



**MUL Observation Submission to MARA by:
Wild Ireland Defence CLG**



Date: 30th March 2026
Ref: MUL application 250019

1. Introduction

- 1.1 Wild Ireland Defence CLG pursue the objectives of education, advocacy, and activism of all types in the protection, conservation, preservation and defence of the natural environment and the species that habituate it. WID make this submission as an observer in order to ensure that the planning application is progressed in compliance with environmental and planning and development laws at local, national and EU level.
- 1.2 This submission is made in respect of Maritime Usage Licence application MUL 250019, which seeks authorisation for a multi-annual programme of geophysical, geotechnical and ecological site investigation works across a substantial offshore area. The works are explicitly intended to inform and facilitate a future offshore wind development of significant scale. While presented as temporary and survey-based in nature, the proposed activity comprises repeated, high-intensity acoustic emissions, intrusive seabed investigations, and sustained vessel operations over a period of up to five years.
- 1.3 This submission demonstrates that the application is vitiated by fundamental legal and scientific deficiencies which preclude the Maritime Area Regulatory Authority from lawfully granting consent. These deficiencies arise under the Environmental Impact Assessment Directive, the Habitats Directive (Articles 6 and 12), the Water Framework Directive, and domestic wildlife legislation. They are compounded by a failure to apply best available scientific knowledge and internationally recognised standards in the assessment of underwater noise.

2. Absence of lawful Environmental Impact Assessment screening

- 2.1 The screening determination provided asserts that no Environmental Impact Assessment is solely because the project does not fall within a listed class of development. It expressly declines to apply Annex III criteria or sub threshold development (Schedule 7 of the

Planning and Development Regulations 2001 (as amended)). This approach is contrary to settled jurisprudence of the Court of Justice. In *Kraaijeveld v Netherlands*, the Court held at paragraph 50¹ that Member States cannot, by means of thresholds or criteria, exclude from the scope of the Directive projects which are likely to have significant effects on the environment.

- 2.2 This approach was confirmed in *Commission v Ireland*², the Court held that the selection criteria and/or thresholds determined by Member States must not have the effect of excluding, in practice, from all assessment projects which are likely to have significant effects on the environment.
- 2.3 Further, in *Marktgemeinde Straßwalchen*³, paragraphs 61-63 provides that the competent authority must take into account all the relevant criteria listed in Annex III to Directive 2011/92 in order to determine whether a project is likely to have significant effects on the environment. No such Annex III assessment has been undertaken. The screening is therefore unlawful and jurisdictionally defective.

3. Internal Contradiction with Appropriate Assessment

- 3.1 The application proceeds to Stage 2 Appropriate Assessment on the basis that Likely Significant Effects cannot be excluded, while simultaneously asserting that no EIA is required. This appears legally incoherent. A project capable of triggering Article 6(3) necessarily meets the threshold of potential significance under the EIA Directive. The absence of any reconciliation between these positions confirms that no lawful, effects-based screening has been undertaken.

4. Project Splitting

- 4.1 The site investigations are expressly preparatory to a 900 MW offshore wind development. They are therefore functionally inseparable from that project. In *Abraham v Walloon Region*⁴, paragraph 27 provides that the Directive would be deprived of its effectiveness if projects could be split into several parts and, as a result, escape the requirement of an environmental impact assessment. The failure to assess the cumulative project constitutes unlawful project splitting. In page 32 of the NIS a number of project are list but there is no effective cumulative assessment. The NIS does not identify if there was any slight/imperceptible or significant impacts for any of the projects/ plans nor prove that cumulative levels of impacts do NOT lead to a combined significant impact on any relevant site or species. Therefore the required legal test has not been completed or satisfied.

1 Case C-72/95, *Aannemersbedrijf P.K. Kraaijeveld BV e.a. v Gedeputeerde Staten van Zuid-Holland*, paragraph 50.

2 Case C-392/96, *Commission v Ireland* [1999] ECR I-5901, paragraph 64.

3 Case C-531/13, *Marktgemeinde Straßwalchen and Others*, paragraphs 61-63.

4 Case Case C-2/07 *Paul Abraham and Others v. Région wallonne*, paragraph 27

5. Failure of Appropriate Assessment

- 5.1 The legal standard for Appropriate Assessment is well established. In *Landelijke Vereniging tot Behoud van de Waddenzee and Nederlandse Vereniging tot Bescherming van Vogels v. Staatssecretaris van Landbouw, Natuurbeheer en Visserij*⁵, paragraph 61, the Court held the competent national authorities are to authorise such an activity only if they have made certain that it will not adversely affect the integrity of that site. That is the case where no reasonable scientific doubt remains as to the absence of such effects. The present assessment acknowledges disturbance pathways but relies on unproven mitigation. It contains no noise modelling, no cumulative analysis, and no definitive findings. It therefore fails the *Landelijke Vereniging*/ *Landelijke* test.

6. Article 12 Habitats Directive – Strict Protection

- 6.1 All cetaceans are protected under Article 12 and the system of strict protection must make it possible to ensure the actual and effective protection of the species concerned. The system of strict protection must be complete, coherent and effective. The application fails to assess disturbance arising from acoustic emissions. Scientific evidence demonstrates that such disturbance is inevitable. No Article 16 derogation has been considered. Consent is therefore legally precluded.
- 6.2 The deficiencies identified in the assessment of underwater noise impacts give rise not only to failures under the EIA Directive and Article 6(3) of the Habitats Directive, but also to a distinct and independent breach of Article 12 of Directive 92/43/EEC. That provision requires Member States to establish a system of strict protection for species listed in Annex IV, including all cetaceans, prohibiting deliberate disturbance, particularly during periods of breeding, rearing, migration and feeding.
- 6.3 The Court of Justice has consistently held that Article 12 imposes a proactive and results-based obligation. In *Case C-103/00 Commission v Greece*⁶, the Court held that Member States must take all necessary measures to prevent disturbance of protected species. In *Case C-98/03 Commission v Germany* it was confirmed that the protection regime must be effective in practice and not merely theoretical. The obligation is therefore engaged wherever a project gives rise to a real risk of disturbance, regardless of whether that disturbance is intentional in the ordinary sense.
- 6.4 In the present case, the application expressly proposes the use of high-energy acoustic sources over a wide marine area and over an extended temporal duration. The scientific evidence, including *Finneran et al. (2023)* and the CMS/ASCOBANS guidance, establishes that such activities are inherently capable of causing behavioural disturbance, displacement from feeding areas, and disruption of migration pathways. These effects fall squarely within the concept of “deliberate disturbance” for the purposes of Article 12.
- 6.5 Notwithstanding this, the application fails to undertake any structured assessment of Article 12 compliance. There is no identification of disturbance thresholds, no modelling of the spatial extent of disturbance, and no evaluation of the likelihood of behavioural responses at the population level. Instead, the assessment relies on generic mitigation measures which, as

5 *Case C-127/02, Landelijke Vereniging tot Behoud van de Waddenzee and Nederlandse Vereniging tot Bescherming van Vogels v. Staatssecretaris van Landbouw, Natuurbeheer en Visserij*

6 *Case C-103/00, Commission of the European Communities v Hellenic Republic.*

noted above, are not capable of preventing behavioural disturbance and are not supported by evidence demonstrating their effectiveness.

- 6.6 Where a project cannot avoid disturbance, the only lawful route to authorisation is through a derogation under Article 16 of the Habitats Directive. That provision requires that three cumulative conditions be met: first, that there is no satisfactory alternative; second, that the derogation is justified by one of the limited grounds set out in Article 16(1), including imperative reasons of overriding public interest; and third, that the derogation will not be detrimental to the maintenance of the population of the species concerned at a favourable conservation status.
- 6.7 No such derogation assessment has been undertaken in this case. The omission is fatal. The Court has made clear that the strict protection regime under Article 12 operates independently of the Article 6(3) assessment and must be complied with in its own right. In circumstances where disturbance cannot be excluded, and no derogation has been sought or justified, the competent authority is precluded from granting consent.

7. Acoustic impacts and failure to apply Best Available Science.

- 7.1 The assessment of underwater noise impacts within the application is fundamentally deficient, both as a matter of scientific methodology and as a matter of law. The proposed works include the deployment of high-energy acoustic sources, including sub-bottom profilers and ultra-high-resolution seismic systems, together with associated vessel activity and repeated survey campaigns over a large marine area and over multiple years. Such activities are well established in scientific literature as giving rise to significant behavioural disturbance, displacement from feeding grounds, and disruption of ecological function across a wide range of marine species, in particular cetaceans and prey-dependent trophic systems.
- 7.2 Notwithstanding the scale, duration and intensity of the proposed acoustic emissions, the application fails to provide any site-specific modelling of noise propagation, fails to quantify spatial extent of ensonification, and fails to assess cumulative acoustic exposure arising from repeated survey campaigns and concurrent activities. This omission is directly contrary internationally accepted standards for environmental assessment of noise-generating activities and renders the assessment incapable of supporting lawful conclusions under either Directive 2011/92/EU or Article 6(3) of Directive 92/43/EEC.
- 7.3 The approach adopted appears to rely, whether expressly or implicitly, on the National Parks and Wildlife Service “Guidance to Manage the Risk to Marine Mammals from Man-made Sound Sources in Irish Waters” (2014). However, it is now expressly acknowledged at State level that this guidance is outdated and requires revision. Parliamentary debate^{7 8} confirms that the guidance is under review in light of advances in scientific understanding. In those circumstances, reliance upon that guidance cannot satisfy the requirement, established in the jurisprudence of the Court of Justice, that environmental assessments must be based on the

7 <https://www.oireachtas.ie/en/debates/question/2024-10-15/352/#:~:text=The%20National%20Parks%20and%20Wildlife,needed%20to%20ensure%20its%20effectiveness.>

8 <https://irl.eu-supply.com/ctm/Supplier/PublicPurchase/237078#:~:text=Detailed%20description:,%2C%20NPWS%20requests%20support:%201.>

best available scientific knowledge at the time of decision-making. Any assessment grounded in superseded guidance is, by definition, incapable of removing reasonable scientific doubt.

- 7.4 In contrast, internationally endorsed guidance adopted under the Convention on Migratory Species, ASCOBANS and ACCOBAMS establishes a far more stringent and scientifically robust framework. The CMS Family Guidelines (see appendix 7.1) recognise anthropogenic underwater noise as a major threat to marine species and require that Environmental Impact Assessments for noise-generating activities include independent scientific modelling of noise propagation, full characterisation of the acoustic source across the entire frequency spectrum, assessment of cumulative sound exposure (including Sound Exposure Level cumulative), and species-specific evaluation of vulnerability and behavioural response . These guidelines emphasise that reliance on simple distance thresholds or qualitative assumptions is scientifically unsound, and that sound propagation is highly dependent on environmental variables such as bathymetry, temperature stratification and seabed composition, all of which must be incorporated into modelling. They further require that mitigation measures be demonstrated to be effective, rather than assumed to be so.
- 7.5 The accompanying advisory note to those guidelines (appendix 7.2) reinforces that modelling must be independent, scientifically grounded, and capable of capturing cumulative exposure from multiple concurrent noise sources, including vessel traffic and sequential survey campaigns . ACCOBAMS guidance similarly requires dynamic, model-based exclusion zones, precautionary thresholds that account for uncertainty, and explicit assessment of long-range propagation and cumulative effects, including the interaction of multiple acoustic sources over time . None of these requirements have been met in the present application. Instead, the assessment relies on generic mitigation measures, such as Marine Mammal Observers, passive acoustic monitoring and soft-start procedures, without any scientific demonstration that such measures are capable of preventing behavioural disturbance or displacement.
- 7.6 The inadequacy of the approach is further underscored when measured against the German regulatory framework (appendix 7.3), which represents a leading example of Best Available Techniques and Best Environmental Practice in the management of underwater noise. German standards impose strict and enforceable thresholds, including limits on cumulative sound exposure (SEL) and peak sound pressure levels, typically applied at defined distances (for example, 750 metres from the source), together with mandatory real-time monitoring and validation of acoustic emissions. These standards also require the deployment of effective noise attenuation technologies, such as bubble curtains and alternative low-noise methods, to ensure compliance with those thresholds. The German approach is explicitly precautionary and is grounded in the requirement to prevent both injury and behavioural disturbance. The complete absence of any equivalent thresholds, modelling or enforceable limits in the present application demonstrates a failure to apply Best Available Techniques and Best Environmental Practice, as required under internationally recognised standards and as implicit in the obligations of the competent authority under EU environmental law.

- 7.7 Recent scientific literature further reinforces the inadequacy of the applicant's approach. Finneran et al. (2023) (appendix 7.4) and subsequent studies confirm that behavioural disturbance in marine mammals occurs at sound levels significantly below those associated with physical injury, and that repeated or prolonged exposure can lead to displacement from critical habitats, reduced foraging efficiency and energetic stress. These findings align with the CMS and ACCOBAMS guidance, which identify behavioural disturbance and habitat displacement as primary impact pathways. Importantly, such impacts are not mitigated by standard operational measures such as visual monitoring or soft-start procedures, which are designed primarily to reduce the risk of acute injury rather than to prevent behavioural responses.
- 7.8 The CMS guidelines further recognise that anthropogenic noise can mask biologically important sounds, disrupt communication and navigation, and displace species from key habitats, including feeding and breeding grounds, with cascading ecological consequences across trophic systems . In the context of the present application, where the site is acknowledged to support prey species and function as an ecologically relevant area for higher trophic species, the failure to assess these pathways is a material omission.
- 7.9 In these circumstances, the absence of site-specific noise modelling, the failure to assess cumulative acoustic exposure, the reliance on outdated national guidance, and the disregard of internationally recognised best practice and current scientific evidence together render the assessment legally deficient. It is not possible, on the basis of the information provided, to conclude that the proposed works will not have significant effects on the environment, nor is it possible to exclude, beyond reasonable scientific doubt, adverse effects on the integrity of European sites. The defect is therefore fundamental and precludes the grant of consent.

8. Water Framework Directive

- 8.1 The WFD assessment asserts no deterioration without quantitative analysis. In Bund für Umwelt und Naturschutz Deutschland⁹, paragraph 69 says Article 4(1)(a) must be interpreted as meaning that Member States are required to refuse authorisation if it may cause deterioration of the status of a body of surface water. There is a process to follow. No such demonstration has been made.
- 8.2 The Water Framework Directive assessment submitted in support of MUL 250019 is fundamentally deficient in both its methodology and its conclusions. While the report correctly identifies that it must demonstrate no deterioration in waterbody status and no interference with the achievement of good status under the River Basin Management Plan , it fails to carry out a scientifically robust or legally compliant assessment of whether those objectives can in fact be met. Instead, the report adopts a screening-led approach which assumes, rather than demonstrates, that the proposed activities are "low risk" and therefore unlikely to affect water quality.
- 8.3 A lacuna in the assessment is its reliance on an analogy between the proposed works and categories of "low risk" activities derived from UK Environment Agency guidance, including minor works such as maintenance, small-scale removals, or single pile

9 Case C-461/13. Bund für Umwelt und Naturschutz Deutschland eV v Bundesrepublik. Deutschland

replacements. This comparison is manifestly inappropriate. The proposed development involves extensive geophysical and geotechnical surveys over a large marine area, including repeated seabed disturbance, boreholes, vibrocores and acoustic surveys over multiple years. These activities are neither comparable in scale nor intensity to the minor works relied upon for screening. The effect of this mischaracterisation is that potentially significant impact pathways are screened out at the outset without proper assessment.

- 8.4 The report further fails to engage meaningfully with the full Zone of Influence as defined within its own methodology. While it acknowledges that the Zone of Influence must include indirect pathways such as sediment plumes, underwater noise, vibration and biological effects extending beyond the immediate footprint, the subsequent assessment reduces the analysis almost entirely to the physical footprint of seabed disturbance. This is particularly evident in the scoping tables, where the conclusion that impacts are negligible is based on the assertion that the seabed footprint is small (e.g. approximately 1 m² per interaction) and represents a minimal percentage of the total waterbody area. This approach is legally and scientifically flawed, as it ignores the fact that WFD impacts are not determined by footprint alone, but by changes to ecological and chemical quality elements across the waterbody.
- 8.5 In particular, the report fails to assess sediment resuspension and plume dispersion arising from intrusive activities such as vibrocores and boreholes. The Zone of Influence definition explicitly recognises that sediment plumes may extend beyond the immediate footprint, yet no modelling or quantitative assessment of sediment transport, turbidity, or contaminant mobilisation is provided. This omission is critical, as sediment resuspension has the potential to affect phytoplankton, benthic communities, and water column processes, all of which are relevant biological quality elements under the Directive.
- 8.6 Equally, the report contains a clear scientific error in asserting that benthic and water column habitats are “not sensitive to noise and vibration impacts”. This statement is inconsistent with current scientific understanding and directly contradicts the report’s own acknowledgement that biological receptors, including fish, may be affected by underwater noise and vibration. The failure to assess acoustic impacts within the WFD framework is particularly significant given that fish are a biological quality element under Annex V of the Directive, and behavioural disturbance or displacement may affect their status classification.
- 8.7 The assessment also fails to consider cumulative effects, despite acknowledging that the Zone of Influence may extend to indirect and interacting pathways. There is no meaningful assessment of in-combination effects with other survey activities, offshore wind developments, or existing pressures within the Celtic Sea. This is a material omission, particularly in a region subject to multiple concurrent and proposed marine developments, and undermines the conclusion that no deterioration will occur.
- 8.8 Finally, the report adopts a mitigation-led reasoning process whereby impacts are assumed to be negligible following the application of unspecified or generic mitigation measures. However, there is no prior demonstration of baseline impact magnitude, nor any quantitative

reassessment of residual effects. This reverses the required legal approach under the Water Framework Directive, as interpreted by the Court of Justice in *Bund für Umwelt und Naturschutz Deutschland*, where the Court held at paragraph 69 that authorisation must be refused where a project may cause deterioration. In the absence of a complete and evidence-based assessment demonstrating that no deterioration will occur, reliance on mitigation cannot cure the deficiency.

- 8.9 Taken together, these flaws demonstrate that the WFD assessment is not a robust, effects-based analysis but rather a qualitative justification exercise designed to support a predetermined conclusion. It does not provide the level of scientific certainty required to exclude deterioration or to demonstrate compliance with Article 4 of the Directive. Accordingly, it cannot lawfully support the grant of conse

9. Natura 2000 Risk Analysis

- 9.1 The evidence demonstrates that multiple sites and species are exposed to unassessed risks, including harbour porpoise, seals, seabirds and migratory fish. The absence of modelling and behavioural assessment means that displacement, disturbance and trophic impacts have not been evaluated in a complete or lawful manner.

10. Conclusion

The application is not robust and conclusive and contains lacunae. There has been no lawful EIA screening, no compliant Appropriate Assessment, no Article 12 compliance, and no adequate assessment of acoustic impacts. The competent authority is not in possession of the information required to make a lawful decision. MARA is therefore precluded in law from granting consent.

Yours Sincerely

Elizabeth Davidson

Wild Ireland Defence CLG.

