least one operator should be on watch and shifts should be organized to allow 24/24h operation, unless automatic detection/alerting systems with proven effectiveness are available

l) Before beginning any emission there should be a dedicated watch of at least 30 minutes to ensure no animals are within the EZ

m) Extra mitigation measures should be applied in deep water areas if beaked whales have been seen diving on the vessel trackline or if habitats suitable for beaked whales are approached: in such a cases the watch should be at least 120 minutes to increase the probability that deep-diving species are detected (e.g. Cuvier’s beaked whales).

n) Every time sources are turned on, there should be a slow increase of acoustic power (ramp-up or soft start) to allow cetaceans sufficient opportunity to leave the ensonified area in the event that visual and passive searches are unsuccessful (the effectiveness of this procedure is still debatable)

o) The beginning of emissions should be delayed if cetacean species are observed within the exclusion zone (EZ) or approaching it. Ramp-up may not begin until 30 minutes after the animals are seen to leave the EZ or 30 minutes after they are last seen (120 minutes in case of beaked whales)

p) Exposing animals to harmful acoustic levels should be avoided by preventing them from entering the EZ, by changing the ship course, if applicable, or by reducing (power-down) or ceasing (shut-down) the acoustic emissions

q) There should be a shut-down of source(s) whenever a cetacean is seen to enter the EZ and whenever aggregations of vulnerable species (such as beaked whales) are detected anywhere within the monitoring area

r) If more than one seismic survey vessel is operating in the same area, they should maintain a minimum separation distance to allow escape routes between sound fields.

s) Data sharing among surveyors should be encouraged to minimize duplicate surveying. Also, if old seismic data can be usefully re-analyzed using new signal processing or analysis techniques, this should be encouraged.

Guidelines for coastal and offshore construction works

Coastal and offshore construction works, which may include demolition of existent structures, may produce high noise levels, even for prolonged periods, depending on the technologies used and on local propagation features that include propagation through the substrate.
Construction works on the coast or on the shoreline, including harbours, may propagate noise (e.g. from pile drivers and jack hammers) over wide areas in particular where the substrate is rocky. Traditional percussive pile-driving produces vibrations that propagate well and can ensonify large marine areas at distances of more than 100km; in such conditions alternative technologies should be used. In some cases mitigation can be achieved through the use of bubble screens or material screens that attenuate sound emitted from the source or other technical modifications.

In the case of prolonged activities, such as construction works of large structures, a scheduling of the most noisy activities could be evaluated as a measure to avoid continuous exposures especially during critical periods for cetaceans living or transiting in the area; the concentration of noisy operations in short periods of time and alternative construction technologies should be also evaluated to minimize noise impacts.

a) Modelling of the generated sound field in relation to geological and oceanographic features (depth/temperature profile, water depth, coastal and seafloor characteristics) should occur, in addition to verification in the field; the area where animals could receive harmful noise levels (Exclusion Zone) should be defined

b) Noise producing activities should be scheduled according to the presence of cetaceans, if seasonal

c) Alternative technologies should be used or countermeasures to reduce noise diffusion, i.e. bubble curtains should be adopted

d) Noise monitoring stations at given distances from the source area should be set up to monitor for both local and long range noise levels and verify if predicted levels are reached or not

e) Visual observation points/platforms to monitor for the presence and behaviour of cetaceans should be set up

f) Before beginning any noise producing action there should be a dedicated watch of at least 30 minutes to ensure no animals are within the EZ

g) In areas where water depths in the EZ exceed 200m the watch should be at least 120 minutes to increase the probability that deep-diving species are detected

It is also important to consider the noise that will be generated by the structures once they are operative. Bridges propagate vibrations related to the traffic; offshore wind-farms and oil extraction platforms produce their own noise and thus their environmental impact should be carefully evaluated and mitigated with dedicated rules.

Guidelines for offshore platforms

Offshore platforms may be used for a variety of different activities, such as seafloor drilling, oil/gas extraction, electricity production (wind-farms), each one with its own particular impacts on the marine environment. Their placement should be carefully regulated; if their impacts include noise, they should be required to undergo a specific implementation of monitoring and mitigation procedures to be defined on a case by case basis and separately for the construction phase and for the operative life. The growing number of windfarms in coastal areas may have an impact on cetaceans, in particular because of the noise they make. They should be designed and operated to produce the lowest possible noise in all activity phases.