CMS FAMILY GUIDELINES ON ENVIRONMENTAL IMPACT ASSESSMENT FOR MARINE NOISE-GENERATING ACTIVITIES

Mindful that Parties to CMS, ACCOBAMS and ASCOBANS have in several resolutions recognized underwater noise as a major threat to many marine species,

Recalling that the Conservation and Management Plan annexed to the Agreement stipulates that ASCOBANS work towards “the prevention of other significant disturbance, especially of an acoustic nature”,

Further recalling Resolution 6.2 *Adverse Effects of Underwater Noise on Marine Mammals during Offshore Construction Activities for Renewable Energy Production*, Resolution 5.4 *Adverse Effects of Sound, Vessels and Other Forms of Disturbance on Small Cetaceans*, Resolution 8.6 *Ocean Energy*, Resolution 8.8 *Addressing the Threats from Underwater Munitions* and Resolution 8.9 *Managing Cumulative Anthropogenic Impacts in the Marine Environment*;

Also recalling related decisions adopted by the Conference of the Parties to CMS, in particular Resolution 12.14 *Adverse Impacts of Anthropogenic Noise on Cetaceans and Other Migratory Species*, by which the *CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities* were adopted,

Noting related decisions adopted by the Meeting of the Parties to ACCOBAMS, in particular Resolution 5.15 *Addressing the Impact of Anthropogenic Noise*, and Resolutions 6.17 and 7.13 *Anthropogenic Noise*,

Taking note of the IWC Resolution 2018-4 *Anthropogenic Underwater Noise*,

Further noting MSFD, OSPAR and HELCOM work on noise data register and marine noise thresholds,

Recalling IMO guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life and taking note of the need for a full implementation of the guidelines by governments and the shipping industry, and noting the ongoing process to revise these guidelines within IMO,

Aware that these resolutions also call for noise-related considerations to be already taken into account in the planning stages of activities, especially by making effective use of Environmental Impact Assessments (EIA),

Reaffirming that the difficulty of quantifying detrimental effects of acoustic disturbance on cetaceans necessitates a precautionary approach in dealing with this issue,

Mindful of the fact that anthropogenic noise should be avoided wherever possible,

Grateful to the Principality of Monaco for providing funds for the development of these guidelines for the CMS Family under the Migratory Species Champion Programme, and to OceanCare for co-funding the project,

Expressing thanks to the experts that contributed to the development of this document, as well as to focal points and members of the scientific advisory bodies and working groups of CMS, ACCOBAMS and ASCOBANS that provided input and comments,

Recognizing that anthropogenic marine noise affects many species, and that the adoption of guidelines for environmental impact assessments for marine noise-generating activities would benefit a number of CMS species, including cetaceans, pinnipeds, marine turtles and sharks,

Noting the recommendations of the 'Best Practice Workshop: Fostering Inter-regional Cooperation in Underwater Noise Monitoring and Impact Assessment in Waters around Europe, within the Context of the European Marine Strategy Framework Directive', jointly organized by ACCOBAMS, ASCOBANS, CMS, and the European Cetacean Society (April 2017),

Noting the ACCOBAMS Workshop on sonar and cetacean interactions (October 2019), aimed to improve dialogue and cooperation of national navies.

The Meeting of the Parties to ASCOBANS

1. *Adopts* the CMS Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities attached as Annex and *welcomes* the Technical Support Information¹ contained in ASCOBANS/MOP9/Inf.6.2.6a;
2. *Strongly encourages* Parties to disseminate the CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities to all national departments involved in deciding on noise-generating activities;
3. *Recognizes* that the work done in relation to underwater noise is rapidly evolving, and *invites* the CMS Scientific Council, in collaboration with the Joint Noise Working Group of CMS, ACCOBAMS and ASCOBANS, to assess the need for updating the guidelines and/or its Technical Support Information regularly, as appropriate;
4. *Encourages* Parties to fully support and transparently provide data towards the ICES impulsive noise registry, as well as consider providing information about planned noise-generating activities to allow making use of the registry as management tool;
5. *Invites* the private sector and other stakeholders to take note of the development of these guidelines in assessing, mitigating and minimizing the negative effects of sound on marine species;
6. *Welcomes* the efforts of the private sector and other stakeholders to reduce anthropogenic noise in the marine environment and *strongly encourages* them to continue making this a priority;
7. *Requests* the Advisory Committee, supported by the Joint Noise Working Group of CMS, ACCOBAMS and ASCOBANS, to continue monitoring new available information on the effects of underwater noise on cetaceans and their prey species, as well as the effective assessment and management of this threat, and to make recommendations to Parties as appropriate;
8. *Requests* the Advisory Committee, supported by the Joint Noise Working Group of CMS, ACCOBAMS and ASCOBANS, to engage and collaborate with other relevant bodies considering anthropogenic noise, including the IWC, ICES, HELCOM and OSPAR;
9. *Recommends* that Parties, the private sector and other stakeholders apply Best Available Technology (BAT) and Best Environmental Practice (BEP) including, where appropriate, clean technology, in their efforts to reduce or mitigate marine noise pollution, taking into account, when published, the CMS Technical Series on *Best Available Technology (BAT) and Best Environmental Practice (BEP) for Three Noise Sources: Shipping, Seismic Airgun Surveys, and Pile Driving* currently under preparation; and

¹ <https://www.cms.int/en/guidelines/cms-family-guidelines-EIAs-marine-noise>

10. *Encourages* Parties to take into account the Action Plan resulting from the ACCOBAMS Workshop on sonar and cetacean interactions, and join collaborative effort in as a voluntary approach.

CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities

These **CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities** have been developed to present the Best Available Techniques (BAT) and Best Environmental Practice (BEP), as called for in CMS Resolutions 9.19, 10.24 and 10.15, ACCOBAMS Resolution 5.15 and ASCOBANS Resolutions 6.2 and 8.11. In addition to the parent convention, CMS, these guidelines are relevant to:

- Agreement on the Conservation of Cetaceans of the Black Seas Mediterranean Seas and Contiguous Atlantic Area (ACCOBAMS)
- Agreement on the Conservation of Seals in the Wadden Sea (Wadden Sea Seals)
- Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)
- MOU Concerning Conservation Measures for the Eastern Atlantic Populations of the Mediterranean Monk Seal (*Monachus monachus*) (Atlantic Monk Seals)
- MOU Concerning Conservation Measures for Marine Turtles of the Atlantic Coast of Africa (Atlantic Marine Turtles)
- MOU Concerning the Conservation of the Manatee and Small Cetaceans of Western Africa and Macaronesia (Western African Aquatic Mammals)
- MOU for the Conservation of Cetaceans and their Habitats in the Pacific Islands Region (Pacific Islands Cetaceans)
- MOU on the Conservation and Management of Dugongs (*Dugong dugon*) and their Habitats throughout their Range (Dugong)
- MOU on the Conservation and Management of Marine Turtles and their Habitats of the Indian Ocean and South-East Asia (IOSEA)
- MOU on the Conservation of Migratory Sharks (Sharks)

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I. Introduction

1. These **CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities** are designed to provide regulators with tailored advice to apply in domestic jurisdictions, as appropriate, to create EIA standards between jurisdictions seeking to manage marine noise-generating activities. The requirements within each of the modules are designed to ensure that the information being provided by proponents will provide decision-makers with sufficient information to make an informed decision about impacts. The modules should be read in tandem with the **Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities** (available at www.cms.int/guidelines/cms-family-guidelines-EIAs-marine-noise). They are structured to stand as one complete unit or to be used as discrete modules, tailored for national and agreement approaches.
2. The sea is the interconnected system of all the Earth's oceanic waters, including the five named 'oceans' - the Atlantic, Pacific, Indian, Southern and Arctic Oceans - a continuous body of salty water that covers over 70 per cent of the Earth's surface. This vast aquatic environment is home to a wider range of higher animal taxa than exists on land. Many marine species have yet to be discovered and the number known to science is expanding annually.
3. The sea also provides people with food—mainly fish, shellfish and seaweed—as well as other marine resources. It is a shared resource for us all.
4. Marine wildlife relies on sound for vital life functions, including communication, prey and predator detection, orientation and for sensing surroundings. The ocean environment is filled with natural sound (ambient noise) from biological (marine animals) and physical processes (earthquakes, wind, ice and rain) (Urick, 1983). Species living in this environment are adapted to these sounds.
5. Over the past century many anthropogenic marine activities have increased levels of noise (Hildebrand 2009; André et.al. 2010; Miksis-Olds and Nichols 2016) These modern anthropogenic noises have the potential for physical, physiological and behavioural impacts (Southall et.al. 2007).
6. Parties to CMS, ACCOBAMS and ASCOBANS have in several resolutions recognized underwater noise as a major threat to many marine species. These resolutions also call for noise-related considerations to be taken into account as early as the planning stages of activities, especially by making effective use of Environmental Impact Assessments (EIAs). The Convention on Biological Diversity Decision XII/23 also encourages governments to require EIAs for noise-generating offshore activities, and to combine acoustic mapping with habitat mapping to identify areas where these species may be exposed to noise impacts. (Prideaux, 2017b)
7. Wildlife exposed to elevated or prolonged anthropogenic noise can suffer direct injury and/or temporary or permanent auditory threshold shifts. Noise can mask important natural sounds, such as the call of a mate, or the sound made by prey or predator. Anthropogenic noise can also displace wildlife from important habitats. These impacts are experienced by a wide range of species including fish, crustaceans, cephalopods, pinnipeds (seals, sea lions and walrus), sirenians (dugong and manatee), sea turtles, the polar bear, marine otters and cetaceans (whales, dolphins and porpoises) (Southall et.al. 2007; Aguilar de Soto, 2017a; 2017b; Castellote, 2017a; 2017b; Frey, 2017; Hooker, 2017; McCauley, 2017; Marsh, 2017; Notarbartolo di Sciara, 2017a; 2017b; 2017c; Parks, 2017; Truda Palazzo, 2017; Vongraven, 2017). Where there is risk, full assessment of impact should be conducted.

8. The propagation of sound in water is complex and requires many variables to be carefully considered before it can be known if a noise-generating activity is appropriate or not. It is inappropriate to generalize sound transmission without fully investigating propagation (Prideaux, 2017a). Often, statements are made in Environmental Impact Assessments that a noise-generating activity is 'X' distance from 'Y' species or habitat and therefore, will have no impact. In these cases, distance is used as a basic proxy for impact but is rarely backed with scientifically modelled information. (Wright et.al. 2013; Prideaux and Prideaux 2015)

9. To present a defensible Environmental Impact Assessment for any noise-generating activity proposal, proponents need to have expertly modelled the noise of the proposed activity in the region and under the conditions they plan to operate. Regulators should have an understanding of the ambient or natural sound in the proposed area. This might require CMS Parties or jurisdictions to develop a metric or method for defining this, by drawing on the range of resources available worldwide. (Prideaux, 2017a)

10. All EIAs should include operational procedures to mitigate impact effectively during activities, and there should be proof of the mitigation's efficacy. These are the operational mitigation procedures that should be detailed in the national or regional regulations of the jurisdictions where the activity is proposed. Operational monitoring and mitigation procedures differ around the world, and may include industry/company best practices. Monitoring often includes, *inter alia*:

- a. periods of visual and other observation before a noise-generating activity commences
- b. passive acoustic monitoring
- c. marine mammal observers
- d. aerial surveys

Primary mitigation often includes, *inter alia*:

- e. delay to start, soft start and shut-down procedures
- f. sound dampers, including bubble curtains and cofferdams; sheathing and jacket tubes
- g. alternative low-noise or noise-free options (such as compiled in the OSPAR inventory of measures to mitigate the emission and environmental impact of underwater noise)

Secondary mitigation, where the aim is to prevent encounters of marine life with noise sources, includes *inter alia*:

- h. spatial & temporal exclusion of activities

11. Approaches to mitigate the impact of particle motion (e.g. reducing substrate or sea ice vibration) should also be investigated. Assessment of the appropriateness and efficacy of all operational procedures should be the responsibility of the government agency assessing Environmental Impact Assessments (EIA).

II. Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities

12. **Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities** is provided as a full document and as stand-alone modules at: www.cms.int/guidelines/cms-family-guidelines-EIAs-marine-noise.

13. This **Technical Support Information** has been specifically designed to provide clarity and certainty for regulators, when deciding to approve or restrict proposed activities. The document provides detailed information about species' vulnerabilities, habitat considerations, impact of exposure levels and proposed assessment criteria for all of the CMS-listed species groups and their prey.

14. The document is structured to cover specific areas, as follows:
- ‘Module A: Sound in Water is Complex’ provides an insight into the characteristics of sound propagation and dispersal. This module is designed to provide decision-makers with necessary foundation knowledge to interpret the other modules in these guidelines and any impact assessments that are presented to them for consideration.
 - ‘Module B: Expert Advice on Specific Species Groups’ presents twelve separate detailed sub-modules covering each of the CMS species groups, focusing on species’ vulnerabilities, habitat considerations, impact of exposure levels and assessment criteria.
 - ‘Module C: Decompression Stress’ provides important information on bubble formation in marine mammals, source of decompression stress, source frequency, level and duration, and assessment criteria.
 - ‘Module D: Exposure Levels’ presents a summary of the current state of knowledge about general exposure levels.
 - ‘Module E: Marine Noise-generating Activities’ provides a brief summary of military sonar, seismic surveys, civil high-powered sonar, coastal and offshore construction works, offshore platforms, playback and sound exposure experiments, shipping and vessel traffic, pingers and other noise-generating activities. Each section presents current knowledge about sound intensity level, frequency range and the activities’ general characteristics. The information is summarized in a table within the module.
 - ‘Module F: Related Intergovernmental or Regional Economic Organization Decisions’ presents the series of intergovernmental decisions that have determined the direction for regulation of anthropogenic marine noise.
 - ‘Module G: Principles of EIAs’ establishes basic principles including strategic environmental assessments, transparency, natural justice, independent peer review, consultation and burden of proof.
 - ‘Module H: CMS-Listed Species Potentially Impacted by Anthropogenic Marine Noise’
15. The evidence presented in the **Technical Support Information** Modules B, C and D establishes that the effective use of EIA for all marine noise-generating activities is in line with CMS Resolutions 9.19, 10.24 and 10.15, ACCOBAMS Resolution 5.15 and ASCOBANS Resolutions 6.2 and 8.11.
16. The **Technical Support Information** was developed before the release of ISO 18405: Underwater acoustics – Terminology that provides valuable consistency to language used. The Guidelines have been slightly adapted to reflect this new ISO standard, without losing the vital connection to the **Technical Support Information**. Decision-makers should refer to both documents wherever possible.

III. Technical Advisory Notes

17. The following advisory notes should be considered in conjunction with the individual EIA Guideline tables, as presented in Modules IV through XI.

III.1. Ambient Sound

18. ISO 18405 refers to ambient sound as “*sound that would be present in the absence of a specified activity*” and “*is location-specific and time-specific*”. These Guidelines more specifically define it as the average ambient (non-anthropogenic) sound levels from biological (marine animals) and physical processes (earthquakes, wind, ice and rain etc) of a given area. It should be measured (including daily and seasonal variations of frequency bands), for each component of an activity, prior to an EIA being developed and presented.

III.2 Sound Intensity

19. ISO 18405 defines sound intensity as “the product of the sound pressure”, which is the contribution to total pressure caused by the action of sound, “and sound particle velocity”, which is the contribution to velocity of a material element caused by the action of sound.

III.3. Exclusion Zones

20. Where exclusion zones are referred to in these Guidelines, these are areas that are designed for the protection of specific species and/or populations. Activities, and noise generated by activities, should not propagate into these areas.

III.4. Independent, Scientific Modelling of Noise Propagation

21. The objective of noise modelling for EIAs is to predict how much noise a particular activity will generate and how it will disperse. The aim is to model the received sound levels at given distances from the noise source. The amount of sound lost at the receiver from the sound source is propagation loss.

22. The intention of EIAs is to assess the impact of proposed activities on marine species and the environment. EIAs should not only present the main output of interest to the activity proponent, but should fully disclose the full frequency bandwidth of a proposed anthropogenic noise source, the intensity/pressure/energy output within that full range, and the principal or mean/median operating frequency of the source(s). (Urlick, 1983, Etter, 2013; Prideaux, 2017a)

23. Many propagation models have been developed such as ray theory, normal modes, multipath expansion, fast field, wavenumber integration or parabolic equation. However, no single model accounts for all frequencies and environments. Factors that influence which propagation model/s should be used include the activity noise frequencies, water depth, seabed topography, temperature and salinity, and spatial variations in the environment. (Urlick, 1983, Etter, 2013; Prideaux, 2017a)

24. The accuracy (i.e. bias) of sound propagation models depends heavily on the accuracy of their input data.

25. Commonly missing in EIAs is the modelling of particle motion propagation. Invertebrates, and some fish, detect sound through particle motion to identify predator and prey. Like sound intensity, particle motion varies significantly close to noise sources and in shallow water. Excessive levels of ensonification of these animal groups may lead to injury (barotrauma). Specific modelling techniques are required to predict the impact on these species.

III.5. Sound Exposure Level cumulative (SEL_{cum})

26. Sound Exposure Level (SEL) is generally referred to as dB 0 to peak or peak to peak (dB 0 to peak or dB p to p) for impulsive noise like air guns or pile driving, and dB Root Mean Squared (dB_{rms}) for non-impulsive noise such as ship noise, dredging or a wind farm’s constant drone. Often this metric is normalized to a single sound exposure of one second (NOAA, 2016). The SEL cumulative (SEL_{cum}) metric allows the cumulative exposure of an animal to a sound field for an extended period (often 24 hours) to be assessed against a predefined threshold for injury. (Southall, 2007; NOAA, 2016)

27. NOAA recommends a baseline accumulation period of 24 hours, but acknowledges that there may be specific exposure situations where this accumulation period requires adjustment (e.g., if activity lasts less than 24 hours or for situations where receivers are predicted to experience unusually long exposure durations). (NOAA, 2016) The limit value for pile driving in Germany is a sound exposure level of SEL₀₅ and the sound pressure level L_{peak}

at a distance of 750 metres.

III.6. Particle Motion/Displacement

28. Sound exposure levels works well for marine mammals but not well for a number of other marine species, including crustaceans, bivalves and cephalopods, because these species are thought to mainly detect sound through particle motion. Particle motion or particle displacement is the displacement of a material element caused by the action of sound. For these Guidelines the motion concerned is the organism resonating in sympathy with the surrounding sound waves, oscillating back and forth in a particular direction, rather than through the tympanic mechanism of marine mammals or swim-bladders of some fish species. (Mooney, et.al., 2010; André, et.al., 2011; Hawkins and Popper, 2016; NOAA, 2016)

29. The detection of particle motion or particle displacement requires different types of sensors than those utilized by a conventional hydrophone. These sensors must specify the particle motion in terms of the particle displacement, or its time derivatives (particle velocity or particle acceleration).

IV. EIA Guideline for Military and Civil High-powered Sonar

This EIA Guideline should be used in combination with the appropriate modules on species and impact from the **Technical Support Information** (B.1-12, C and D) as required for individual regional and domestic circumstances.

The EIA Guideline for Shipping and Vessels Traffic (V) should be used when the vessel is underway/making way with sonar off.

Component	Detail
Description of area	- Detail of the spatial extent and nature of the activity – including seabed bathymetry and composition, description of known stratification characteristics and broad ecosystem descriptions – as well as the spatial area that will experience anthropogenic noise, generated by the proposed activity, above natural ambient sound levels - Detail of the typical weather conditions and day length for the area during the proposed activity period - Identification of previous and simultaneous activities, their seasons and duration in the same or adjoining areas, existence and location of any marine protected areas, and a review of activity findings and implications

Component	Detail
Description of the equipment and activity	• Explanation of all activity technologies available and why each proposed technology is chosen • Description of the activity technology including: a. name and description of the vessel/s to be used (except where details would risk national security) b. total duration of the proposed activity c. proposed timing of operations – season/time of day/during all weather conditions d. signal duration and sound intensity level (dB peak to peak) in water @ 1 metre, frequency ranges and ping rate • Specification of the activity including anticipated nautical miles to be covered, track-lines, speed of vessels and sonar power setting changes • Identification of other activities having an impact in the region during and after the planned activity, if there is information, accompanied by the analysis and review of potential cumulative or synergistic impacts
Modelling of noise propagation loss	• Detail of independent, scientific modelling of noise propagation loss in the same season/weather conditions as the proposed activity accounting for local propagation features (depth and type of sea bottom, local propagation paths related to thermal stratification, SOFAR or natural channel characteristics) from point source out to a radius where the noise levels generated are close to natural ambient sound levels • Identification and mapping of proposed exclusion zones for species and description of how noise propagation into these zones will be minimized, taking into consideration the local propagation features
Species impact	• General: a. Identification and density of species likely to be present that will experience sound transmission generated by the proposed activity above natural ambient sound levels; and calculated from this, the extent of the impact zones b. Specification of the type of impact predicted (direct and indirect) as well as direct and indirect impacts on prey species c. Information on the behaviour of each species group, and the ability to detect each of the species for mitigation purposes (e.g. for marine mammals this will include diving behaviour, vocal behaviour, and conspicuousness when at the surface). • For each species group, also detail of the following (refer to module B species summaries): a. Species vulnerabilities: i. specific vulnerabilities to noise ii. lifecycle components of these vulnerabilities b. Habitat: i. specific habitat components considered ii. presence of critical habitat (calving, spawning, feeding grounds, resting bays etc.) c. Scientific assessment of impact: i. exposure levels ii. total exposure duration iii. determination of precautionary safe/harmful exposure levels (direct impact, indirect impact and disturbance) that account for uncertainty and avoids erroneous conclusions. • Quantification of the effectiveness of proposed mitigation methods

Component	Detail
Mitigation and monitoring plans	• Detail of: a. Scientific monitoring programmes before the survey to assess species distribution and behaviour, to facilitate the incorporation of monitoring results into the impact assessment. b. Scientific monitoring programmes, conducted during and after the activity, to assess impact c. Transparent processes for regular real-time public reporting of activity progress and all impacts encountered d. Most appropriate methods of species detection (e.g. visual/acoustic) and the range of available methods, and their advantages and limitations, as well their practical application during the activity. e. Impact mitigation proposals: i. 24-hour visual or other means of detection, especially under conditions of poor visibility (including high winds, night conditions, sea spray or fog) ii. establishing exclusion zones to protect specific species, accompanied by scientific and precautionary justification for these zones iii. soft start and shut-down protocols iv. spatio-temporal restrictions
Reporting plans	• Detail of post operation reporting plans including verification of the effectiveness of mitigation
Consultation and independent review	• Description of consultation, prior to EIA submission: a. List of stakeholders consulted b. Detail of information provided to stakeholders, opportunities given for appropriate engagement and the timeframe for feedback c. Explanation of what amendments and changes have been made to the proposed activity in response to the comments, queries, requests and concerns d. Explanation of which comments, queries, requests and concerns have not been accommodated and why • Description of independent review of draft EIA: a. Detail of the independent reviewers (species experts) including affiliation and qualifications b. Description of the comments, queries, requests and concerns received from each reviewer c. Explanation of what amendments and changes have been made to the proposed activity in response to the comments, queries, requests and concerns d. Explanation of which comments, queries, requests and concerns have not been accommodated and why

V. EIA Guideline for Shipping and Vessels Traffic

This EIA Guideline should be used in combination with the appropriate modules on species and impact from the **Technical Support Information** (B.1-12, C and D) as required for individual regional and domestic circumstances.

This EIA Guideline is directed to shipping regulators, including port and harbour authorities. Cumulative impact of shipping, identifying appropriate exclusion zones and shipping lanes should be the focus.

Component	Detail
Description of area	- Detail of the spatial extent and nature of the activity – including seabed bathymetry and composition, description of known stratification characteristics and broad ecosystem descriptions – as well as the spatial area that will experience anthropogenic noise, generated by the proposed shipping, above natural ambient sound levels - Detail of the typical weather conditions and day length for the area during the proposed activity period - Existence and location of any marine protected areas
Description of vessels and equipment	- Description of vessel/s (tonnage, propulsion and displacement) and equipment activity - Detail of all activities including sound intensity levels (dB_{rms}) @ 1 metre and frequency ranges (all frequencies to encompass, <i>inter alia</i>, propeller resonance, harmonics, cavitations, engine and hull noise) - Identification of other activities having an impact in the region accompanied by the analysis and review of potential cumulative or synergistic impacts
Modelling of noise propagation loss	- Detail of independent, scientific modelling of noise propagation loss in confined areas (harbours and channels) and accounting for local propagation features (depth and type of sea bottom, local propagation paths related to thermal stratification, SOFAR or natural channel characteristics) from point source out to a radius where the noise levels generated are close to natural ambient sound levels - Identification and mapping of proposed species exclusion zones and description of how noise propagation into these zones will be minimized, taking into consideration the local propagation features

Component	Detail
Species impact	• General: a. Identification and density of species likely to be present that will experience sound transmission generated by the proposed activity above natural ambient sound levels. Calculated from this, the extent of the impact zones, and the number of animals affected by the activity. b. Specification of the type of impact predicted (direct and indirect) as well as direct and indirect impacts on prey species c. Information on the behaviour of each species group, and the ability to detect each of the species for mitigation purposes (e.g. for marine mammals this will include diving behaviour, vocal behaviour, and conspicuousness when at the surface). • For each species group, also detail of the following (refer to module B species summary): a. Species vulnerabilities: i. specific vulnerabilities to noise ii. lifecycle components of these vulnerabilities b. Habitat: i. specific habitat components considered ii. presence of critical habitat (calving, spawning, feeding grounds, resting bays etc.) c. Scientific assessment of impact: i. exposure levels ii. total exposure duration iii. determination of precautionary safe/harmful exposure levels (direct impact, indirect impact and disturbance) that account for uncertainty and avoids erroneous conclusions
Monitoring plans	• Explanation of access to the evaluation of ongoing scientific monitoring data to assess impacts • Quantification of the effectiveness of proposed mitigation methods • Spatio-temporal restrictions
Consultation and independent review	• Description of consultation, prior to EIA submission: a. List of stakeholders consulted b. Detail of information provided to stakeholders, opportunities given for appropriate engagement and the timeframe for feedback c. Explanation of what amendments and changes have been made to the proposed activity in response to the comments, queries, requests and concerns d. Explanation of which comments, queries, requests and concerns have not been accommodated and why • Description of independent review of draft EIA: a. Detail of the independent reviewers (species experts) including affiliation and qualifications b. Description of the comments, queries, requests and concerns received from each reviewer c. Explanation of what amendments and changes have been made to the proposed activity in response to the comments, queries, requests and concerns d. Explanation of which comments, queries, requests and concerns have not been accommodated and why

VI. EIA Guideline for Seismic Surveys (Air Gun and Alternative Technologies)

This EIA Guideline should be used in combination with the appropriate modules on species and impact from the **Technical Support Information** (B.1-12, C and D) as required for individual regional and domestic circumstances.

Component	Detail
Description of area	• Detail of the spatial extent and nature of the survey – including seabed bathymetry and composition, description of known stratification characteristics and broad ecosystem descriptions – as well as the spatial area that will experience anthropogenic noise, generated by the proposed survey, above natural ambient sound levels • Detail of the typical weather conditions and day length for the area during the proposed activity period • Identification of previous and simultaneous activities, their seasons and duration in the same or adjoining areas, existence and location of any marine protected areas, and a review of activity findings and implications
Description of the equipment and activity	• Explanation of all survey technologies available (including low-noise or noise-free options) and why the proposed technology has been chosen. If low-noise options have not been chosen, an explanation should be provided about why these technologies are not preferred • Description of the survey technology including: a. name and description of the vessel/s to be used b. total duration of the proposed survey, date, timeframe c. proposed timing of operations – season/time of day/during all weather conditions d. sound intensity level (dB peak to peak) in water @ 1 metre and all frequency ranges and discharge rate e. if an air gun technology is proposed: i. number of arrays ii. number of air guns within each array iii. air gun charge pressure to be used iv. volume of each air gun in cubic inches v. official calibration figures supplied by the survey vessel to be charted, for noise modelling vi. depth the air guns to be set vii. number and length of streamers, distance set apart and depth the hydrophones are set • Specification of the survey including anticipated nautical miles to be covered, track-lines, speed of vessels, start-up and shut-down procedures, distance and procedures for vessel turns including any planned air gun power setting changes • Identification of other activities having an impact in the region during the planned survey, accompanied by the analysis and review of potential cumulative or synergistic impacts

Component	Detail
Modelling of noise propagation loss	• Detail of independent, scientific modelling of noise propagation loss in the same season/weather conditions as the proposed activity accounting for local propagation features (depth and type of sea bottom, local propagation paths related to thermal stratification, SOFAR or natural channel characteristics) from point source out to a radius where the noise levels generated are close to natural ambient sound levels • Identification and mapping of proposed species exclusion zones and description of how noise propagation into these zones will be minimized, taking into consideration the local propagation features
Species impact	• General: a. Identification and density of species likely to be present that will experience sound transmission generated by the proposed activity above natural ambient sound levels. Calculated from this, the extent of the impact zones, and the number of animals affected by the activity. a. Specification of the type of impact predicted (direct and indirect) as well as direct and indirect impacts to prey species b. Information on the behaviour of each species group, and the ability to detect each of the species for mitigation purposes (e.g. for marine mammals this will include diving behaviour, vocal behaviour, and conspicuousness when at the surface). • For each species group, also detail of the following (refer to module B species summary): a. Species vulnerabilities: i. specific vulnerabilities to noise ii. lifecycle components of these vulnerabilities b. Habitat: i. specific habitat components considered ii. presence of critical habitat (calving, spawning, feeding grounds, resting bays etc.) c. Scientific assessment of impact: i. exposure levels ii. total exposure duration iii. determination of precautionary safe/harmful exposure levels (direct impact, indirect impact and disturbance) that account for uncertainty and avoids erroneous conclusions

Component	Detail
Mitigation and monitoring plans	• Detail of: a. Scientific monitoring before the survey to assess baselines, species distribution and behaviour to facilitate the incorporation of monitoring results into the impact assessment b. Scientific monitoring programmes, conducted during and after the survey, to assess impact, including noise monitoring stations placed at specified distances c. Transparent processes for regular real-time public reporting of survey progress and all impacts encountered d. Most appropriate methods of species detection (e.g. visual/acoustic) and the range of available methods, and their advantages and limitations, as well their practical application during the activity. e. Impact mitigation proposals: i. 24-hour visual or other means of detection, especially under conditions of poor visibility (including high winds, night conditions, sea spray or fog) ii. establishing exclusion zones to protect specific species, including scientific and precautionary justification for these zones iii. soft start and shut-down protocols iv. protocols in place for consistent and detailed data recording (observer/PAM sightings and effort logs, survey tracks and operations) v. detailed, clear, chain of command for implementing shut-down mitigation protocols vi. spatio-temporal restrictions • Quantification of the effectiveness of proposed mitigation methods
Reporting plans	• Detail of post operation reporting plans including verification of the effectiveness of mitigation, and any shut-down procedures occurring and reasons why
Consultation and independent review	• Description of consultation, prior to EIA submission: a. List of stakeholders consulted b. Detail of information provided to stakeholders, opportunities given for appropriate engagement and the timeframe for feedback c. Explanation of what amendments and changes have been made to the proposed survey in response to the comments, queries, requests and concerns d. Explanation of which comments, queries, requests and concerns have not been accommodated and why • Description of independent review of draft EIA: a. Detail of the independent reviewers (species experts) including affiliation and qualifications b. Description of the comments, queries, requests and concerns received from each reviewer c. Explanation of what amendments and changes have been made to the proposed survey in response to the comments, queries, requests and concerns d. Explanation of which comments, queries, requests and concerns have not been accommodated and why

VII. EIA Guideline for Construction Works

This EIA Guideline should be used in combination with the appropriate modules on species and impact from the **Technical Support Information** (B.1-12, C and D) as required for individual regional and domestic circumstances. This guideline should be applied to all forms of marine construction, including dredging and similar vessel based activities where ships may be stationary, but under way. All commissioning and decommissioning activities should also follow these guidelines.

Component	Detail
Description of area	- Detail of the spatial extent and nature of the activity – including seabed bathymetry and composition, description of known stratification characteristics and broad ecosystem descriptions – as well as the spatial area that will experience anthropogenic noise, generated by the proposed activity, above natural ambient sound levels - Detail of the typical weather conditions and day length for the area during the proposed activity period - Identification of previous and simultaneous activities, their seasons and duration in the same or adjoining areas, existence and location of any marine protected areas, and a review of activity findings and implications
Description of the equipment and activity	- Explanation of all activity technologies available and why each proposed technology is chosen, including consideration of noise-free installation methods - Specification of: a. total duration of the proposed activity b. proposed timing of operations – season/time of day/during all weather conditions c. sound intensity level (dB peak to peak) in water @ 1 metre and frequency ranges d. If explosives are proposed: i. what type of explosive and what charge weight is proposed, also whether the explosive is going to be used on the seabed or subsurface ii. specification of sound intensity level (dB 0 to peak) in water @ 1 metre, frequency range and number of detonations and interval time - Description of noise counter measures e.g.: bubble curtains, noise dampers and cofferdams, including a description of state-of-the-art technology, Best Environmental Practice (BEP) or Best Available Technology (BAT) - Identification of other activities having an impact in the region during the planned activity, accompanied by the analysis and review of potential cumulative or synergistic impacts
Modelling of noise propagation loss	- Detail of independent, scientific modelling of noise propagation loss in the same season/weather conditions as the proposed activity accounting for local propagation features (depth and type of sea bottom, local propagation paths related to thermal stratification, SOFAR or natural channel characteristics) from point source out to a radius where the noise levels generated are close to natural ambient sound levels - Identification and mapping of proposed exclusion zones for species and description of how noise propagation into these zones will be minimized, taking into consideration the local propagation features

Component	Detail
Species impact	• General: a. Identification and density of species likely to be present that will experience sound transmission generated by the proposed activity above natural ambient sound levels; and calculated from this, the extent of the impact zones b. Specification of the type of impact predicted (direct and indirect) as well as direct and indirect impacts to prey species c. Information on the behaviour of each species group, and the ability to detect each of the species for mitigation purposes (e.g. for marine mammals this will include diving behaviour, vocal behaviour, and conspicuousness when at the surface). • For each species group, also detail of the following (refer to module B species summary): a. Species vulnerabilities: i. specific vulnerabilities to noise ii. lifecycle components of these vulnerabilities b. Habitat: i. specific habitat components considered ii. presence of critical habitat (calving, spawning, feeding grounds, resting bays etc.) c. Scientific assessment of impact: i. exposure levels ii. total exposure duration iii. determination of precautionary safe/harmful exposure levels (direct impact, indirect impact and disturbance) that account for uncertainty and avoids erroneous conclusions
Mitigation and monitoring plans	• Detail of: a. Scientific monitoring programmes, conducted before, during and after the activity, to assess impact, including noise monitoring stations placed at specified distances b. Transparent processes for regular real-time public reporting of activity progress and all impacts encountered c. Most appropriate methods of species detection (e.g. visual/acoustic) and the range of available methods, and their advantages and limitations, as well their practical application during the activity. d. Impact mitigation proposals: i. 24-hour visual or other means of detection, especially under conditions of poor visibility (including high winds, night conditions, sea spray or fog) ii. establishing exclusion zones to protect specific species, including scientific and precautionary justification for these zones iii. soft start and shut-down protocols iv. spatio-temporal restrictions • Quantification of the effectiveness of proposed mitigation methods
Reporting plans	• Detail of post operation reporting plans including verification of the effectiveness of mitigation, and any shut-down procedures occurring and reasons why

Component	Detail
Consultation and independent review	• Description of consultation, prior to EIA submission: a. List of stakeholders consulted b. Detail of information provided to stakeholders, opportunities given for appropriate engagement and the timeframe for feedback c. Explanation of what amendments and changes have been made to the proposed activity in response to the comments, queries, requests and concerns d. Explanation of which comments, queries, requests and concerns have not been accommodated and why e. If it is decided that BEP or BAT is not used, this should be justified • Description of independent review of draft EIA: a. Detail of the independent reviewers (species experts) including affiliation and qualifications b. Description of the comments, queries, requests and concerns received from each reviewer c. Explanation of what amendments and changes have been made to the proposed activity in response to the comments, queries, requests and concerns d. Explanation of which comments, queries, requests and concerns have not been accommodated and why

VIII. EIA Guideline for Offshore Platforms

This EIA Guideline should be used in combination with the appropriate modules on species and impact from the **Technical Support Information** (B.1-12, C and D) as required for individual regional and domestic circumstances.

All commissioning and decommissioning activities should also follow these guidelines. Where impulsive activities, such as offshore platforms being constructed through impact driven piles, the guidelines for VII: Construction Works should also be applied.

Component	Detail
Description of area	• Detail of the spatial extent and nature of the activity – including seabed bathymetry and composition, description of known stratification characteristics and broad ecosystem descriptions – as well as the spatial area that will experience anthropogenic noise, generated by the proposed activity, above natural ambient sound levels • Detail of the typical weather conditions and day length for the area during the proposed activity period • Identification of previous and simultaneous activities, their seasons and duration in the same or adjoining areas, existence and location of any marine protected areas, and a review of activity findings and implications

Component	Detail
Description of the equipment and activity	• Explanation of all activity technologies available and why each proposed technology is chosen, including consideration of alternatives • Description of the activity technology including name and description of the vessel/s and sea floor equipment to be used • Specification of: a. total duration of the proposed activity b. sound intensity level (dB_{rms}) in water @ 1 metre (from noise source e.g.: platform caissons or drill ship's hull etc.) and frequency ranges c. sound intensity levels (peak and rms) during planned maintenance schedules • Identification of other activities having an impact in the region during the planned activity, accompanied by the analysis and review of potential cumulative or synergistic impacts
Modelling of noise propagation loss	• Detail of independent, scientific modelling of noise propagation loss in the same season/weather conditions as the proposed activity accounting for local propagation features (depth and type of sea bottom, local propagation paths related to thermal stratification, SOFAR or natural channel characteristics) from point source out to a radius where the noise levels generated are close to natural ambient sound levels • Identification and mapping of proposed exclusion zones for species and description of how noise propagation into these zones will be minimized, taking into consideration the local propagation features
Species impact	• General: a. Identification and density of species likely to be present that will experience sound transmission generated by the proposed activity above natural ambient sound levels; and calculated from this, the extent of the impact zones b. Specification of the type of impact predicted (direct and indirect) as well as direct and indirect impacts to prey species c. Information on the behaviour of each species group, and the ability to detect each of the species for mitigation purposes (e.g. for marine mammals this will include diving behaviour, vocal behaviour, and conspicuousness when at the surface). • For each species group, also detail of the following (refer to module B species summary): a. Species vulnerabilities: i. specific vulnerabilities to noise ii. lifecycle components of these vulnerabilities b. Habitat: i. specific habitat components considered ii. presence of critical habitat (calving, spawning, feeding grounds, resting bays etc.) c. Scientific assessment of impact: i. exposure levels ii. total exposure duration: iii. determination of precautionary safe/harmful exposure levels (direct impact, indirect impact and disturbance) that account for uncertainty and avoids erroneous conclusions

Component	Detail
Mitigation and monitoring plans	• Detail of: a. Scientific monitoring programmes, conducted before, during and after the activity, to assess impact, including noise monitoring stations placed at specified distances b. Transparent processes for regular real-time public reporting of activity progress and all impacts encountered c. Most appropriate methods of species detection (e.g. visual/acoustic) and the range of available methods, and their advantages and limitations, as well their practical application during the activity. d. Impact mitigation proposals e. 24-hour visual or other means of detection, especially under conditions of poor visibility (including high winds, night conditions, sea spray or fog) f. Spatio-temporal restrictions • Quantification of the effectiveness of proposed mitigation methods
Reporting plans	• Detail of post operation reporting plans including verification of the effectiveness of mitigation
Consultation and independent review	• Description of consultation, prior to EIA submission: a. List of stakeholders consulted b. Detail of information provided to stakeholders, opportunities given for appropriate engagement and the timeframe for feedback c. Explanation of what amendments and changes have been made to the proposed activity in response to the comments, queries, requests and concerns d. Explanation of which comments, queries, requests and concerns have not been accommodated and why • Description of independent review of draft EIA: a. Detail of the independent reviewers (species experts) including affiliation and qualifications b. Description of the comments, queries, requests and concerns received from each reviewer c. Explanation of what amendments and changes have been made to the proposed activity in response to the comments, queries, requests and concerns d. Explanation of which comments, queries, requests and concerns have not been accommodated and why

IX. EIA Guideline for Playback and Sound Exposure Experiments

This EIA Guideline should be used in combination with the appropriate modules on species and impact from the **Technical Support Information** (B.1-12, C and D) as required for individual regional and domestic circumstances.