Guidelines for Playback & Sound Exposure Experiments

Playback and Controlled Exposure Experiments (CEEs) are experiments in which animals in the wild are exposed to controlled doses of sound for the purposes of assessing their behavioural or physiological responses. CEEs are one of several methods that have historically been and are increasingly being applied to the study of cetacean behavioural responses to sound. These approaches can complement opportunistic observations or the tagging of animals around noise-producing activities. CEEs (which include some recent experiments under the generic heading of Behavioural Response Studies (BRS)), are designed to introduce small amounts of additional sound into the ocean in order to scientifically determine responses and assess the potential risk from human activities. However, playbacks may carry some risks themselves to target individuals and potentially expose not only the target species and/or individuals to be studied, but also additional ones. These considerations need to be carefully addressed through precautionary protocols in the execution of CEEs and the possible risks should be balanced against the potential for these studies to provide answers to management and/or scientific questions on a case by case basis.

Given that some CEEs can be controversial, and because of the known underlying concerns, it is particularly important that they are carefully designed and carefully conducted and their limitations and risks acknowledged. In order to achieve optimal scientific and conservation value, those involved in conducting, funding and managing large-scale CEE experiments should strive for international cooperation, coordination and very transparent information exchange and where possible joint programmes of work. Avoidance of duplicative or overlapping research will also help to prevent any unnecessary introduction of noise into the marine environment.

Controlled Exposure Experiments typically strive to use, without exceeding harmful levels, sound exposures that are as realistic as possible (relative to known human sound sources), but with the capability of close control over the type and nature of exposures. Many CEEs are designed to minimize the exposure required to elicit a detectable response. Opportunistic studies, on the other hand, involve actual sound sources and, thus, more realistic exposures, though the lack of experimental control in some circumstances can limit the power of resulting observations.

Both kinds of studies must include (or be preceded) by baseline studies of behaviour and physiology so that the results of the experiments are meaningful and can be properly interpreted. . To increase the utility of the results to regulatory decision-making, researchers conducting CEEs should openly communicate the design, procedures, and results of such studies to policymakers.

As with all biological research, methods that can yield conclusive results with less risk of harm to the animals should be preferred. Systematic observations using ongoing sound-producing activities should be used in place of CEEs if they can provide similar information with similar power to detect effects. It is noted, however, that the lack of experimental control over sources in opportunistic contexts, as well as the safety and/or national security considerations inherent in some situations can significantly limit their value in many real-world applications. Systematic studies of ongoing sound-producing activities can validate and strengthen monitoring efforts required as mitigation, and have the benefit that such studies do not introduce additional sound directed at the mammals. The advantages of both observational and experimental studies are increased as more attention is given to optimizing measurement methods and study designs with the greatest power to detect real effects and provide convincing results. In practice, research investigating the impacts of large sound sources could be most successful when using a suite of approaches including observations of both controlled and uncontrolled sound exposures. Therefore, controlled experiments and opportunistic observations are usually best seen not as alternatives, but rather as complementary approaches that yield the most powerful results when both are conducted.

Sound exposure experiments require an explicit protocol to manage possible interactions among the sound source(s) and the target(s); in general, while designing and conducting such experiments, these guidelines should be taken into consideration:

- use sound exposures that are as realistic as possible (while minimizing exposure required to detect responses) and with the same or similar characteristics of sound that the mammals are likely to be exposed to
- model sound propagation from the source to the targets based on local oceanographic features and background noise information
- use available technologies to monitor both target and non-target animals; monitor other individuals and species – which may require different methods but may provide additional information
- design experiments so that monitored animals are those exposed to highest levels
- halt sound emission if adverse response or behavioural changes are observed on either target or non target animals
- limit repeated exposures on the same target(s) unless required by the research protocol
- avoid enclosed areas, avoid blocking escape routes
- avoid "chasing" animals during playbacks; if they move away -- don't modify the course to follow them with the playback source
- exposures that are expected to elicit particular behavioural responses (e.g., responses elicited by predator sounds, conspecific signals) may be particularly useful control stimuli in CEEs; however, such exposures should be used only as necessary as part of a careful experimental paradigm that includes specific mitigation and monitoring protocols. In such cases, it is important to consider that the response may not be related to the loudness of the exposure but to the behavioural significance of the signal used.