Component	Detail
Description of area	- Detail of the spatial extent and nature of the activity – including seabed bathymetry and composition, description of known stratification characteristics and broad ecosystem descriptions – as well as the spatial area that will experience anthropogenic noise, generated by the proposed activity, above natural ambient sound levels - Detail of the typical weather conditions and day length for the area during the proposed activity period - Identification of previous and simultaneous activities, their seasons and duration in the same or adjoining areas, existence and location of any marine protected areas, and a review of activity findings and implications
Description of the equipment and activity	- Noting that the scale of the noise needed to elicit a response (with respect to level and duration) may be much lower than in industry activities; and that noise can be controlled in order to affect only a small area or small number of individuals, the noise control measures of the experimental design should be described in detail. - Explanation of all technologies available for the activity and why each proposed technology is chosen - Description of the chosen technology including name and description of the vessel/s to be used - Specification of: - lowest practicable sound intensity level required - total duration of the proposed activity - proposed timing of operations – season/time of day/during all weather conditions - sound intensity level (dB peak to peak) in water @ 1 metre and all frequency ranges and discharge rate - if an air gun technology is proposed refer to VI - if explosives are proposed refer to VII - Specification of the activity including anticipated nautical miles to be covered, track-lines, speed of vessels, start-up and shut-down procedures, distance and procedures for vessel turns including any planned air gun power setting changes - Identification of other activities having an impact in the region during the planned activity, accompanied by the analysis and review of potential cumulative or synergistic impacts
Modelling of noise propagation loss	- Detail of independent, scientific modelling of noise propagation loss in the same season/weather conditions as the proposed activity accounting for local propagation features (depth and type of sea bottom, local propagation paths related to thermal stratification, SOFAR or natural channel characteristics) from point source out to a radius where the noise levels generated are close to natural ambient sound levels - Identification and mapping of proposed exclusion zones for species and description of how noise propagation into these zones will be minimized, taking into consideration the local propagation features

Component	Detail
Species impact	• General: a. Identification and density of species likely to be present that will experience sound transmission generated by the proposed activity above natural ambient sound levels; and calculated from this, the extent of the impact zones b. Specification of the type of impact predicted (direct and indirect) as well as direct and indirect impacts to prey species c. Information on the behaviour of each species group, and the ability to detect each of the species for mitigation purposes (e.g. for marine mammals this will include diving behaviour, vocal behaviour, and conspicuousness when at the surface). • For each species group, also detail of the following (refer to module B species summary): a. Species vulnerabilities: i. specific vulnerabilities to noise ii. lifecycle components of these vulnerabilities b. Habitat: i. specific habitat components considered ii. presence of critical habitat (calving, spawning, feeding grounds, resting bays etc.) c. Scientific assessment of impact: i. exposure levels ii. total exposure duration iii. determination of precautionary safe/harmful exposure levels (direct impact, indirect impact and disturbance) that account for uncertainty and avoids erroneous conclusions iv. how the experiment design will monitor target and non-target species and the steps that will be taken to halt sound emission if adverse response or behavioural changes are observed v. how exposures that are expected to elicit particular behavioural responses (e.g. responses elicited by predator sounds, conspecific signals) will inform specific mitigation and monitoring protocols. In such cases, impact assessment should also articulate what responses may not be related to the loudness of the exposure but to the behavioural significance of the signal/noise used.

Component	Detail
Mitigation and monitoring plans	• Detail of: a. Scientific monitoring programmes, conducted before, during and after the activity, to assess impact b. Transparent processes for regular real-time public reporting of activity progress and all impacts encountered c. Most appropriate methods of species detection (e.g. visual/acoustic) and the range of available methods, and their advantages and limitations, as well their practical application during the activity. d. Impact mitigation proposals: i. 24-hour visual or other means of detection, especially under conditions of poor visibility (including high winds, night conditions, sea spray or fog) ii. establishing exclusion zones to protect specific species, including scientific and precautionary justification for these zones iii. soft start and shut-down protocols iv. spatio-temporal restrictions • Quantification of the effectiveness of proposed mitigation methods
Reporting plans	• Detail of post operation reporting plans including verification of the effectiveness of mitigation
Consultation and independent review	• Description of consultation, prior to EIA submission: a. List of stakeholders consulted b. Detail of information provided to stakeholders, opportunities given for appropriate engagement and the timeframe for feedback c. Explanation of what amendments and changes have been made to the proposed activity in response to the comments, queries, requests and concerns d. Explanation of which comments, queries, requests and concerns have not been accommodated and why • Description of independent review of draft EIA: a. Detail of the independent reviewers (species experts) including affiliation and qualifications b. Description of the comments, queries, requests and concerns received from each reviewer c. Explanation of what amendments and changes have been made to the proposed activity in response to the comments, queries, requests and concerns d. Explanation of which comments, queries, requests and concerns have not been accommodated and why

X. EIA Guideline for Pingers (Acoustic Deterrent/Harassment Devices, Navigation)

This EIA Guideline should be used in combination with the appropriate modules on species and impact from the **Technical Support Information** (B.1-12, C and D) as required for individual regional and domestic circumstances.

Component	Detail
Description of area	• Detail of the spatial extent and nature of the activity – including seabed bathymetry and composition, description of known stratification characteristics and broad ecosystem descriptions – as well as the spatial area that will experience anthropogenic noise, generated by the proposed activity, above natural ambient sound levels. • Detail of the typical weather conditions and day length for the area during the proposed activity period • Identification of previous and simultaneous activities, their seasons and duration in the same or adjoining areas, existence and location of any marine protected areas, and a review of activity findings and implications
Description of the equipment and activity	• Explanation of all technologies available for the activity and why the proposed technology is chosen, including the description should also contain the consideration of alternatives • Specification of sound intensity level (dB peak to peak) in water @ 1 metre, frequency ranges and ping rate, sound exposure level (SEL), as well as proposed spacing of pingers • Identification of other activities having an impact in the region accompanied by the analysis and review of potential cumulative or synergistic impacts
Modelling of noise propagation loss	• Detail of independent, scientific modelling of noise propagation loss in the same season/weather conditions as the proposed activity accounting for local propagation features (depth and type of sea bottom, local propagation paths related to thermal stratification, SOFAR or natural channel characteristics) from point source out to a radius where the noise levels generated are close to natural ambient sound levels • Identification and mapping of proposed exclusion zones for species and description of how noise propagation into these zones will be minimized, taking into consideration the local propagation features

Component	Detail
Species impact	• General: a. Identification and density of species likely to be present that will experience sound transmission generated by the proposed activity above natural ambient sound levels; and calculated from this, the extent of the impact zones a. Specification of the type of impact predicted (direct and indirect) as well as direct and indirect impacts to prey species b. Information on the behaviour of each species group, and the ability to detect each of the species for mitigation purposes (e.g. for marine mammals this will include diving behaviour, vocal behaviour, and conspicuousness when at the surface). • For each species group, also detail of the following (refer to module B species summary): a. Species vulnerabilities: i. specific vulnerabilities to noise ii. lifecycle components of these vulnerabilities b. Habitat: i. specific habitat components considered ii. presence of critical habitat (calving, spawning, feeding grounds, resting bays etc.) c. Scientific assessment of impact: i. exposure levels ii. total exposure duration iii. determination of precautionary safe/harmful exposure levels (direct impact, indirect impact and disturbance) that account for uncertainty and avoids erroneous conclusions
Monitoring plans	• Detail of scientific monitoring programmes, conducted before, during and after the activity, to assess impact • Spatio-temporal restrictions • Quantification of the effectiveness of proposed mitigation methods
Reporting plans	• Detail of post operation reporting plans including verification of the effectiveness of mitigation
Consultation and independent review	• Description of consultation, prior to EIA submission: a. List of stakeholders consulted b. Detail of information provided to stakeholders, opportunities given for appropriate engagement and the timeframe for feedback c. Explanation of what amendments and changes have been made to the proposed activity in response to the comments, queries, requests and concerns d. Explanation of which comments, queries, requests and concerns have not been accommodated and why • Description of independent review of draft EIA: a. Detail of the independent reviewers (species experts) including affiliation and qualifications b. Description of the comments, queries, requests and concerns received from each reviewer c. Explanation of what amendments and changes have been made to the proposed activity in response to the comments, queries, requests and concerns d. Explanation of which comments, queries, requests and concerns have not been accommodated and why

XI. EIA Guideline for Other Noise-generating Activities (Acoustic Data Transmission, Wind, Tidal and Wave Turbines and Future Technologies)

This EIA Guideline should be used in combination with the appropriate modules on species and impact from the **Technical Support Information** (B.1-12, C and D) as required for individual regional and domestic circumstances.

All commissioning and decommissioning activities should also follow these guidelines.

Component	Detail
Description of area	- Detail of the spatial extent and nature of the activity – including seabed bathymetry and composition, description of known stratification characteristics and broad ecosystem descriptions – as well as the spatial area that will experience anthropogenic noise, generated by the proposed activity, above natural ambient sound levels - Detail of the typical weather conditions and day length for the area during the proposed activity period - Identification of previous and simultaneous activities, their seasons and duration in the same or adjoining areas, existence and location of any marine protected areas, and a review of activity findings and implications
Description of the equipment and activity	- Explanation of all technologies available for the activity - Specification of sound intensity level (dB) in water @ 1 metre, and frequency ranges. This should include dB peak to peak for acoustic data transmission for example, dB_{rms} for wind, tidal and wave turbines and future technologies categorized accordingly - Identification of other activities having an impact in the region during the planned activity, accompanied by the analysis and review of potential cumulative or synergistic impacts
Modelling of noise propagation loss	- Detail of independent, scientific modelling of noise propagation loss in the same season/weather conditions as the proposed activity accounting for local propagation features (depth and type of sea bottom, local propagation paths related to thermal stratification, SOFAR or natural channel characteristics) from point source out to a radius where the noise levels generated are close to natural ambient sound levels - Identification and mapping of proposed exclusion zones for species and description of how noise propagation into these zones will be minimized, taking into consideration the local propagation features

Component	Detail
Species impact	• General: a. Identification and density of species likely to be present that will experience sound transmission generated by the proposed activity above natural ambient sound levels; and calculated from this, the extent of the impact zones b. Specification of the type of impact predicted (direct and indirect) as well as direct and indirect impacts to prey species c. Information on the behaviour of each species group, and the ability to detect each of the species for mitigation purposes (e.g. for marine mammals this will include diving behaviour, vocal behaviour, and conspicuousness when at the surface). • For each species group, also detail of the following (refer to module B species summary): a. Species vulnerabilities: i. specific vulnerabilities to noise ii. lifecycle components of these vulnerabilities b. Habitat: i. specific habitat components considered ii. presence of critical habitat (calving, spawning, feeding grounds, resting bays etc.) c. Scientific assessment of impact: i. exposure levels ii. total exposure duration iii. determination of precautionary safe/harmful exposure levels (direct impact, indirect impact and disturbance) that account for uncertainty and avoids erroneous conclusions • Quantification of the effectiveness of proposed mitigation methods
Monitoring plans	• Explanation of ongoing scientific monitoring programmes to assess impact • Most appropriate methods of species detection (e.g. visual/acoustic) and the range of available methods, and their advantages and limitations, as well their practical application during the activity. • Spatio-temporal restrictions
Consultation and independent review	• Description of consultation, prior to EIA submission: a. List of stakeholders consulted b. Detail of information provided to stakeholders, opportunities given for appropriate engagement and the timeframe for feedback c. Explanation of what amendments and changes have been made to the proposed activity in response to the comments, queries, requests and concerns d. Explanation of which comments, queries, requests and concerns have not been accommodated and why • Description of independent review of draft EIA: a. Detail of the independent reviewers (species experts) including affiliation and qualifications b. Description of the comments, queries, requests and concerns received from each reviewer c. Explanation of what amendments and changes have been made to the proposed activity in response to the comments, queries, requests and concerns d. Explanation of which comments, queries, requests and concerns have not been accommodated and why

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Additional references are detailed in the Technical Support Information at www.cms.int/guidelines/cms-family-guidelines-EIAs-marine-noise.



Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities



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Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities

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Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities

Parties to the Convention on Migratory Species (CMS), the Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS) and the Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS) have recognized underwater noise as a major threat to many marine species. Several resolutions have been passed calling for effective measures to mitigate and minimize the impact of noise pollution on marine life.

CMS, ACCOBAMS and ASCOBANS decisions also recognize that addressing this issue effectively requires that noise-related considerations should be taken into account starting with the planning stage of activities, especially by making effective use of Environmental Impact Assessments (EIA). The Convention on Biological Diversity Decision XII/23 encourages governments to require EIAs for noise-generating offshore activities and to combine acoustic mapping with habitat mapping to identify areas where these species may be exposed to noise impacts.

A considerable number of national and regional operational guidelines detail the impacts to be avoided and mitigation measures to be taken during proposed operations. For the most part, these focus on cetaceans. Few guidelines cover other species, and almost none has been developed for the specific content that should be provided in EIAs before approvals and permits are granted.

Thanks to a voluntary contribution from the Principality of Monaco under the Migratory Species Champions programme, and an additional contribution from OceanCare, the CMS, ASCOBANS and ACCOBAMS Secretariats are pleased to have developed guidelines for Environmental Impact Assessment for noise-generating offshore industries, providing a clear pathway to implementing the Best Available Techniques (BAT) and Best Environmental Practice (BEP).

This Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities is structured to stand as one complete unit or to be used as discrete modules, tailored for national and agreement approaches.

The full document and the stand-alone modules are online at cms.int/guidelines/cms-family-guidelines-EIAs-marine-noise



The [Government of the Principality of Monaco](#) were recognized as Champion for their generous support and commitment towards marine species conservation for the period 2015–2017. The development of this Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities has been funded with the contribution granted by Monaco under the Migratory Species Champion Programme.



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Acronyms

ACCOBAMS	Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contiguous Atlantic Area
ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas
BAT	Best Available Techniques
BEP	Best Environmental Practice
CBD	Convention on Biological Diversity
CMS	Convention on the Conservation of Migratory Species of Wild Animals or Convention on Migratory Species
dB	decibels
DSC	deep sound channel
EEH	Equal Energy Hypothesis
EIA	Environmental Impact Assessment
IMO	International Maritime Organization
IWC	International Whaling Commission
NOAA	National Oceanic and Atmospheric Administration (US)
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PTS	permanent threshold shift
RMS	root mean squared
SEA	Strategic Environmental Assessment
SEL	sound exposure level
SEL _{cum}	cumulative sound exposure level
SIL	Sound Intensity Level
SOCAL-BRS	Biological and Behavioural Response Studies of Marine Mammals in Southern California
SOFAR	Sound Fixing and Ranging Channels
SPL	Sound Pressure Level
TTS	temporary threshold shift
UK	United Kingdom of Great Britain and Northern Ireland
US	United States of America

Tables

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Executive Summary

The sea is the interconnected system of all the Earth's oceanic waters, including the five named 'oceans' - the Atlantic, Pacific, Indian, Southern and Arctic Oceans - a connected body of salty water that covers over 70 percent of the Earth's surface.

This vast environment is home to a broader spectrum of higher animal taxa than exists on land. Many marine species have yet to be discovered, and the number known to science is expanding annually. The sea also provides people with substantial supplies of food, mainly fish, shellfish and seaweed, in addition to marine resource extraction. It is a shared resource for us all.

Levels of anthropogenic marine noise have doubled in some areas of the world, every decade, for the past 60 years. When considered in addition to the number other anthropogenic threats in the marine environment, increasing noise can be a life-threatening trend for many marine species.

Marine wildlife rely on sound for vital life functions, including communication, prey and predator detection, orientation and for sensing surroundings. While the ocean is certainly a sound-filled environment and many natural (or biological) sounds are very loud; wildlife is not adapted to anthropogenic noise.

Animals exposed to elevated or prolonged anthropogenic noise can suffer direct injury and temporary or permanent auditory threshold shifts. Noise can mask important natural sounds, such as the call of a mate, the sound made by prey or a predator. They can be displaced from important habitats. These impacts are experienced by a wide range of species including fish, crustaceans and cephalopods, pinnipeds (seals, sea lions and walrus), sirenians (dugong and manatee), sea turtles, the polar bear, marine otters and cetaceans (whales, dolphins and porpoises).

The *Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities* has been developed to present the Best Available Techniques (BAT) and Best Environmental Practice (BEP). The document is structured to stand as one complete unit or to be used as discrete modules, tailored for national and agreement approaches.

The modules that follow are structured to cover species area, as follows:

'Module A: Sound in Water is Complex' provides an insight into the characteristics of sound propagation and dispersal. This module is designed to provide decision-makers with necessary foundation knowledge to interpret the other modules in these guidelines and any impact assessments that are presented to them for consideration.

'Module B: Expert Advice on Specific Species Groups' presents 12 separate detailed sub-modules covering each of the CMS species groups, focusing on species' vulnerabilities, habitat considerations, the impact of exposure levels and assessment criteria.

'Module C: Decompression Stress' provides important information on bubble formation in marine mammals, source of decompression stress, source frequency, level and duration, and assessment criteria.

'Module D: Exposure Levels' presents a summary of the current state of knowledge about general exposure levels.

'Module E: Marine Noise-generating Activities' provides a summary of military sonar, seismic surveys, civil high-powered sonar, coastal and offshore construction works, offshore platforms, playback and sound exposure experiments, shipping and vessel traffic, pingers and other noise-generating activities. Each section presents



current knowledge about sound intensity level, frequency range and the general characteristics of activities. The information is summarized in a table within the module.

‘Module F: Related Intergovernmental or Regional Economic

Organisation Decisions’ presents the series of intergovernmental decisions that have determined the direction for regulation of anthropogenic marine noise.

‘Module G: Principles of EIAs’ establishes basic principles including strategic environmental assessments, transparency, natural justice, independent peer review, consultation and burden of proof.

‘Module H: CMS-Listed Species Potentially Impacted by Anthropogenic Marine Noise’ provides the list of relevant CMS listed as of CMS CoP11.

The *Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities* is structured to stand as one complete unit or to be used as discrete modules, tailored for national and agreement approaches.

The complete document and the discrete modules are online at: cms.int/guidelines/cms-family-guidelines-EIAs-marine-noise

A. Sound in Water is Complex

Geoff Prideaux
Wild Migration

The ocean environment is filled with natural sound from animals and physical processes. Species living in this environment are adapted to these sounds. Over the past century, many anthropogenic marine activities have increased levels of noise. (André *et al* 2010, Hildebrand 2009) These modern anthropogenic noises have the potential for physical, physiological and behavioural impacts on marine fauna—mammals, reptiles, fish and invertebrates. (Southall *et al* 2007)

The propagation of sound in water is complex and requires many variables to be carefully considered before it can be known if a noise-generating activity is appropriate or not. It is inappropriate to generalize sound transmission without fully investigating propagation.

Often, statements are made in Environmental Impact Assessments that a noise-generating activity is ‘X’ distance from ‘Y’ species or habitat, and therefore will have no impact. In these cases, distance is used as a proxy for impact but is rarely backed with scientifically modelled information. (Wright *et al* 2013, Prideaux and Prideaux 2015)

The behaviour of sound in the marine environment is different from sound in air. The extent and way that sound travels (propagation) is affected by many factors, including the frequency of the sound, water depth and density differences within the water column that vary with temperature, salinity and pressure. (Clay and Medwin 1997, Etter 2013, Lurton 2010, Wagstaff 1981) Seawater is roughly 800–1,500 times denser than air and sound travels around five times faster in this medium. (Lurton 2010) Consequently, a sound arriving at an animal is subject to propagation conditions that are complex. (Calambokidis *et al* 2002, Hildebrand 2009, Lurton 2010, McCauley *et al* 2000)

To present a defensible Environmental Impact Assessment for any noise-generating activity proposal, proponents need to have ‘independent, scientific modelling of sound propagation’ of the proposed activity in the

region and under the conditions they plan to operate.

Understanding what basic concepts should be presented is important to assess if the Environmental Impact Assessment is defensible and sufficient.

A.1. Basic concepts

The study of acoustics is a specialised and technical field. Professional acousticians will consider much more complexities beyond the scope of this paper.

The basic concepts that decision-makers may need to understand are outlined in a very simplified form, specifically to be accessible to a lay-audience.

A.1.1. Elasticity

The speed of sound is not a fixed numerical value. Sound wave speed varies widely and depends on the medium, or material, it is transmitted through, such as solids, gas or liquids. Sound waves move through a medium by transferring kinetic energy from one molecule to the next. (Lurton 2010) Each medium has its own elasticity (or resistance to molecular deformity). This elasticity factor affects the sound wave’s movement significantly. Solid mediums, such as metal, transmit sound waves extremely fast because the solid molecules are tightly packed together, providing only tiny spaces for vibration. Through this high-elasticity medium, solid molecules act like small springs aiding the wave’s movement. The speed of sound through aluminium, for example, is around $6,319\text{ms}^{-1}$. Gas, such as air, vibrates at a slower speed because of larger spaces between each molecule. This allows greater deformation and results in lower elasticity. Sound waves, moving through air at a temperature of 20°C , will only travel around 342ms^{-1} . Liquid molecules, such as seawater, bond together in a tighter formation compared with gas molecules. This results in less

deformation, creating a higher elasticity than gas. Sound waves, moving through the water at 22°C, travel at around $1,484\text{ms}^{-1}$.