Guidelines for shipping

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. It is still difficult to say how much the radiated noise should be reduced to get visible effects. However, noise reduction should be evaluated in order to reduce both local and long range effects (see quieting technologies).

Guidelines for other mitigation cases

Any activity that produces noise levels that may pose risks to cetaceans requires attention and the implementation of monitoring and mitigation procedures. Some of the cases reported in this chapter (touristic boats and whale watching) may not produce physical injuries; however they contribute to the underwater noise and may have a significant impact on the behaviour and welfare of the animals, and, in the long term, a negative effect on the local population. At least in sensitive areas these should be taken under control and eventually limited.

Touristic boats

Tourist traffic in some areas is becoming a serious problem; noise irradiated by engines and propellers is an important component of the disturbance to animals.

Tourist boats should avoid approaching dolphins and dolphins schools, as well as larger cetaceans, and especially if calves are present. Specific guidelines are already available and their distribution should be supported as much as possible.

In case of sensitive habitats and marine protected areas, the relevant authorities should severely restrict the use of tourist motorboats and eventually encourage the use quieter electric engine boats.

Boats should be as quiet as possible and noise controls should be made at the beginning of every field season. Noise limits should be set to reduce the behavioural disturbance to animals as much as possible.

Whale watching
Whale watching is an activity that is increasing every year and that may have an impact on cetacean populations, stocks, and individuals. Rules and permits are already in force in many countries, but the noise issue is seldom taken into consideration. Noise irradiated by engines and propellers is an important component of the disturbance to animals. Beyond complying with national rules and restrictions, whale watching operators should also comply with noise emission restrictions.

Boats should be as quiet as possible and noise controls should be made at the beginning of every field season. Noise limits should be set to reduce the behavioural disturbance to animals as much as possible.

Explosive disposal of residual war weapons, use of explosives for testing or for decommissioning structures
In many areas of the Mediterranean Sea the detonation of residual war weapons is a recurrent activity that needs special care; also explosives are used widely for offshore decommissioning of structures and for military trials, e.g. for testing ships and submarines.

In all such cases, the definition of an Exclusion Zone is required, based on the power of the expected explosion(s) and on the oceanographic features; consequently the EZ area should be monitored to be sure no animals are inside. The watch before starting operations should be at least 30 min; it should be prolonged to 120 minutes in areas where deep divers could be present. Additional measures could include the use of absorbing materials, e.g. bubble curtains that are proven to attenuate the shock wave or at least to dampen the shock wave onset. The use of aversive sound devices to remove animals from the danger area for the relatively short period of blasting holds great promise for mitigation. However, further studies to develop and test such devices with the range of species of interest would be required before these could be relied on for mitigation.

Underwater acoustically active devices
Underwater acoustics is an expanding field and new acoustic technologies are continuously developed, tested and applied for a variety of uses, e.g. for searching/monitoring/exploiting environmental resources, for conducting scientific research, and for military purposes.

Examples of activities that may require a permit include: oceanographic experiments based on the use of high power acoustic sources, including the use of acoustic positioning devices, the use of deterrent devices (Pingers, Acoustic Deterrent Devices, and Acoustic Harassment Devices, in particular if used in array configurations), e.g. to protect commercial fisheries or to protect industrial water intakes (cooling systems).

In all cases where high noise levels are expected in areas with the potential presence of cetaceans, at least the following guidelines should apply:

- **a)** There should be modelling of the generated sound field in relation to oceanographic features (depth/temperature profile, water depth, coastal and seafloor characteristics) and verification in the field; the area where animals could receive harmful noise levels (Exclusion Zone) should be defined
- **b)** Activities should be planned for areas with low cetacean densities, avoiding wherever possible sensitive species, such as beaked whales, and sensitive habitats (e.g. breeding areas, nursing areas, etc.)
- **c)** Noise producing activities should be scheduled according to the presence/absence of cetaceans, if seasonal
- **d)** Noise monitoring stations should be set up to monitor for both local and long range noise levels and verify if predicted levels are reached or not

e) Visual observation points or mobile platforms should be set up to monitor for the presence and behaviour of cetaceans

f) PAM stations or mobile platforms should be setup to monitor for the presence and behaviour of cetaceans

g) Before beginning any noise producing action there should be a dedicated watch of at least 30 minutes to ensure no animals are within the EZ

In areas where water depths in the EZ exceed 200m the watch should be at least 120 minutes to increase the probability that deep-diving species are detected.