(Brekhovskikh and Lysanov 2006, Au and Hastings 2009, Ross 2013) Temperature also affects molecules. Molecules move faster under higher temperatures, transmitting sound waves more rapidly across the medium. Conversely, decreasing temperatures cause the molecules to vibrate at a slower pace, hindering the sound wave's movement. (Brekhovskikh and Lysanov 2006, Au and Hastings 2009, Ross 2013) The temperature of seawater at different depths is therefore of importance to modelling.

A.1.2. Spherical Spreading, Cylindrical Spreading, Transmission Loss and Absorption Loss

The way sound propagates is also important. Spherical spreading is simply sound leaving a point source in an expanding spherical shape. As sound waves reach the sea surface and seafloor, they can no longer maintain their spherical shape, and they begin to resemble the shape of an expanding cheese wheel. This is called cylindrical spreading.

The transmission loss, or the decrease in the sound intensity levels, happens uniformly in all directions during spherical transmission. However, when sound is in a state of cylindrical transmission, it cannot propagate uniformly. The sound is effectively contained between the sea surface and the sea floor, while the radius still expands uniformly (the sides of the cheese wheel). The height is now fixed, and so the sound intensity level decreases more slowly. (Urick 1983, Au and Hastings 2009, Lurton 2010, Jensen *et al* 2011)

In actuality, the seabed is rarely, if ever, flat and parallel to the sea surface. These natural variations add extra complexities to modelling cylindrical spreading. (Lurton 2010, Jensen *et al* 2011)

Absorption is a form of loss that obeys a different law of variation with range than the loss due to spreading. It involves a process of conversion of acoustic energy into heat and thereby represents a true loss of acoustic energy where the propagation is taking place. (Urick 1983) Absorption losses are less for lower frequencies noise relative to higher frequency noise; that is lower frequency noise generally propagates further in the marine environment.

However, all of these characteristics must be known to model accurately, as should the water depth and the rise and fall of the seabed surrounding it.

A.1.3. Sound Fixing and Ranging Channels (SOFAR)

As well as spherical and cylindrical spreading, another variable can impact how far sound will be transmitted. This is usually called a Sound Fixing and Ranging Channel (SOFAR) and is a horizontal layer of water in the ocean at which depth, the speed of sound is at its minimum.

The SOFAR channel is created through the interactive effect of temperature and water pressure (and, to a smaller extent, salinity). This occurs because the pressure in the ocean increases with depth, but the temperature is more variable, generally falling rapidly in the main thermocline from the surface to around a thousand metres deep and then remaining almost unchanged from there to the ocean floor. Near the surface, the rapidly falling temperature causes a decrease in sound speed (or a negative sound speed gradient). With increasing depth, the increasing pressure causes an increase in sound speed (or a positive sound speed gradient). The depth where the sound speed is at a minimum is called the sound channel axis. The speed gradient above and below the sound channel axis acts as a lens, bending sound towards the depth of minimum speed. The portion of sound that remains within the sound channel encounters no acoustic loss from the reflection of the sea surface and seafloor. Because of this low transmission loss, very long distances can be obtained from moderate acoustic power. (Urick 1983, Brekhovskikh and Lysanov 2006, Lurton 2010, Jensen *et al* 2011)

A.1.4. Decibels (dB)

The decibel (dB), 1/10th of a Bel, is used to measure sound level. It is the unit that will be presented in documentation.

The dB is a logarithmic unit used to describe a ratio. The ratio may be power, sound pressure or intensity.

The logarithm of a number is the exponent to which another fixed value, the base, must be raised to produce that number. For example, the logarithm of 1,000 to base 10 is 3, because 1,000 is 10 to the power 3:

$$1,000 = 10 \times 10 \times 10 = 10^3.$$

More generally, if $x = b^y$, then y is the logarithm of x to base b , and is written $y = \log_b(x)$, so $\log_{10}(1,000) = 3$. (Au and Hastings 2009, Jensen *et al* 2011, Ross, 2013)

A common mistake made by people that are unfamiliar with the dB scale is to assume that 10dB is half as loud as 20dB and a third of 30dB.

To explain, suppose there are two

loudspeakers, the first playing a sound with power P1, and another playing a louder version of the same sound with power P2, but everything else (distance and frequency) remains the same.

The difference in decibels between the two is defined as:

$10 \log (P2/P1)$ dB where the log is to base 10.

If the second produces twice as much power as the first, the difference in dB is:

$10 \log (P2/P1) = 10 \log 2 = 3$ dB.

To continue the example, if the second has 10 times the power of the first, the difference in dB is:

$10 \log (P2/P1) = 10 \log 10 = 10$ dB.

If the second has a million times the power of the first, the difference in dB is:

$10 \log (P2/P1) = 10 \log 1,000,000 = 60$ dB.

This example shows one feature of decibel scales that are useful in discussing sound: they can describe very big ratios using manageable numbers.

A.1.5. Peak and RMS values

Peak value, as the term implies, is the point of a sound wave with the greatest amplitude. Peak values should be provided with impulsive (also known as plosive, explosive and pulsive) sounds like seismic air guns, pile driving, low-frequency sonar and explosives. (Au and Hastings 2009)

RMS (root mean squared) is the formula used to calculate the mean of a sound wave over time. RMS values should be provided with constant non-impulsive (also known as non-plosive or continuous) sounds like shipping propeller and engine noise, oil rig operations, some mid to high-frequency sonar and water-based wind turbines. (Au and Hastings 2009)

This is important to note as attempts to establish noise thresholds based on one pressure metric when modelling has utilised another, will produce errors that can reduce the effectiveness of any proposed mitigation measures. For example, noise measured in RMS can be ~10 dB less than the peak level and ~16 dB less than the peak-to-peak level.

A.1.6. Phase

Phase can be best described as the relational alignment with two or more sound waves over time. Very simplistically, waves with the same phase will constructively interfere to produce a wave whose amplitude is the sum of the two interfering waves, while

two waves which are 180 degrees out of phase will destructively interfere to cancel each other out. (Rossing and Fletcher 2013)

A.1.7. MicroPascals (μPa)

The pascal (Pa) is the standard measure for pressure. Scientists have agreed to use 1 microPascal (1 μPa) as the reference pressure for underwater sound. This figure will usually be represented at one meter from a noise source (ie 1 μPa @ 1m)

Most anthropogenic sound in the marine environment is produced across a large area. Sound measured in the acoustic 'near-field' environment tends to be highly variable, and if the sound is intense, can be physically impossible to measure.

To overcome this, sound modelling often makes source level measurements in the acoustic 'far-field' at sufficient distance from the source that the field has settled down. Source levels are then calculated back by a measured or modelled transmission loss to present a μPa measurement. This can introduce some assumptions/errors.

A.2. Necessity of Modelling

A.2.1. Sound Exposure Level cumulative (SEL_{cum})

Sound exposure level (SEL) is an important parameter when considering the impact of anthropogenic noise on marine species. SEL is a measure of the total energy contained within a noise signature; it depends on both amplitude of the sound and duration. This is often normalised to 1 second and is reported as 1 μPa²s.

According to NOAA's paper, Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing, (NOAA, 2016) sound exposure level works well for marine mammals but not well for other marine species (crustaceans, bivalves, cephalopods, finned fish, etc) because many non-mammal marine species detect sound through particle motion (the organism resonating in sympathy with the surrounding sound waves) rather than through a tympanic mechanism as with marine mammals. A more informed measurement introduced to modelling is sound exposure level cumulative (SEL_{cum}) by which a time component is extended beyond 1 second. (NOAA, 2016)

NOAA has set a default time of 24 hours for SEL_{cum}. An alternate prescribed time

can be applied to SEL_{cum} if stated. Within the SEL_{cum} metric, a reference to sound intensity level (0 to peak, peak to peak or rms) is not relevant due to the extended time parameter. (NOAA, 2016)

A.2.2. Independent, scientific modelling of sound propagation

These complexities illustrate the necessity for 'independent, scientific modelling of sound propagation' of sound propagation from noise-generating activities. (Urick 1983, Etter 2013) While noise modelling is common for land-based anthropogenic noise-producing activities, it is less common for proposals in the marine environment. The lack of rigorous noise modelling in the marine setting needs to be urgently addressed. (Prideaux and Prideaux 2015)

Independent, scientific modelling of sound propagation of each noise-generating activity proposal should be impartially conducted to provide decision-makers with credible and defensible information. The accuracy (i.e. bias) of models of sound propagation depends heavily on the accuracy of their inputs. Similarly, quantification of the precision (i.e. variability) of sound propagation models is rarely acknowledged but is also heavily dependent on the precision of the inputs into these models.

The modelling should provide a clear indication of sound dispersal characteristics, informed by local propagation features. (Urick 1983, Etter 2013)

With this information, the acoustic footprint of the noise-generating activity can be identified, and informed decisions about levels of noise propagation can be made. (Prideaux and Prideaux 2015)

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B. Expert Advice on Specific Species Groups

The sea is the interconnected system of all the Earth's oceanic waters, including the five named 'oceans' - the Atlantic, Pacific, Indian, Southern and Arctic Oceans - a connected body of salty water that covers over 70 percent of the Earth's surface.

This vast environment is home to a broader spectrum of higher animal taxa than exists on land. Many marine species have yet to be discovered, and the number known to science is expanding annually. The sea also provides people with substantial supplies of food, mainly fish, shellfish and seaweed. It is a shared resource for us all.

Levels of anthropogenic marine noise have doubled in some areas of the world, every decade, for the past 60 years. (McDonald and Hildebrand *et al* 2006, Weilgart 2007) When considered in addition to the number other anthropogenic threats in the marine environment, increasing noise can be a life-threatening trend for many marine species.

Marine wildlife rely on sound for its vital life functions, including communication, prey and predator detection, orientation and for sensing surroundings. (Hawkins and Popper 2014, Simmonds, Dolman *et al* 2014) While the ocean is certainly a sound-filled environment and many natural (or biological) sounds are very loud, wildlife is not adapted to anthropogenic noise.

The species groups covered in the following sub-modules are:

- [Inshore Odontocetes](#)
- [Offshore Odontocetes](#)
- [Beaked Whales](#)
- [Mysticetes](#)
- [Pinnipeds](#)
- [Polar Bears](#)
- [Sirenians](#)
- [Marine and Sea Otters](#)
- [Marine Turtles](#)
- [Fin-fish](#)
- [Elasmobranchs](#)
- [Marine Invertebrates](#)

General principles

Building on the information from module section A.1, sound waves move through a medium by transferring kinetic energy from one molecule to the next. Animals that are exposed to elevated or prolonged anthropogenic noise may experience passive resonance (particle motion) resulting in direct injury ranging from bruising to organ rupture and death (barotrauma). This damage can also include permanent or temporary auditory threshold shifts, compromising the animal's communication and ability to detect threats. Animals can be displaced from important habitats. Finally, noise can mask important natural sounds, such as the call of a mate, the sound made by prey or a predator.

These mechanisms, as well as factors such as stress, distraction, confusion and panic, can affect reproduction, death and growth rates, in turn affecting the long-term welfare of the population. (Southall, Schusterman *et al* 2000, Southall, Bowles *et al* 2007, Clark, Ellison *et al* 2009, Popper *et al* 2014, Hawkins and Popper 2016)

These impacts are experienced by a wide range of species including fish, crustaceans and cephalopods, pinnipeds (seals, sea lions and walrus), sirenians (dugong and manatee), sea turtles, the polar bear, marine otters and cetaceans (whales, dolphins and porpoises)—the most studied group of marine species when considering the impact of marine noise.

The NOAA acoustic guidelines (NOAA 2016), which employ the most up-to-date scientific information on the effects of noise on marine mammals, for impulsive and non-impulsive noise sources, are based on a dual metric—dB peak for instantaneous sound pressure and SEL accumulated over 24 h for both impulsive and non-impulsive, whichever is reached first. It is important to note that some jurisdictions, notably Germany, require appropriate sound intensity level metrics (0 to peak) in addition to SEL at a specified distance. Their dual requirement is because the way the energy is delivered—regarding both the duty cycle and the energy within the individual pulses of sound—influences the effects of sound exposure.

Sound exposure levels work well for marine mammals but not well for a number of other marine species, including crustaceans, bivalves and cephalopods, because these species detect sound through particle motion

(the organism resonating in sympathy with the surrounding sound waves) rather than through a tympanic mechanism of marine mammals or swim-bladders of some fish species. (Mooney, et.al., 2010; André, et.al., 2011; NOAA, 2016) Where sound pressure acts in all directions, particle pressure is an oscillation back and forth in a particular direction. The detection of particle motion requires different types of sensors than those utilized by a conventional hydrophone. These sensors must specify the particle motion regarding the particle displacement, or its time derivatives (particle velocity or particle acceleration).

There is the need for a coordinated effort by biologists and physicists to quantify (through both dedicated measurements and modelling) particle motion in the marine environment to assess noise impacts on fish and invertebrates. Dedicated measurements need to be carried out to collect data on particle motion at different depths and locations for the different sound sources.

While specific metrics about the impact of sound pressure are presented, where available, impact metrics (standard specifications and measurements) have not yet been developed for particle motion impact on marine species. Decisions makers are urged to use their judgement about the potential impact of particle motion, in the absence of well-defined guidelines.

The thresholds used in many jurisdictions consider only the onset of Permanent Threshold Shift (PTS) as an auditory injury, whereas in Germany, the onset of Temporary Threshold Shift (TTS) is

Table 1: Potential results of sound exposure (from Hawkins and Popper 2016)

Impact	Effects on animal
Mortality	Death from damage sustained during sound exposure
Injury to tissues; disruption of physiology	Damage to body tissue, e.g internal haemorrhaging, disruption of gas-filled organs like the swim bladder, consequent damage to surrounding tissues
Damage to the auditory system	Rupture of accessory hearing organs, damage to hair cells, permanent threshold shift, temporary threshold shift
Masking	Masking of biologically important sounds including sounds from conspecifics
Behavioural changes	Interruption of normal activities including feeding, schooling, spawning, migration, and displacement from favoured areas
<i>These effects will vary depending on the sound level and distance</i>	

considered the threshold of injury. This is based on the finding that in the long term even a TTS can result in neuron degeneration of synaptic contacts between hair cells and nerves (Kujawa and Liberman 2009; Kujawa and Liberman, 2015)

The current knowledge base is summarized in the following modules. If the Technical Background Information is revised at a later stage, the inclusion of diving seabirds would be a helpful addition.

This important volume of information should guide the assessment of Environmental Impact Assessment proposals.

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B.1. Inshore Odontocetes

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Odontocetes close to shore or in shallow waters

Consider when assessing

- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Offshore platforms
- Playback and sound exposure experiments
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- Agreement on the Conservation of Cetaceans of the Black Seas Mediterranean Seas and Contiguous Atlantic Area (ACCOBAMS)
- Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)
- MOU for the Conservation of Cetaceans and their Habitats in the Pacific Islands Region (Pacific Islands Cetaceans)
- MOU Concerning the Conservation of the Manatee and Small Cetaceans of Western Africa and Macaronesia (West African Aquatic Mammals)

Related modules

- Refer also to modules B.10, B.12 and C when assessing impact to inshore odontocetes

B.1.1. Species Vulnerabilities

Close-range, acute noise exposure is known to generate spatial displacement, often extended over the duration of the noise exposure (Anderwald *et al* 2013, Pirodda *et al* 2013), temporary hearing impairment (temporary threshold shifts or TTS)(e.g. Kastelein *et al* 2015, Lucke *et al* 2009) reduction in both occurrence and efficiency, or even cessation, of foraging behaviour (e.g. Pirodda *et al* 2014).

Permanent hearing impairment (permanent threshold shifts or PTS) has not been documented empirically (unethical) but is

expected to occur and exposure thresholds have been predicted (e.g. Southall *et al* 2007, NOAA 2016) , see table 2.

Long-range (and therefore of wider spatial magnitude), chronic noise exposure is also known to generate spatial displacement, often extended over the duration of the noise exposure (Campana *et al* 2015). Masking of communication and other biologically important acoustic signals also occurs (e.g. Gervaise *et al* 2012).

Spatial displacement can cause the temporary loss of important habitat, such as prime feeding ground, forcing individuals to exploit suboptimal foraging areas. This effect is of significant concern if foraging behaviour is seasonal and/or if foraging habitat is limited or patched. Similarly, displacement can reduce breeding opportunities if it occurs during the mating season. Therefore, foraging habitat and breeding season are particularly sensitive components to noise impact.

B.1.2. Habitat Considerations

Inshore odontocetes often feed on opportunistic, seasonally abundant prey (e.g. Shane *et al* 1986). Habitat is often degraded due to proximity to highly populated coastal areas, and are particularly exposed to higher levels of existing anthropogenic underwater noise (associated with coastal development, commercial ports, recreational boat ramps, etc.) in parts of their habitat range. Thus, populations have been fragmented or are in the process of being fragmented. For these reasons, suboptimal habitat should be available to perform the biological tasks that will be disturbed by the introduction of noise. Population structure should be known in enough detail to allow evaluation of the population's resilience to the disturbance. Some odontocetes show diel (24 hour cycle) movement patterns from offshore to inshore regions for resting (Thorne *et al* 2012), or prey accessibility (Goodwin 2008). Similarly, seasonal patterns have been described for inshore odontocetes mainly driven by their prey's life cycle (Pirodda *et al* 2014) or seasonality in human disturbance (Castellote *et al* 2015). These movement patterns and co-occurring disturbances should be considered to minimize odontocetes' exposure to noise or reduce cumulative impact. Some species have small home ranges or show high site fidelity with low connectivity. They therefore may be more vulnerable to population level impacts, particularly in areas of repeated anthropogenic activity. Caution should be taken to minimise overlaps with such areas. Appropriate scheduling of noise-generating activities at

periods with the lowest presence of odontocetes should be prioritized. Feeding can be concentrated in habitat specific features such as river mouths (Goetz *et al* 2007) or canyons (Moors-Murphy 2014). These spatial particularities of habitat should also be considered and their disturbance minimized.

B.1.3. Impact of Exposure Levels

The harbour porpoise has been described as the inshore odontocete most sensitive to noise exposure among the species of which we have data (Lucke *et al* 2009, Dekeling *et al* 2014, but see Popov *et al* 2011).

Based on the NOAA acoustic guidelines (NOAA 2016), which employ the most up-to-date scientific information on the effects of noise on marine mammals, onset of physiological effects, that is TTS and PTS, for impulsive and non-impulsive noise sources is based on a dual metric (dB peak for instantaneous sound pressure and SEL accumulated over 24 h for both impulsive and non-impulsive, whichever is reached first) and is summarized in the table (below) for high frequency hearing specialists, which includes the harbour porpoise.

These thresholds are based on weighted measurements, which take into consideration hearing sensitivity across frequencies for each hearing functional group. For more details please see NOAA (2016).

A more restrictive decision from the German Federal Maritime and Hydrographic Agency on the onset for physiological effects on harbour porpoises must also be considered in this context. This Agency has implemented a different threshold since 2003, specifically for pile driving operations. Criteria consist of a dual metric, SEL = 160dB re 1 mPa²/s and SPL(peak-peak) = 190 dB re 1μPa. Both measures should not be exceeded at a distance of 750 m from the piling site.

Regarding onset of behavioural disruption, NOAA has not yet updated its guidelines, and a threshold of 120 dB RMS for non-impulsive and 160 dB RMS for impulsive noise remain as the onset thresholds for all cetacean species. New information obtained

through controlled noise exposure studies on offshore cetacean species (e.g. SOCAL-BRS, 3S), suggests that onset of behavioural disruption is context dependent, and not only received levels but also distance to the source might play an important role in triggering a reaction. Few studies have been focused on behavioural reaction to noise on inshore odontocetes. These show how the onset of a response is triggered by the perceived loudness of the sound, not just received levels (Dyndo *et al* 2015). At least for harbour porpoises, this finding lends weight to the recent proposal by Tougaard *et al* (2015) that behavioural responses can be predicted from a certain level above their threshold at any given frequency (e.g. in the range of 40–50 dB above the hearing threshold for harbour porpoise).

For loud noise sources such as large diameter pile driving or seismic surveys commonly found in inshore odontocete habitat, the onset for behavioural response can occur at very substantial distances (e.g. Tougaard *et al* 2009, Thompson *et al* 2013).