Annex 2: IMO GUIDELINES FOR THE REDUCTION OF UNDERWATER NOISE FROM COMMERCIAL SHIPPING TO ADDRESS ADVERSE IMPACTS ON MARINE LIFE[281]

1 Preamble

1.1 Concern has been raised that a significant portion of the underwater noise generated by human activity may be related to commercial shipping. The international community recognizes that underwater-radiated noise from commercial ships may have both short and long-term negative consequences on marine life, especially marine mammals.

1.2 It is important to recognize that both the technical and cost-effectiveness of measures considered, either individually or in combination, will be strongly dependent on the design, operational parameters, and mandatory requirements relevant for a particular ship. A successful strategy to reduce radiated noise should consider interactions and contributions from measures provided to achieve other objectives such as reduction of onboard noise and improvements in energy efficiency.

1.3 When efforts have been made to mitigate underwater noise, as far as reasonable and practical, evaluation should be undertaken to determine the success or otherwise of ship noise reduction efforts and to guide and enhance future activities at noise reduction. Such evaluation can include forms of radiated-noise measurements, simulations or other ways of data gathering.

2 Application

2.1 These Guidelines can be applied to any commercial ship.

2.2 These Guidelines do not address the introduction of noise from naval and war ships and the deliberate introduction of noise for other purposes such as sonar or seismic activities.

3 Purpose

3.1 These non-mandatory Guidelines are intended to provide general advice about reduction of underwater noise to designers, shipbuilders and ship operators. They are not intended to form the basis of a mandatory document.

3.2 Given the complexities associated with ship design and construction, the Guidelines focus on primary sources of underwater noise. These are associated with propellers, hull form, onboard machinery, and operational aspects. Much, if not most, of the underwater noise is caused by propeller cavitation, but onboard machinery and operational modification issues are also relevant. The optimal underwater noise mitigation strategy for any ship should at least consider all relevant noise sources.

3.3 These Guidelines consider common technologies and measures that may be relevant for most sectors of the commercial shipping industry. Designers, shipbuilders, and ship operators are encouraged to also consider technologies and operational measures not included in these Guidelines, which may be more appropriate for specific applications.

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[281] As contained in the Annex to IMO document MEPC.1/Circ.833

4 Definitions

4.1 *Cavitation inception speed* is the lowest ship speed at which cavitation occurs.

4.2 *Propeller cavitation* is the formation and implosion of water vapour cavities caused by the decrease and increase in pressure as water moves across a propeller blade. Cavitation causes broadband noise and discrete peaks at harmonics of the blade passage frequency in the underwater noise spectrum. The broadband noise is caused by growth and collapse of a vast amount of individual cavitation bubbles in water. The discrete noise peaks are caused by the volume fluctuations of the sheet and tip vortex cavities.

4.3 *Underwater noise,* or the *underwater-radiated noise level,* for the purposes of these Guidelines refers to noise from commercial ships[*].

5 Predicting underwater noise levels

5.1 Underwater noise computational models may be useful for both new and existing ships in understanding what reductions might be achievable for certain changes in design or operational behaviour. Such models may be used to analyse the noise sources on the ship, the noise transmission paths through the ship and estimate the total predicted noise levels. This analysis can help shipowners, shipbuilders and designers, to identify noise control measures that could be considered for the specific application, taking into account expected operational conditions. Such measures may include amongst others: vibration isolation mounts (i.e. resilient mounts) for machinery and other equipment, dynamic balancing, structural damping, acoustical absorption and insulation, hull appendages and propeller design for noise reduction.

5.2 Types of computational models that may assist in reducing underwater noise include:

.1 Computational Fluid Dynamics (CFD) can be used to predict and visualize flow characteristics around the hull and appendages, generating the wake field in which the propeller operates;

.2 Propeller analysis methods such as lifting surface methods or CFD can be used for predicting cavitation;

.3 Statistical Energy Analysis (SEA) can be used to estimate high-frequency transmitted noise and vibration levels from machinery; and

.4 Finite Element Analysis (FEA) and Boundary Element Method (BEM) may contribute to estimate low-frequency noise and vibration levels from the structure of the ship excited by the fluctuating pressure of propeller and machinery excitation.