B.1.4. Assessment Criteria

Several key characteristics on the biology of a species should be adequately assessed in an EIA. Population stock structure is a critical element to allow evaluating potential negative effects outside the scope of the individual level. This information is often unavailable for inshore odontocetes, and regulators or decision makers should adopt a much stricter position regarding this criterion for impact assessment decisions. Correct impact evaluation cannot be accomplished without understanding the extent of a potentially impacted population. Because spatial displacement is by far the most prominent effect to occur in noisy activities occurring in inshore odontocete habitat, sufficient information on habitat use and the availability of unaffected suboptimal habitat should be addressed in the evaluation. Other more general points should not be forgotten when determining if this species group has been adequately considered by an EIA, such as the correct relationship between the spectral

content of the noise source and hearing information for the affected species, and the integration of both behavioural and physiological effects for the estimated proportion of the population to be affected by the activity. One more important point to consider, is the

Table 2: TTS and PTS from impulsive and non-impulsive noise sources for inshore odontocetes (from NOAA 2016, based on high frequency functional group.)

Metric	TTS onset		PTS onset	
	Impulsive	Non-impulsive	Impulsive	Non-impulsive
LE,24h	140 dB	153 dB	155 dB	173 dB
Lpk,flat	196 dB	n/a	202 dB	202 dB

potential for cumulative effects, due to the coastal exposure of these populations of inshore odontocetes. The introduction of new anthropogenic noise should be assessed in consideration with other already occurring stressors in their habitat, such as other noise sources, chemical pollutants, or physical disturbance, among others.

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B.2. Offshore Odontocetes

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Odontocetes in deeper waters

Consider when assessing

- Military sonar
- Seismic surveys
- Civil high power sonar
- Offshore platforms
- Playback and sound exposure experiments
- Vessel traffic greater than 100 metric tons

Related CMS agreements

- Agreement on the Conservation of Cetaceans of the Black Seas Mediterranean Seas and Contiguous Atlantic Area (ACCOBAMS)
- Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)
- MOU for the Conservation of Cetaceans and their Habitats in the Pacific Islands Region (Pacific Islands Cetaceans)
- MOU Concerning the Conservation of the Manatee and Small Cetaceans of Western Africa and Macaronesia (West African Aquatic Mammals)

Related modules

- Beaked whales are considered separately in module B.3.
- Refer also to modules B.10, B.12 and C when assessing impact to offshore odontocetes

B.2.1. Species Vulnerabilities

While spatial displacement has been well documented in several inshore odontocetes species, little data is available for offshore odontocetes (other than beaked whale species), but similar behavioural responses are expected. Few direct measures of displacement are available (e.g. Goold 1996, Bowles *et al* 1994), and some indirect measures of disturbance exist, such as changes in vocal behaviour in short beaked common dolphins, Atlantic spotted dolphins and striped dolphins in the presence of anthropogenic noise (Papale *et al* 2015). Sperm whales exposed to tactical active sonar reduced energy intake or showed significant displacement with no immediate

compensation (Isojunno *et al* 2016, Miller *et al* 2012). However, sperm whales chronically exposed to seismic airgun survey noise in the Gulf of Mexico did not appear to avoid a seismic airgun survey, though they significantly reduced their swimming effort during noise exposure along with a tendency toward reduced foraging (Miller *et al* 2009). Changes in vocal behaviour are normally associated with displacement in other odontocetes (e.g. Holt *et al* 2009, Lesage 1999).

Physiological impact by close-range, acute noise exposure, such as temporary threshold shift, has never been described in offshore odontocetes due to the difficulty to maintain these species in captivity. There is just one anecdotal description of physiological injury due to airgun noise exposure on a pantropical spotted dolphin (Graya and Van Waerebeek, 2011).

This lack of evidence should not be considered conclusive but rather as reflecting the absence of studies. Furthermore, due to similarities in sound functionality, hearing anatomy and physiology between offshore and inshore odontocetes, the vulnerabilities described for inshore species are expected to be very similar for offshore species.

Because of the lack of knowledge on offshore odontocete habitat seasonal preferences (e.g. it is not known whether reproduction occurs in similar habitats as where foraging occurs), noise impact on these species cannot be broken into lifecycle components.

B.2.2. Habitat Considerations

Little survey effort has been dedicated to offshore waters in most exclusive economic offshore zones and even less in international waters. As a consequence, data on offshore odontocete occurrence, distribution and habitat preferences is scarce for most species. However, some generalizations can be highlighted: Sperm whales do not use offshore regions uniformly, topography plays a key role in shaping their distribution (e.g. Pirota *et al* 2011). Moreover, solitary individuals use the habitat differently from groups (Whitehead 2003).

The occurrence of eddies, often associated with numerous seafloor topographic structures (canyons and seamounts), are known to favour ecosystem richness and consequently, cetacean occurrence (Ballance *et al* 2006, Hoyt 2011, Redfern *et al* 2006, Correia *et al* 2015). Therefore, areas where eddies are known to occur, particularly those related to underwater topography features,

should be taken into special consideration when assessing impact to offshore odontocetes, even if no knowledge on cetacean occurrence is available.

B.2.3. Impact of Exposure Levels

Offshore odontocetes fall in their majority into the mid frequency hearing specialists. This group was considered for noise impact assessments during an international panel review (Southall *et al* 2007). This review has been updated in recent efforts by the U.S. Navy and NOAA. NOAA's most updated draft on acoustic guidelines (NOAA 2016) considers

TTS and PTS, for impulsive and non-impulsive noise sources is based on a dual metric (dB peak for unweighted instantaneous sound pressure (Lpk) and SEL accumulated over 24 h (LE,24h) for both impulsive and non-impulsive, whichever is reached first) and is summarized in the table below for mid frequency hearing specialists (Table 3).

Please note cumulative thresholds are based on weighted measurements, which take into consideration hearing sensitivity across frequencies for each hearing functional group. For more details please see NOAA (2016).

Regarding onset of behavioural disruption, NOAA has not yet updated its guidelines, and a threshold of 120 dB RMS for non-impulsive and 160 dB RMS for impulsive noise remains as the onset thresholds for all cetacean species. Recent results from one of the few behavioural response studies where offshore odontocetes, other than beaked whales, are targeted identified higher thresholds than expected for avoidance of military tactic sonar by free-ranging long-finned pilot whales (Antunes *et al* 2015). The US Navy currently uses a generic dose-response relationship to predict the responses of cetaceans to naval active sonar (US Navy 2008), which has been found to underestimate behavioural impacts on killer whales and beaked whales in multiple studies (Tyack *et al* 2011, DeRuiter *et al* 2013, Miller *et al* 2012 and 2014, Kuningas *et al* 2013). The navy curve appears to match more closely results with long-finned pilot whales, though the authors of this study suggest that the probability of avoidance for pilot whales at long distances from sonar sources could well be underestimated. These results highlight how

functional hearing grouping, particularly for offshore odontocete species, might not be the most conservative approach for noise mitigation purposes. Behavioural responses of cetaceans to sound stimuli often are strongly affected by the context of the exposure, which implies that species and the received sound level alone is not enough to predict type and strength of a response. Although limited in sample size, this new information has not yet been profiled in EIA procedures. Contextual variables are important and should be included in the assessment of the effects of noise on cetaceans (see Ellison *et al* 2012 for a context-based proposed approach).

Table 3: TTS and PTS from impulsive and non-impulsive noise sources for offshore odontocetes, excluding beaked whales (from NOAA 2016, based on mid frequency functional group)

Metric	TTS onset		PTS onset	
	Impulsive	Non-impulsive	Impulsive	Non-impulsive
LE,24h	170 dB	178 dB	185 dB	198 dB
Lpk,flat	224 dB	n/a	230 dB	230 dB

B.2.4. Assessment Criteria

Because our limited knowledge on offshore odontocete ecology and their seasonal habitat preferences, common sense mitigation procedures such as avoiding the season of higher odontocete occurrence might be difficult to implement. However, habitat predictive modelling is often applicable with limited data (Redfern *et al* 2006), and should be encouraged in situations where impact assessments suffer from odontocete data deficit.

It should also be noted that in some particular cases, spatial displacement has generated drastic indirect effects at the population level. Good examples are the several episodes of large numbers of narwhals entrapped in ice in Canada and West Greenland attributed to displacement caused by seismic surveys (Heide –Jørgensen *et al* 2013). Displacement in offshore areas could drive odontocetes towards fishing grounds, increasing the risk of entanglement. In cases where planned offshore disturbance is proposed near potential risk areas for odontocetes, this indirect impact mechanism must be evaluated. In the case of sperm whales, regulations tend to be made assuming that animals avoid areas with high sound levels. Thus some policies assume benefits of avoidance in terms of reduced sound exposure, even in the absence of evidence that it occurs

for some noise sources (Madsen *et al* 2006). Avoidance can also have adverse effects, with the biological significance depending upon whether important activities are affected by animal movement away from an aversive sound.

Other more general points should not be forgotten when determining if this species group has been adequately considered by an EIA, such as the correct relationship between the spectral content of the noise source and hearing information for the affected species, and the integration of both behavioural and physiological effects for the estimated proportion of the population to be affected by the activity.

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B.3. Beaked Whales

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Consider when assessing

- Military sonar
- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Offshore platforms
- Playback and sound exposure experiments
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- Agreement on the Conservation of Cetaceans of the Black Seas Mediterranean Seas and Contiguous Atlantic Area (ACCOBAMS)
- Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)
- MOU for the Conservation of Cetaceans and their Habitats in the Pacific Islands Region (Pacific Islands Cetaceans)

Related modules

- Refer also to modules B.10, B.12 and C when assessing impact to beaked whales

B.3.1. Species Vulnerabilities

Beaked whales (Ziphiids) became widely known to the public due to mass mortalities of whales stranded with gas/fat emboli when exposed to submarine-detection naval sonar or underwater explosions (Jepson *et al* 2003, Fernández *et al* 2005). Most researchers agree that a ‘fight or flight’ stress response is responsible for the deaths of whales following noise disturbances (Cox *et al* 2006). Interruption of foraging and avoidance at high speed have been found in different species of beaked whales subject to playbacks of naval sonar at 1/3rd octave RMS received levels as low as 89–127 dB re 1 μ Pa (Tyack *et al* 2011, DeRuiter *et al* 2013, Miller *et al* 2015). Beaked whales may also be sensitive to other sources of anthropogenic noise, as suggested by the effectiveness of acoustic pingers in reducing the bycatch of beaked whales in deep-water fisheries, much higher than for other species (Carretta *et al* 2011), and

by their apparent response to low levels of ship noise (Aguilar de Soto *et al* 2006). There has been a number of mass-strandings of beaked whales coincident in time and space with seismic activities (Malakof 2001, Castellote and Llorens 2016), but the lack of adequate post-mortem examinations has prevented assessing possible cause-effects relationships in these cases. This means that any intense underwater anthropogenic noise can be considered as of concern for beaked whales: blasting, intense naval and scientific sonar, seismics, pingers, etc.

It is still unknown why beaked whales are more sensitive to noise than many other marine mammal species. The reasons may lie in their specialized way of life. Ziphiids stretch their physiological capabilities to perform dives comparable to sperm whales, but with a much smaller body size (Tyack *et al* 2006). Their poor social defences from predators such as highly vocal killer whales may explain why beaked whales limit their vocal output (Aguilar de Soto *et al* 2012) and respond behaviourally to sound at relatively low received levels. The combination of a low threshold of response and a potentially delicate physiological balance may explain why behavioural responses can cause mortalities (Cox *et al* 2006).

Population data for beaked whales are scarce offshore, but long-term monitoring shows that local populations in nearshore deep-waters are small (<100-150 individuals), have high site-fidelity and apparently low connectivity and calving rate (Claridge, 2013, Reyes *et al* 2015). These characteristics generally reduce animal resilience to population-level impacts. Differences in population structure, with a reduced number of young, have been found between beaked whales inhabiting a naval training range and a semi-pristine neighbouring area in the Bahamas (Claridge, 2013). In summary, while discrete noise activities are of concern due to potential acute exposures/responses, there is a risk for population-level effects of noise on beaked whales inhabiting areas where impacts are repetitive.

B.3.2. Habitat Considerations

Some of the 22 species of the Ziphiidae family can be found in the deep waters of all oceans. However, beaked whales have a low probability of visual and acoustic detection (Barlow *et al* 2006, Barlow *et al* 2013) and knowledge about their distribution and abundance is poor, preventing identification of hot-spots offshore. Until more data exist, the assumption is that any area with deep waters is potential beaked whale habitat year-round.

Most mass-strandings related to naval sonar or underwater explosives have been recorded when the activities occurred in nearshore areas of steep bathymetry, suggesting that whales might die due to the stranding process. However, there is at least one mass-stranding case indicating that animals can die offshore before stranding: the naval exercise “Majestic Eagle”. This exercise occurred > 100 km offshore from the Canary Islands and dead whales were carried to the shore by the current and winds. The whales showed the same pathological findings identified previously as symptomatic of whales stranded alive in coincidence to naval exposure (Fernández *et al* 2012).

Thus, the vulnerability of beaked whales and their wide distribution make EIA relevant whenever human activities emitting intense sound occur near the slope or in abyssal waters offshore.

B.3.3. Impact of Exposure Levels

Beaked whales show strong avoidance reactions to a variety of anthropogenic sounds with the most sensitive fraction of the population responding at received levels of naval sonar below 100 dB re 1 μ Pa, and most of the animals tested responding at received levels of 140 dB re 1 μ Pa. This corresponds to ranges of several km from the ship operating the sonar (Miller *et al* 2015, Tyack *et al* 2011).

There are no data for thresholds of response for other noise sources. The range at which beaked whales may be expected to be at risk of disturbance from a given anthropogenic noise can be estimated from the characteristics of the sound source, acoustic propagation modelling and the dose: response data provided by behavioural response studies. For example, Tolstoy *et al* (2009) present broadband calibrated acoustic data on a seismic survey performed in shallow waters and received at deep (1600 m) and shallow water (50 m) sites. The line fit to have 95% of the received levels falling below a given received level (RL) was $RL = 175.64 - 29.21 \log_{10}(\text{range in km})$ for the deep water site and $RL = 183.62 - 19 \log_{10}(\text{range in km})$ at the shallow site. Solving the equation for shallow water and a RL of 140 dB at which beaked whales may be expected to be disturbed, the potential disturbance range would be $\text{range} = 10^{(43.62/19)} = 197 \text{ km}$. The range predicted to disturb more sensitive individuals within the population would be greater.

The spectrum of the air gun sounds reported by Tolstoy *et al* (2009) is highest below 80 Hz, well below the naval sonars whose effects have been studied for dose-

response curves, and in a frequency range where beaked whales are expected to have less sensitive hearing. It is difficult to weight the level of air guns by the hearing of beaked whale given the data available, but it is possible to make a rough estimate of the energy from air guns in the third octave band (which roughly match the frequency bands over which the mammalian ear integrates energy) of the naval sonars whose effects have been measured. The broadband SEL measured at 1 km for shallow water was 175 dB re 1 $\mu\text{Pa}^2\text{s}$. Third octave levels were also reported for a shot recorded in shallow water at 1 km range. The third octave level for this shot at the 3 kHz sonar frequency was about 130 dB re 1 $\mu\text{Pa}^2\text{s}$, suggesting that this frequency band was about 45 dB lower than the broadband source level (SL). This suggests using a sound pressure level of $183.62 - 45 \text{ dB}$ to estimate received level in this frequency band at 1 km range. In addition, seawater absorbs sound at about 0.18 dB/km at the 3 kHz sonar frequencies, and this absorption must be accounted for in the transmission loss. Therefore Transmission Loss (TL) = $19 \log_{10}(\text{range}) + 0.18 * \text{range}$. The range at which sensitive beaked whales, which respond at 100 dB re 1 μPa may respond, given that $TL = SL - RL$, i.e. $19 \log_{10}(\text{range}) + 0.18 * \text{range} = 183.62 - 45 - 100 = 38.62$, is estimated at 43 km.

These rough calculations show that beaked whales could be expected to be disturbed by exposure to airguns at ranges of 43-197+ km, assuming conditions as found by Tolstoy *et al* (2009). The actual values will depend upon the actual signature of the air gun array to be used, and the propagation conditions in the area. This guidance coupled with current data on beaked whale responses to anthropogenic noise suggests that each proposer should assess how sound is expected to propagate from the survey site to any beaked whale habitat with hundreds of km. If any of this habitat is expected to be exposed to levels of sound above those shown to disturb beaked whales (i.e. 100 dB re 1 μPa for the most sensitive individuals tested), then a further assessment should be made of the number of animals likely to be disturbed.

B.3.4. Assessment Criteria

EIA should consider different types of impacts, ranging from exposure of whales to intense received levels causing hearing damage to behavioural reactions with potential physiological consequences in some cases, to displacement and ecological effects (e.g. reduction in feeding rates or displacement

from preferred habitat due to avoidance behaviour resulting in lower fitness).

A framework for mitigation targeted to reduce risk of the different impacts above needs to be included in the EIA, including actions during the planning-phase, real-time mitigation protocols and post-activity reporting to inform future planning and mitigation (e.g. Aguilar de Soto *et al* 2015). An effective mitigation method is spatio-temporal avoidance of high density areas (Dolman *et al* 2011). This is informed by surveys and habitat modelling and can be aided by simulation engines. However, the scarcity of data supporting density maps for beaked whales increases uncertainty about the number of whales to be expected in a given area and the identification of high density areas. Thus, planning-phase mitigation is essential but it does not eliminate the possibility of encountering and affecting/harming beaked whales. Another aspect of planning-phase mitigation is the choice of acoustic devices to be used during the activity, as well as the source levels required to achieve the objectives of the activity. *In situ* measurements of sound transmission loss shortly before the activity may allow adjustment of source level to below the maximum, so that the maximum is not used by default. A protocol towards reducing total acoustic energy and peak source levels transmitted to the environment should be defined before the activity, for any activity, within workable limits.

Depending on the activity, EIA may require updated information of the density of beaked whales and other vulnerable species, before the activity, in order to allow current data to be compared with existing density maps and to improve their accuracy. Also, if a choice of locations is evaluated, it would be possible to decide locating the activity in the place with lower concentration of vulnerable species.

A powerful and cost-effective way to monitor the effects would be to moor passive acoustic recorders in the beaked whale habitats exposed to sound levels above 100 dB re 1 µPa and to monitor both the actual levels of anthropogenic sound and also to monitor for the rates at which beaked whale echolocation clicks are detected. In the case of seismic, modern seismic surveys often include the deployment of cabled geophones at the seabed. These could be easily equipped with high frequency hydrophones to record beaked whales and other marine fauna.

Given the low probability of visual detection of beaked whales even in good sea conditions, real-time mitigation methods

proposed in the EIA require increasing probability of detection by using passive acoustic monitoring systems with detectors programmed for automated classification of beaked whale vocalizations. Automatic detections can then be checked by trained personnel to take decisions about initiation of mitigation protocols.

B.3.5. Species not listed on the CMS Appendices that should also be considered during assessments

All beaked whales not currently listed by CMS seem to be particularly vulnerable to anthropogenic marine noise.

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B.4. Mysticetes

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Consider when assessing

- Military sonar
- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Offshore platforms
- Playback and Sound Exposure Experiments
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- Agreement on the Conservation of Cetaceans of the Black Seas Mediterranean Seas and Contiguous Atlantic Area (ACCOBAMS)
- Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)
- MOU for the Conservation of Cetaceans and their Habitats in the Pacific Islands Region (Pacific Islands Cetaceans)

Related modules

- Refer also to modules B.12 and C when assessing impact to mysticetes

B.4.1. Species Vulnerabilities

Mysticete whales are all known to rely upon acoustic communication to mediate critical life history activities, including social interactions associated with breeding, raising young, migration and foraging (Edds-Walton 1997, Clark 1990). Research into the hearing capabilities of mysticetes, based primarily on anatomical modelling, indicate that mysticetes, as a group, are possibly capable of hearing signals from a minimum of approximately 7 Hz up to 35 kHz (Southall *et al* 2007). This range of frequencies spans many sources of anthropogenic noise in the ocean, excluding only the highest frequency sonar systems and pinger systems > 25 kHz (Hildebrand *et al* 2009). Previous research has documented impacts of noise exposure to physiology, behaviour, and habitat usage in mysticetes (Richardson *et al* 1995, Nowacek *et al* 2007, Tyack 2008).

Physiological impacts have been documented in mysticetes in response to noise exposure. This includes evidence of a decrease in physiological stress levels in North Atlantic right whale associated with a reduction in shipping noise (Rolland *et al* 2012). Techniques are currently under development to allow testing of acute stress responses to short-term high amplitude noise exposure (Hunt *et al* 2013).