5.3 The value of a modelling exercise is enhanced if its predictive capabilities are assessed in case studies under various operational conditions.

[*] Underwater-radiated noise level is reported in sound pressure levels in decibels and expressed as 10 times the logarithm of the square of the ratio of the rms sound pressure to a reference pressure of 1 micro Pascal. When it is a ship source level, the sound pressure level is adjusted to a level at 1 m from the source.

6 Standards and references

6.1 Underwater noise should be measured to an objective standard for any meaningful improvements.

1. The International Organization for Standardization (ISO) has developed the (ISO/PAS) 17208-1 – Acoustics – Quantities and procedures for description and measurement of underwater sound from ships – Part 1: General requirements for measurements in deep water. This measurement standard is for deep water which implies that the water depth should be larger than 150 m or 1.5 times overall ship length (engineering method), whichever is greater. This is a temporary publicly available standard. This standard is based on the American National Standards Institute and the Acoustical Society of America (ANSI/ASA) S12.64-2009 "Quantities and Procedures for Description and Measurement of Underwater Sound from Ships, Part 1: General Requirements".

2. ISO is also developing ISO/DIS 16554 – Ship and marine technology – Measurement and reporting of underwater sound radiated from merchant ships – deep-water measurement, which is expected to be published in 2013. The standard would provide shipyards, shipowners and ship surveyors with a well-established measurement method for underwater sound radiated from merchant ships for use at the final delivery stage of ships.

6.2 Several research ships have been designed using the noise specification proposed by the International Council for the Exploration of the Sea (ICES) Cooperative Research Report No.209 (CRR 209). It should be noted that the ICES CRR 209 noise specification was designed for fishery research ships so that marine life would not be startled during biomass surveys; it was not intended to be used as a commercial ship design standard to prevent potential harm of marine life. However, certain design arrangements used to meet ICES CRR 209 may still be useful for new commercial ships to reduce underwater noise.

6.3 Other underwater noise rating criteria are available and may prove useful as guidance.

7 Design considerations

7.1 The largest opportunities for reduction of underwater noise will be during the initial design of the ship. For existing ships, it is unlikely to be practical to meet the underwater noise performance achievable by new designs. The following design issues are therefore primarily intended for consideration for new ships. However, consideration can also be given to existing ships if reasonable and practicable. While flow noise around the hull has a negligible influence on radiated noise, the hull form has influence on the inflow of water to the propeller. For effective reduction of underwater noise, hull and propeller design should be adapted to each other. These design issues should be considered holistically as part of the overall consideration of ship safety and energy efficiency.

7.2 *Propellers*

7.2.1 Propellers should be designed and selected in order to reduce cavitation. Cavitation will be the dominant radiated noise source and may increase underwater noise significantly. Cavitation can be reduced under normal operating conditions through good design, such as optimizing propeller load, ensuring as uniform water flow as possible into propellers (which can be influenced by hull design), and careful selection of the propeller characteristics such as: diameter, blade number, pitch, skew and sections.

7.2.2 Ships with a controllable pitch propeller could have some variability on shaft speed to reduce operation at pitch settings too far away from the optimum design pitch which may lead to unfavourable cavitation behaviour (some designs may be able to operate down to a shaft speed of two thirds of full).

7.2.3 The ship and its propeller could be model tested in a cavitation test facility such as a cavitation tunnel for optimizing the propeller design with respect to cavitation induced pressure pulses and radiated noise.

7.2.4 If predicted peak fluctuating pressure at the hull above the propeller in design draft is below 3 kPa (1st harmonic of blade rate) and 2 kPa (2nd harmonic) for ships with a block coefficient below 0.65 and 5 kPa (1st harmonic) and 3 kPa (2nd harmonic) for ships with a block coefficient above 0.65, this could indicate a potentially lower noise propeller. Comparable values are likely to be 1 kPa higher in ballast condition.

7.2.5 Noise-reducing propeller design options are available for many applications and should be considered. However, it is acknowledged that the optimal propeller with regard to underwater noise reduction cannot always be employed due to technical or geometrical constraints (e.g. ice-strengthening of the propeller). It is also acknowledged that design principles for cavitation reduction (i.e. reduce pitch at the blade tips) can cause decrease of efficiency.

7.3 *Hull design*

7.3.1 Uneven or non-homogeneous wake fields are known to increase cavitation. Therefore, the ship hull form with its appendages should be designed such that the wake field is as homogeneous as possible. This will reduce cavitation as the propeller operates in the wake field generated by the ship hull.

7.3.2 Consideration can be given to the investigation of structural optimization to reduce the excitation response and the transmission of structure-borne noise to the hull.

8 Onboard machinery

8.1 Consideration should be given to the selection of onboard machinery along with appropriate vibration control measures, proper location of equipment in the hull, and optimization of foundation structures that may contribute to reducing underwater radiated and onboard noise affecting passengers and crew.

8.2 Designers, shipowners and shipbuilders should request that manufacturers supply information on the airborne sound levels and vibration produced by their machinery to allow analysis by methods described in section 5.2 and recommend methods of installation that may help reduce underwater noise.

8.3 Diesel-electric propulsion has been identified as an effective propulsion-train configuration option for reducing underwater noise. In some cases, the adoption of a diesel-electric system should be considered as it may facilitate effective vibration isolation of the diesel generators which is not usually possible with large direct drive configurations. The use of high-quality electric motors may also help to reduce vibration being induced into the hull.

8.4 The most common means of propulsion on board ships is the diesel engine. The large two-stroke engines used for most ships' main propulsion are not suitable for consideration of resilient mounting. However, for suitable four-stroke engines, flexible couplings and resilient mountings should be considered, and where appropriate, may significantly reduce underwater noise levels. Four-stroke engines are often used in combination with a gear box and controllable pitch propeller. For effective noise reduction, consideration should be given to mounting engines on resilient mounts, possibly with some form of elastic coupling between the engine and the gear box. Vibration isolators are more readily used for mounting of diesel generators to foundations.

8.5 Consideration should be given for the appropriate use of vibration isolation mounts as well as improved dynamic balancing for reciprocating machinery such as refrigeration plants, air compressors, and pumps. Vibration isolation of other items and equipment such as hydraulics, electrical pumps, piping, large fans, vent and AC ducting may be beneficial for some applications, particularly as a mitigating measure where more direct techniques are not appropriate for the specific application under consideration.

9 Additional technologies for existing ships

In addition to their use for new ships, the following technologies are known to contribute to noise reduction for existing ships:

1. design and installation of new state-of-the-art propellers;

2. installation of wake conditioning devices; and

3. installation of air injection to propeller (e.g. in ballast condition).

10 Operational and maintenance considerations

10.1 Although the main components of underwater noise are generated from the ship design (i.e. hull form, propeller, the interaction of the hull and propeller, and machinery configuration), operational modifications and maintenance measures should be considered as ways of reducing noise for both new and existing ships. These include, among others:

10.2 ***Propeller cleaning***

Propeller polishing done properly removes marine fouling and vastly reduces surface roughness, helping to reduce propeller cavitation.

10.3 ***Underwater hull surface***

Maintaining a smooth underwater hull surface and smooth paintwork may also improve a ship's energy efficiency by reducing the ship's resistance and propeller load. Hence, it will help to reduce underwater noise emanating from the ship. Effective hull coatings that reduce drag on the hull, and reduce turbulence, can facilitate the reduction of underwater noise as well as improving fuel efficiency.

10.4 ***Selection of ship speed***

10.4.1 In general, for ships equipped with fixed pitch propellers, reducing ship speed can be a very effective operational measure for reducing underwater noise, especially when it becomes lower than the cavitation inception speed.

10.4.2 For ships equipped with controllable pitch propellers, there may be no reduction in noise with reduced speed. Therefore, consideration should be given to optimum combinations of shaft speed and propeller pitch.

10.4.3 However, there may be other, overriding reasons for a particular speed to be maintained, such as safety, operation and energy efficiency. Consideration should be given in general to any critical speeds of an individual ship with respect to cavitation and resulting increases in radiated noise.

10.5 ***Rerouteing and operational decisions to reduce adverse impacts on marine life***

Speed reductions or routing decisions to avoid sensitive marine areas including well-known habitats or migratory pathways when in transit will help to reduce adverse impacts on marine life.