Behavioral impacts have been documented in mysticetes in response to a variety of noise sources over the past three decades. This includes evidence of military sonar affecting movement, foraging and acoustic behaviour (Miller *et al* 2000, Tyack 2009, Goldbogen *et al* 2013), seismic survey and air guns affecting movement and acoustic behaviour (Malme *et al* 1988, Di Iorio and Clark 2010, Castellote *et al* 2012), vessel noise affecting foraging, social and acoustic behaviour (Melcon *et al* 2012), and response to playback of predator and/or alarm stimuli (Cummings and Thompson 1971, Dunlop *et al* 2013, Nowacek *et al* 2004)

Habitat usage impacts have been documented in a number of cases. Previous studies have documented abandonment of habitat areas during periods of intense noise. One of the earliest documented cases occurred when commercial dredging and shipping activities resulted in abandonment of a critical calving ground in gray whales for the duration of human activities in an enclosed shallow water bay (Bryant *et al* 1984). Seismic surveys have resulted in large-scale, temporary, displacements of mysticete whales away from regions of seismic exploration in the Mediterranean (Castellote *et al* 2012). A further concern, of long-standing (Payne and Webb 1971), is the potential for even relatively low amplitude anthropogenic noise raising the background noise to a degree that it significantly reduces the range of communication for mysticetes. Recent studies have demonstrated the potential degree of masking experienced by mysticetes in urbanized habitat areas due to vessel traffic (Clark *et al* 2009, Hatch *et al* 2012). This is a major concern to result in chronic erosion of suitable habitat conditions through raising the baseline background noise levels.

B.4.2. Habitat Considerations

Based on previous studies, mysticetes show variable response to noise exposures in different habitat areas, possibly linked to differences in the behavioural states and/or the availability of suitable alternative habitats (Nowacek *et al* 2007). Most mysticete whales

show some level of seasonal migratory behaviours (Corkeron and Connor 1999), therefore many habitats may seasonably pose relatively higher or lower risk depending on presence or absence of particular species. Calving grounds, breeding grounds, and foraging grounds are seasonally vulnerable areas for which there may not be suitable alternate habitat for many species, and would be of particular concern to highly endangered populations with limited available critical habitat areas.

Studies of responsiveness to noise exposure have been conducted on calving and breeding grounds (Miller *et al* 2000), on migratory corridors (e.g. Malme *et al* 1988, Tyack 2009, Dunlop *et al* 2013), and on foraging grounds for a variety of species (Di Iorio and Clark 2010, Parks *et al* 2011, Goldbogen *et al* 2013). Studies of migrating whales indicate that individuals may be highly responsive to noise exposure during migration, but may be able to deviate around acoustic disturbance without significant changes to the migratory distance (Malme *et al* 1988, Tyack 2009, Dunlop *et al* 2013).

The greatest data gaps regarding relative risk by h

abitat and season come from the facts that a) many species only have been tested in one type of habitat area and b) detection of an overt behavioural response may not truly indicate disturbance if animals are unable or unwilling to leave the habitat for foraging or breeding purposes. Also, for several species there is little known on the location of biologically important habitats (breeding, calving and foraging grounds). Future research to assess physiological responses to the same acoustic disturbance in multiple habitat areas are needed to have a high level of confidence regarding the actual impacts of noise exposure to mysticetes.

B.4.3. Impact of Exposure Levels

Relatively little data are available regarding the hearing abilities of mysticetes. Much of the current level of understanding comes from either anatomical modelling studies (Ketten 2000) or indirectly through interpretation of behavioural responses of mysticetes to controlled exposure experiments (Mooney *et al* 2012). A thorough review of exposure criteria for behavioural responses for mysticetes is summarized in Southall *et al*

(2007). The thresholds for detectable behavioural responses to noise exposure varied by species, location and time of year, giving a wide range of thresholds for responses to multiple pulses and non-pulse signals.

Table 4: TTS and PTS from impulsive and non-impulsive noise sources for mysticetes (NOAA 2016)

Metric	TTS onset		PTS onset	
	Impulsive	Non-impulsive	Impulsive	Non-impulsive
SEL cum 24h	168 dB	179 dB	183 dB	199 dB
dB peak	213 dB	n/a	219 dB	n/a

Peak sound pressure (dB peak) has a reference value of 1 μPa , and the 24 hour cumulative sound exposure level (SEL cum 24h) has a reference value of 1 $\mu\text{Pa}^2\text{s}$.

B.4.4. Assessment Criteria

Based on an extensive body of literature on the effects of noise on mysticetes (including physiology, behaviour and temporary habitat abandonment), a number of detailed criteria should be considered to assess potential risk of an signal generating activity. These include:

- Amplitudes, signal structure (pulse, multi-pulse, non-pulse), and anticipated cumulative time of exposure.
- Vulnerability of the species or sustainable ‘take’ – Some mysticete species and stocks are highly endangered, and warrant additional consideration if proposed activities have any potential to cause impacts at any level.
- Seasonal variability in the potential risk due to migratory timing of occupancy (can activities be seasonally shifted to minimize overlap with mysticete presence in critical habitat areas?).
- Data on noise exposure studies of target species, or closely related species, with similar signal type
- Comparison of the proposed acoustic exposure relative to the ambient, background levels and spectra of environmental noise (i.e. relatively low level noise exposure may be more significant in acoustically ‘pristine’ habitats).
- Consideration of potential cumulative effects of an additional introduction of sound into the environment (i.e. increase in potential for masking, increase in duration of exposure on daily and/or seasonal scales).

B.4.5. Species not listed on the CMS Appendices that should also be considered during assessments

Several of the CMS Appendix I and II species have not previously been studied regarding responses to noise exposure.

In particular, relatively little is known regarding the acoustic behaviours of sei whale, *Balaenoptera borealis*, Antarctic minke whale, *Balaenoptera bonaerensis*, Bryde's whale, *Balaenoptera edeni* and Omura's whale, *Balaenoptera omurai*.

In addition to the species listed in CMS Appendix I and II gray whale, *Eschrichtius robustus*, should be considered, due to recent documentation of individuals in 'novel' habitats including multiple confirmed sightings in the Atlantic Ocean (McKeon *et al* 2016) and severely threatened stocks in the Eastern Pacific (Rugh 2005).

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B.5. Pinnipeds

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Consider when assessing

- Military sonar
- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Offshore platforms
- Playback and sound exposure experiments
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- Agreement on the Conservation of Seals in the Wadden Sea (Wadden Sea seals)
- MOU Concerning Conservation Measures for the Eastern Atlantic Populations of the Mediterranean Monk Seal (*Monachus monachus*) (Atlantic monk seals)

Related modules

- Refer also to modules B.10, B.12 and C when assessing impact to pinnipeds

B.5.1. Species Vulnerabilities

Pinnipeds are sensitive to sound in both air and under water, therefore, they are likely to be susceptible to the harmful effects of loud noise in both media. Recent research has revealed that many pinnipeds have a better hearing sensitivity in water than was previously believed. (Southall *et al* 2000, 2008, Reichmuth *et al* 2013)

In developing guidelines for underwater acoustic threshold levels for the onset of permanent and temporary threshold shifts in marine mammals, NOAA has been considering two pinniped families: Phocidae and Otariidae. Phocid species have consistently been found to have a more acute underwater acoustic sensitivity than otariids, especially in the higher frequency range. This reflects the fact that phocid ears are better adapted underwater for hearing than those of otariids, with larger, more dense middle ear ossicles. (NOAA, 2016) The effective auditory bandwidth in water of typical Phocid pinnipeds (underwater) is thought to be 50 Hz to 86 kHz while for Otariid pinnipeds (underwater) it is 60 Hz to 39 kHz (NOAA, 2016). The draft NOAA

guidelines do not pertain to marine mammal species under the U.S. Fish and Wildlife Service's jurisdiction, including the third family of pinnipeds: Odobenidae (walrus), which means there is no update on the auditory bandwidth of walrus.

Behavioural responses to anthropogenic noise have been documented in a number of different pinnipeds at considerable ranges indicating the need for precautionary mitigation (Kelly *et al* 1988) In addition to noise-induced threshold shifts, behavioural responses have included seals hauling out (possibly to avoid the noise) (Bohne *et al* 1985, 1986, Kastak *et al* 1999) and cessation of feeding (Harris *et al* 2001).

It is likely that pinniped foraging strategies also place them at risk from anthropogenic noise. Some pinnipeds forage at night, others transit to foraging locations by swimming along the bottom, and many dive to significant depths or forage over significant distances (Fowler *et al* 2007, Villegas-Amtmann *et al* 2013, Cronin *et al* 2013) with Australian sea lions foraging offshore out to 189 km (Lowther *et al* 2011).

In most respects, noise-induced threshold shifts in pinnipeds follow trends similar to those observed in odontocete cetaceans. Unique to pinnipeds are their vibrissae (whiskers), which are well supplied with nerves, blood vessels and muscles, functioning as a highly sensitive hydrodynamic receptor system (Miersch *et al* 2011). Vibrissae have been shown to be sufficiently sensitive to low frequency waterborne vibrations to be able to detect even the subtle movements of fish and other aquatic organisms (Renouf, 1979, Hanke *et al* 2012, Shatz and Groot, 2013). Ongoing masking through ensonification may impede the sensitivity of vibrissae and the animal's ability to forage.

It is possible that even if no behavioural reaction to anthropogenic noise is evident, masking of intraspecific signals may occur. (Kastak and Schusterman, 1998)

B.5.2. Habitat Considerations

Spatial displacement of pinnipeds by noise has been observed (e.g Harris *et al* 2001), however observations are too sparse and definitely require greater attention to be understood in ways that can inform management. Such displacement is likely to have serious consequences if affecting endangered species in their critical habitats, such as Mediterranean monk seals in Greece or Turkey. Displacement can cause the temporary loss of important habitat, such as feeding grounds, forcing individuals to either move to

sub-optimal feeding location, or to abandon feeding altogether. Noise can also reduce the abundance of prey (refer to modules on fin-fish and cephalopods in these guidelines).

Displacement can also reduce breeding opportunities, especially during mating seasons. Foraging habitat and breeding seasons are therefore important lifecycle components of pinniped vulnerabilities. In particular, the periods of suckling and weaning are vulnerable times for both mothers and pups.

Many pinnipeds species exhibit high site fidelity. For some there is little or no interchange of females between breeding colonies, even between those separated by short distances, such as in Australian sea lions, *Neophoca cinerea* (Campbell *et al* 2008). The site fidelity of these animals increases their risk of local extinction, especially at sites with low population numbers (e.g monk seals).

Some species of pinnipeds can range far offshore and because they are difficult to sight and identify at sea their offshore foraging may only be revealed by telemetry studies. These studies usually involve tagging individuals that might come ashore hundreds or even thousands of miles from offshore foraging habitats.

B.5.3. Impact of Exposure Levels

Onset of temporary threshold shift (TTS) and permanent threshold shift (PTS) for impulsive and non-impulsive noise, and at peak levels (for instantaneous impact) as well as sound exposure levels (SEL) accumulated over a 24 hour period based on the latest updates of the NOAA acoustic guidelines (NOAA, 2016), are summarized in the tables that follow (right).

Walrus, *Odobenus rosmarus*, hearing is relatively sensitive to low frequency sound, thus the species is likely to be susceptible to anthropogenic noise. (Kastelein *et al* 2002) TTS and PTS levels can be inferred from Southall *et al* (2007) for Odobenidae.

Kastelein *et al* 2002 has drawn useful general observations by

comparing hearing studies of the California sea lion, *Zalophus californianus*, harbour seal, *Phoca vitulina*, ringed seal, *Pusa hispida*, harp seal, *Pagophilus groenlandicus*, northern fur seal, *Callorhinus ursinus*, gray seal, *Halichoerus grypus*, Hawaiian monk seal, *Monachus schauinslandi* and northern elephant seal, *Mirounga angustirostris* to those of walrus. The high frequency cut-off of walrus hearing is much lower than other pinnipeds tested so far. The hearing sensitivity of the walrus *Odobenus rosmarus*, between 500 Hz and 12 kHz is similar to that of some phocids. The walrus, is much more sensitive to frequencies below 1 kHz than sea lion species tested. (Kastelein *et al* 2002) Other sensitive pinnipeds such as harbour seals (about 20 dB more sensitive to signals at 100 Hz than California sea lions) and elephant seal, *Mirounga angustirostris* and *Mirounga leonine*, are also more likely to hear low-frequency anthropogenic noise. (Kastak and Schusterman, 1998)

Assessment should consider that routine deep-divers, that dive to or below the deep sound channels, may be exposed to higher sound levels than would be predicted based on simple propagation models. Assessment should also consider convergence zones which may result in areas with higher sound levels at greater ranges.

Table 5: TTS and PTS from impulsive and non-impulsive noise sources for phocidae (from NOAA 2016)

Metric	TTS onset		PTS onset	
	Impulsive	Non-impulsive	Impulsive	Non-impulsive
SEL cum 24h	170dB	181dB	185dB	201dB
dB peak	212dB	n/a	218dB	218dB

Table 6: TTS and PTS from impulsive and non-impulsive noise sources for otariidae (from NOAA 2016)

Metric	TTS onset		PTS onset	
	Impulsive	Non-impulsive	Impulsive	Non-impulsive
SEL cum 24h	188dB	199dB	203dB	219dB
dB peak	226dB	n/a	232dB	232dB

Table 7: TTS and PTS from impulsive and non-impulsive noise sources for odobenidae (from Southall *et al* 2007)

Metric	TTS onset		PTS onset	
	Impulsive	Non-impulsive	Impulsive	Non-impulsive
SEL cum 24h	171dB	171dB	186dB	203dB
dB peak	212dB	212dB	218dB	218dB

B.5.4. Assessment Criteria

There have been surprisingly few studies of the effects of anthropogenic noise, particularly from seismic surveys, on pinnipeds (Gordon *et al* 2003).

The lack of evidence of dramatic effects of anthropogenic noise on pinnipeds, in contrast to the well-known mortality incidents with some cetaceans, does not necessarily mean that noise has negligible consequences on pinniped conservation, and more attention should be dedicated to achieving a better understanding of possible impacts. For instance, some pinnipeds may not appear to have been physically displaced by loud noise, moving instead to the sea surface, but these animals may be effectively prevented from foraging, due to an ensonified foraging environment.

It is important that assessment of impact for pinnipeds considers both the physiological impact (TTS and PTS) as well as the very real possibility of masking, causing both behavioural responses and making prey less available.

B.5.5. Species not listed on the CMS Appendices that should also be considered during assessments

The following species are also sensitive to anthropogenic marine noise:

- walrus, *Odobenus rosmarus*
- harbour seal, *Phoca vitulina*
- northern elephant seal, *Mirounga angustirostris*
- southern elephant seal, *Mirounga leonine*
- Caspian seal, *Phoca caspica*
- Australian sea lion, *Neophoca cinerea*
- Hawaiian monk seal, *Neomonachus schauinslandi*

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B.6. Polar Bears

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Consider when assessing

- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Offshore platforms
- Playback and sound exposure experiments
- Pingers and other noise-generating activities

Related modules

- Refer also to modules B.1 and B.5 when assessing impact to polar bears

B.6.1. Species Vulnerabilities

There are two studies of polar bear hearing, showing that polar bears have hearing similar to humans, and that best sensitivity was shown between 11.2 – 22.5 kHz (Nachtigall *et al* 2007), and 8 – 14 kHz (Owen and Bowles 2011).

There have not been many specific studies of polar bears and noise. It has been shown that polar bears in Spitsbergen are disturbed by snowmobiles and can show strong behavioural reactions on a distance of 2-3 km, females with cubs showing stronger reactions at longer distance than adult males (Andersen and Aars 2008).

Polar bear would be highly vulnerable when hunting, as they are hunting for seals and depend on stealth, either by sneaking up on seals or by waiting at seal breathing holes in the ice (Stirling 1974, Stirling and Latour 1978). Studies indicate that denning females could be somewhat protected from noise from seismic air guns, although they could be vulnerable if sound sources are within close proximity of the den (less than 100 m) (Blix and Lentfer 1992).

B.6.2. Habitat Considerations

Polar bear's essential habitat is sea ice. Polar bears would prefer to stay on sea ice covering shallow and productive shelf areas (Durner *et al* 2009, Schliebe *et al* 2006). There would be particular concerns associated with all activities that have an impact in areas which resource selection functions have shown are preferred sea ice habitat for polar bears (Durner *et al* 2009).

Some models project an ice-free Arctic Basin in summer in just a few years from now, before 2020 (Maslowski *et al* 2012), and modelling studies have shown that most subpopulations will be reduced and experience large environmental stress (Amstrup *et al* 2008, Hamilton *et al* 2014).

Although not exclusively associated with specific habitats, there are certain activities that might be a concern. Some industrial activities are located in important habitat, of special concern is oil drilling activities on sea ice in productive sea areas, and the prospect of new developments of petroleum exploration in critical habitat, especially in North America. It must be noted that there are little or no specific studies of the effect of noise or manmade sound on polar bears, thus the level of impact is to a large degree inferred from general expert knowledge of the effect of disturbance on these animals.

Future impact from disturbance from sound exposure needs to be focused on denning areas in spring, and areas of sea ice and glacier fronts that are used by females with cubs-of-the-year to find food immediately after den emergence. Arctic areas in northern Canada, bordering to the Arctic Basin are generally the areas where one expects sea ice habitat to persist for the longest period (Amstrup *et al* 2007).

B.6.3. Impact of Exposure Levels

Given the specific vulnerability of polar bears to habitat loss, the exposure level of polar bears, especially in denning areas in spring, and areas of sea ice and glacier fronts that are used by females with cubs-of-the-year to find food immediately after den emergence should be prioritized.

B.6.4. Assessment Criteria

An assessment of the future impact of noise would have to take into account the dramatically decreasing area of critical sea ice habitat, in some areas the length of the ice-free period from ice melt in spring till ice freeze-up in fall, has increased by more than 140 days in the period 1979-2015 (Laidre *et al* 2015).

A minimum would be that EIAs on impact of sound would assess to what extent sound exposure would be detrimental to reproductive success by directly considering the effect of sound in denning areas and productive sea ice areas in the vicinity of denning areas, and also areas of sea ice over productive shelf areas.

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B.7. Sirenians

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Consider when assessing

- Military sonar
- Seismic surveys
- Civil high power sonar
- Coastal construction works
- Playback and sound exposure experiments
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- MOU Concerning the Conservation of the Manatee and Small Cetaceans of Western Africa and Macaronesia (West African Aquatic Mammals)
- MOU on the Conservation and Management of Dugongs (*Dugong dugon*) and their Habitats throughout their Range (Dugong)

B.7.1. Species Vulnerabilities

Even though traditional ecological knowledge and field observations (Marsh *et al* 1978, Hartman 1979) suggest that sirenians (manatees and dugongs) have ‘exceptional acoustic sensitivity’, scientific research on their hearing and reactions to marine noise is relatively sparse. Published hearing studies are based on the Florida manatee, *Trichechus manatus latirostris*, while behavioural studies on reactions to noise are limited to the Florida manatee, the Antillean manatee, *Trichechus manatus*, and the dugong, *Dugong dugon*. Although most of this research is limited to sounds in water, behavioural observations indicate that sirenians are capable of detecting some sounds in air above the surface (Hartman 1979).

Evoked potentials recorded for Florida manatees (Bullock *et al* 1982, Mann *et al* 2005) demonstrated variable sensitivity over a range of frequencies from about 200Hz to 35–40 kHz with greatest sensitivity in the lower range at 1–1.5 kHz. In-water behavioural audiograms of four captive Florida manatees identified the frequency range of best hearing as 6 to 32 kHz (Gerstein *et al* 1999, Gerstein 2002, Gaspard *et al* 2012), with individual variation within this range. Peak hearing

sensitivity has been variously reported as 16–18 kHz (Gerstein *et al* 1999, Gerstein 2002) and 8 kHz (Gaspard *et al* 2012). Gaspard *et al* (2012) also reported that one of their test animals appeared to be able to hear loud sounds as low as 0.25 kHz and ultrasonic frequencies as high as 90.5 kHz. Gerstein *et al* (1999) speculated that the greater sensitivity to higher frequencies observed in their audiogram research may be an adaptation that enabled manatees to avoid the complications associated with perceiving sound reflections propagated from the water–air interface (Lloyd mirror effect) in the shallow depths typical of their habitats, raising the interesting question of what these animals can hear when at the surface.

Both Gerstein (1999) and Gaspard *et al* (2012) conducted in-water behavioural experiments on captive Florida manatees to measure critical ratios. The differences in their results likely reflect both their different experimental protocols and individual differences in the manatees’ responses. Gaspard *et al* (2012) found that the manatees have relatively narrow auditory filters and struggle to hear lower and higher pitched sounds above background noise. However, manatee hearing was much sharper at 8 kHz – the frequency at which manatees communicate – where they could still distinguish tones that were only 18.3 dB louder than the background. This estimate of the manatee’s critical ratio (8 kHz) is among the lowest measured in mammals (Gaspard *et al* 2012) suggesting that generic marine mammal impact guidelines may not be appropriate for sirenians.

Field studies show that both the Florida manatee (Miksis-Olds *et al* 2007) and the dugong (Hodgson and Marsh 2007) exhibit short-term behavioural responses to noise. Miksis-Olds and Wagner (2010) showed that elevated sound levels affect the patterns of behaviour of the Florida manatee and that the response is a function of the manatee’s behavioural state. When ambient sounds were highest, the manatees spent more time feeding and less time milling. In contrast, Hodgson and Marsh’s (2007) experimental and behavioural studies showed that the time that dugongs spent feeding and travelling was unaffected by boat presence, the number of boat passes and whether a pass included a stop and restart. However, focal dugongs were less likely to continue feeding if the boat passed within 50 m, than if the boat passed at a greater distance. Boats passing at a range of speeds, and at distances of less than 50 m to over 500 m evoked mass movements of dugong feeding herds, but such movements only lasted a

couple of minutes. Castelblanco-Martínez and Arévalo-González (2015) experimentally studied the effects of side-scan sonar operating 455 kHz on the behaviour of 12 captive Antillean manatees. All the observed manatees variously showed behavioural changes including stopping foraging and feeding, significantly reducing displacement and remaining still at the bottom or at the surface, and increasing displacement behaviour. One male displayed continuous spinning movements for almost the entire experimental session. Most animals avoided the area nearest to the transducer.

Sirenians are not wilderness animals (Marsh *et al* 2011). Manatees occur in the inshore waters of Florida and have continued to use the intra-coastal waterway and residential canal estates, despite a high level of vessel activity (for references see Marsh *et al* 2011). Dugongs continue to use Johore Strait between Singapore and Peninsula area, one of the most heavily-used coastal waterways in the world, and are often detected in ports and military training areas along the Queensland east coast on the basis of their feeding trails and satellite tracking (Marsh *et al* 2011, Cleguer *et al* 2016). Hodgson *et al* (2007) experimentally tested the behavioural responses of dugongs to 4 and 10 kHz acoustic alarms (pingers). The rate of decline of the number of dugongs within the focal arena did not change significantly while pingers were activated. Dugongs passed between the pingers irrespective of whether the alarms were active or inactive, fed throughout the experiments and did not change their orientation to investigate pinger noise, or their likelihood of vocalizing. Thus despite the short-term behavioural responses noted above, there is no evidence that wild dugongs or Florida manatees are displaced by underwater noise, including side scan sonar (Gonzalez-Socoloske *et al* 2009). The reaction of dugongs and manatees to impulsive sounds does not appear to have been formally tested.

Both manatees and dugongs use underwater sound for communication. There have been numerous studies of sirenian communication sounds (see Marsh *et al* 2011). Characteristics of individual call notes seem fairly similar among the species of sirenians. Frequency ranges are typically from 1 to 18 kHz, often with harmonics and non-harmonically related overtones (e.g Anderson and Barclay 1995, Sousa-Lima *et al* 2002, O'Shea and Poche 2006).

Adults of both sexes produce vocalizations, but exchanges of communication calls are most common

between cows and their nursing calves. Florida manatee calves vocalize at much greater rates than adults (Sousa-Lima *et al* 2002, O'Shea and Poche 2006). Manatees other than cows and calves vocalize at rates that vary with activity and behavioural context, and are lowest during resting, intermediate while travelling, and highest at nursing and other social situations (Reynolds 1981, Bengtson and Fitzgerald 1985, Williams 2005, O'Shea and Poche 2006, Miksis-Olds and Tyack 2009). Dugongs seem to vocalize more often during dark, early morning hours (Ichikawa *et al* 2006). No data are available on vocal communication in African manatees, *Trichechus senegalensis*, although recordings and sound spectrograms of calls of an isolated captive calf in Cote d'Ivoire were similar to those of some Florida and Amazonian manatee calves (TJ O'Shea unpublished). Florida manatees may alter vocalization parameters in response to environmental noise levels (Miksis-Olds and Tyack 2009). Sakamoto *et al* (2006) attempted to quantify the effect of vessel noise on the vocal characteristics of dugongs (number of call per minute, dominant frequency and call duration). None of the changes was significant.

We know of no information regarding PTS, TTS or noise-induced auditory damage in sirenians.

B.7.2. Habitat Considerations

In the marine environment, both manatees and dugongs mostly occur in shallow waters because of their dependence of seagrass communities (Marsh *et al* 2011). Antillean and African manatees are both riverine and estuarine and in the marine environment mainly occur in water less than 5 m deep. Dugongs are strictly marine, feeding in waters up to about 35 m deep. They may occasionally cross ocean trenches (see Marsh *et al* 2011), but typically spend most of their lives in much shallower inshore coastal and island waters often commuting with the tide to or from intertidal seagrass meadows (Marsh *et al* 2011). There is increasing evidence that dugong migration corridors follow topographic features such as coastlines (Zeh *et al* 2016 in press) or reef crests (Cleguer 2015).

B.7.3. Impact of Exposure Levels

Given that the available evidence suggests that manatees and dugongs are unlikely to be displaced by noise, the most practical approach to reducing the risk of impacts is avoidance of the overlap of acute sound impacts with seasonal aggregation sites

and periods when the animals are likely to be under stress. Seasonal aggregation sites are most likely at the high latitude limits of the ranges of dugongs and manatees and typically occur as a behavioural repose to thermal conditions or prolonged periods of rough weather (see Marsh *et al* 2002 and 2011 for details of some well-known sites in Florida, Australia and the Arabian region). Site-specific information on this topic should be a focus of the Environmental Impact Assessment process. Extreme weather events such as cyclones or prolonged cold fronts can cause substantial increases in mortality (Marsh *et al* 2011, Meager and Limpus 2013) and noisy construction impacts should be planned to avoid times of likely environmental stress.

B.7.4. Assessment Criteria

We know of no field studies on the effects of anthropogenic noise, other than vessel noise on sirenians. The effect of vessel noise *per se* seems much less than that of vessel collisions. This lack of evidence does not prove that noise has negligible consequences for sirenian conservation, and more attention should be dedicated to a better understanding of possible impacts and ways to ameliorate them. A precautionary approach to the exposure of manatees and dugongs to noise, especially at key habitats and aggregation sites, is warranted.

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B.8. Marine and Sea Otters

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Consider when assessing

- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Playback and sound exposure experiments
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related modules

- Refer also to modules B.10, B.12 and C when assessing impact to marine and sea otters

B.8.1. Species Vulnerabilities

The marine otter, *Lontra felina*, and sea otter, *Enhydra lutris*, are amphibious marine mammals that may be vulnerable to coastal anthropogenic disturbance. Auditory thresholds for sea otters have been measured in air and underwater from 125 Hz to 40 kHz. Critical ratios data indicate that although sea otters can detect underwater sounds, their hearing appears to be primarily air adapted and not specialized for detecting signals in background noise. (Ghoul and Reichmuth 2012, 2014, 2016)

B.8.2. Habitat Considerations

There is little definitive research available about the specific anthropogenic noise vulnerabilities of this species group, but given the frequency range of hearing and the knowledge that these animals are social communicators and benthic foragers, (McShane *et al* 1995, Leuchtenberger *et al* 2014, Lemasson *et al* 2014, Thometz *et al* 2015) this species group should be considered. Their dependence on restricted nearshore habitats puts sea otters at risk from acoustic disturbance and activities occurring both on land and at sea. (Ghoul and Reichmuth 2016)

B.8.3. Impact of Exposure Levels

Ghoul and Reichmuth (2016) have conducted the only known assessment of sea otter hearing sensitivity. They found that hearing was most sensitive at 8 and 16 kHz,

where measured thresholds were the lowest at 69 dB re 1 μ Pa. The range of best sensitivity in water spanned ~4.5 octaves, from 4 to 22.6 kHz. The roll-off in high-frequency hearing was typically steep and had a 28-dB increase within a half-octave frequency step. Low-frequency hearing (0.125–1 kHz) was notably poor. The sea otter was unable to detect signals below 100 dB re 1 μ Pa within this frequency range. Noise spectral density levels in the underwater testing enclosure were sufficiently low to ensure that the measured thresholds were not influenced by background noise, especially at frequencies above 0.5 kHz, where noise levels were below 60 dB re 1 μ Pa/ $\sqrt{\text{Hz}}$. (Ghoul and Reichmuth 2016)

B.8.4. Assessment Criteria

Regulators estimating zones of auditory masking for sea otters should follow the guidance given for other marine mammals and opt for conservative estimates until additional data are available. (Southall *et al* 2000)

B.8.5. Species not listed on the CMS Appendices that should also be considered during assessments

Sea otters, *Enhydra lutris*, are classified by IUCN as Endangered, and should also be considered during assessments.

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B.9. Marine Turtles

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Consider when assessing

- Military sonar
- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Offshore platforms
- Playback and sound exposure experiments
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- MOU Concerning Conservation Measures for Marine Turtles of the Atlantic Coast of Africa (Atlantic marine turtles)
- MOU on the Conservation and Management of Marine Turtles and their Habitats of the Indian Ocean and South-East Asia (IOSEA)

Related modules

- Refer also to modules B.12 and C when assessing impact to marine turtles

B.9.1. Species Vulnerabilities

Although the ecological role of hearing has not been well studied for sea turtles, hearing capacity has been inferred from morphological and electrophysiological studies. (Southwood *et al* 2008)

Sea turtles do not have an external ear, in fact, the tympanum is simply a continuation of the facial tissue. Researchers have speculated that the cochlea and saccule are not optimized for hearing in air, but rather are adapted for sound conduction through two media, bone and water. Recent imaging data strongly suggest that the fats adjacent to the tympanal plates in at least three sea turtle species are highly specialized for underwater sound conduction. (Moein Bartol and Musick, 2003)

Hearing range (50-1200 Hz: Viada *et al* 2008, Martin *et al* 2012, Popper *et al* 2014) coincides with the predominant frequencies of anthropogenic noise, increasing the likelihood that sea turtles might experience negative effects from noise exposure.

At present, sea turtles are known to sense low frequency sound, however, little is known about the extent of noise exposure from anthropogenic sources in their natural habitats, or the potential impacts of increased anthropogenic noise exposure on sea turtle biology. Behaviour responses have been clearly demonstrated. (Samuel *et al* 2005)

Prolonged exposure could be highly disruptive to the health and ecology of the animals, encouraging avoidance behaviour, increasing stress and aggression levels, causing physiological damage through either temporary or even permanent threshold shifts, altering surfacing and diving rates, or masking orientation cues. (Samuel *et al* 2005)

B.9.2. Habitat Considerations

Sea turtles have been shown to exhibit strong fidelity to fixed migratory corridors, habitual foraging grounds, and nesting areas (Avens *et al* 2003), and such apparent inflexibility could prevent sea turtles from selecting alternate, quieter habitats.

The potential of noise for displacing turtles from their favoured or optimal habitat is unknown, but if it were to occur it could have negative consequences on growth, orientation, etc.

B.9.3. Impact of Exposure Levels

Sea turtles are low frequency specialists, but their range appears to differ between populations. Animals belonging to one population of subadult green turtles have been shown to detect frequencies between 100-500 Hz with their most sensitive hearing between 200-400Hz. Another responded to sounds from 100-800 Hz, with their most sensitive range being 600-700Hz. Juvenile Kemp's ridley turtles had a range of 100-500Hz, with their most sensitive hearing been 110-200Hz. (Moein Bartol and Ketten, 2006)

B.9.4. Assessment Criteria

It is important that assessment of impact for sea turtles both considers the physiological impact (TTS and PTS) as well as the very real possibility of masking prey movements, and impacts to nesting behaviour, in particular during inter-nesting resting. Some sea turtles may not appear to noise-generating industries to have been physically displaced by loud noise but these animals may be effectively prevented from foraging, due to an ensouffied foraging environment.

Possible effects of distribution (avoidance behaviour) orientation, and even communication (e.g in the hatching phase) cannot be discounted.

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B.10. Fin-fish

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Consider when assessing

- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons

Related CMS agreements

- Agreement on the Conservation of Cetaceans of the Black Seas Mediterranean Seas and Contiguous Atlantic Area (ACCOBAMS)
- Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)
- MOU for the Conservation of Cetaceans and their Habitats in the Pacific Islands Region (Pacific Islands Cetaceans)
- MOU Concerning the Conservation of the Manatee and Small Cetaceans of Western Africa and Macaronesia (West African Aquatic Mammals)
- Agreement on the Conservation of Seals in the Wadden Sea (Wadden Sea seals)
- MOU Concerning Conservation Measures for the Eastern Atlantic Populations of the Mediterranean Monk Seal (*Monachus monachus*) (Atlantic monk seals)
- MOU Concerning Conservation Measures for Marine Turtles of the Atlantic Coast of Africa (Atlantic marine turtles)
- MOU on the Conservation and Management of Marine Turtles and their Habitats of the Indian Ocean and South-East Asia (IOSEA)
- MOU on the Conservation of Migratory Sharks (Sharks)

Related modules

- Refer also to modules B.12 when assessing impact to fish

B.10.1. Species Vulnerabilities

The use of explosives will kill fin-fish inside a certain range (Yelverton *et al* 1975), with impact zones given in Popper *et al* (2014). Intense non-explosive, impulse noise such as pile driving or seismic surveys may impact adult fin-fish by: a) creating

physiological damage such as rupturing gas spaces (ie. Halverson *et al* 2012), b) damaging sensory systems (McCauley *et al* 2003), c) creating adverse behavioural responses (e.g. Pearson *et al* 1996, McCauley *et al* 2003, Slotte *et al* 2004, Fewtrell and McCauley 2012, Hawkings *et al* 2014), d) masking the reception of signals of interest, or e) disrupting prey physiology, behaviour or abundance. For fin-fish the sustained but less intense noise from vessels or offshore construction activities may commonly produce behavioural impacts or masking of communication signals as indicated above. Fin-fish exposed to lower level, man-made noise for suitable time periods may receive damage to hearing systems and so suffer a loss of fitness.

There is an enormous amount of variability in the degree of sophistication of fin-fish hearing systems and habits which may pre-dispose or protect them from impacts of man-made noise sources, thus it is difficult to generalize known impacts across all fin-fish species with a high degree of confidence. In general terms: explosives routinely cause fin-fish deaths out to some range and sub-lethal injuries beyond this, pile driving is known to produce serious physiological and organ damage to fin-fish at short range, in some cases marine seismic surveys with air guns have produced hearing damage to fin-fish while in other cases such damage has not been observed, and most man-made noise sources are capable of producing fin-fish behavioural or masking impacts to some degree. Behavioural response to an approaching noise source by fin-fish seems to be reasonably generic, pelagic fin-fish tend to move downwards to eventually lie close to the seabed or flee laterally while site-attached fish may initially seek shelter in refuges or flee. At least some species of fin-fish do habituate to continual and stationary low level noise as they readily colonize man-made offshore facilities. The longer-term implications of consistent behaviour changes or slight physiological impairment from intense signals produced by seismic surveys are not well understood.

Many fin-fish form aggregations at specific times and places to spawn and produce fertilized eggs. Such aggregations may be spaced across several months or may occur only on few occasions per season. Many fin-fish species produce communication sounds as part of such aggregations (ie. McCauley 2001). Disruptions to such fin-fish spawning aggregations by excessive noise causing physiological or behavioural changes and which overlaps a large fraction of the species' seasonal spawning period will have deleterious

impacts on the following years reproductive output.

All fin-fish are dependent on smaller prey species which may be impacted by man-made noise sources. Prey may include fin-fish or invertebrates. In general terms small, common, fin-fish prey species, such as sardines, herring or pilchards, have well developed sensory systems thus may be equally or more vulnerable to exposure to intense man-made noise than the larger fin-fish which prey on them. The response of marine invertebrates to intense signals such as seismic survey noise, are poorly known so it is difficult to draw conclusions or comparisons on how invertebrate prey fields will be impacted by noise exposure. Any changes to prey fields induced by a man-made noise source will impact fauna, possibly negatively, higher up the food chain.

All impacts of man-made noise sources on fin-fish need to be gauged at the population level. Noise sources which produce short term impacts, localized impacts compared with a species range, or which do not overlap well with habitats or time and spatial overlap of spawning periods would be expected to be of low severity from a population perspective, and vice versa.

B.10.2. Habitat Considerations

Fin-fish occupy an enormous variety of habitats, from deep ocean depths, pelagic systems, reefs and shoals, estuarine waters to inland waterways. Some fish may utilize multiple habitats on a seasonal or life cycle basis. In general terms habitats which are enclosed, such as estuaries, bays or reefs for site attached fin-fish, may be more susceptible to exposure by intense sound sources as the fin-fish have little options to escape the source. By contrast fin-fish that occupy physically larger spaces, such as oceanic species, have more options of where to flee and may be less constrained by the implications of moving geographical regions to avoid a noise source.

B.10.3. Impact of Exposure Levels

Known impacts of intense impulse noise exposure on fin-fish include consistencies in fish behavioural response to sound, but many anomalies. For high-energy impulse signals, such as seismic survey signals, the following can be said:

Fish behaviour most often changes at some range near to an approaching seismic vessel and generalized changes include diving, lateral spread or fleeing an area (e.g. Pearson *et al* 1996, McCauley *et al* 2003, Slotte *et al*

2004, Fewtrell and McCauley 2012, Hawkings *et al* 2014).

Fish behaviour is strongly impacted by an approaching seismic source above received levels of 145–150 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$ (SEL) (McCauley *et al* 2003), which equates to around 2–10 km using measured air gun arrays > 2000 cui.

Avoidance to an approaching seismic vessel by fish may be partly driven by the fish behavioural state, with feeding fishes appearing to be more tolerant and in one instance not showing avoidance to an approaching seismic survey vessel (Penä *et al* 2013).

Catch rates in some fisheries are altered during and after seismic operations, prolonged seismic can cause large-scale displacement of fish resulting in decreased fish abundance in and near a seismic operations area and increased fish abundance at long range (tens of km) from the seismic operations area (Engås *et al* 1996, Slotte *et al* 2004),

Long-term monitoring of reef fish community structure before and after a seismic survey programme showed no large-scale change in community structure (Miller and Cripps 2013) and fish sound production behaviour (chorusing) continued after a seismic programme with no apparent long-term change (McCauley 2011),

Exposure to accurately emulated repeated pile driving signals suggest physical injury (organ damage) arises at levels equivalent to 1920 strikes at 179 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$ or 960 strikes at 182 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$, or an equivalent single strike SEL of 210–211 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$ (Halvorsen *et al* 2012).

In a review of experimental findings of sound on fishes Popper *et al* (2014) present sound exposure guidelines for fin-fish in the form of estimated levels at which the following occur: 1) mortality and potential mortal injury, 2) impairment – recoverable injury, 3) impairment – TTS, 4) impairment – masking, and 5) behavioural changes. They present these impacts for three categories of fin-fish, 1) no swim bladder, 2) swim bladder present but no links to otolith system, or 3) swim bladder present with links to otolith system, plus sea turtles and eggs/larvae. Popper *et al* (2014) present this data for sources of explosives, pile driving, air gun arrays, sonar and shipping. Given the lack of experimental evidence for most of these categories they were forced to: 1) either extrapolate from another exposure type, animal group or both, and 2) rather than presenting threshold levels often present the subjectively evaluated likelihood of an impact type occurring at 'near' (tens of m),

'intermediate' (hundreds of m) and 'far' (thousands of m) ranges. The thresholds listed for physical injury (mortality and impairment-recoverable injury) for pile driving and seismic air gun signals are the same, being primarily based on the pile driving work of Halverson *et al* (2012). Readers are referred to Popper *et al* (2014) for the particular thresholds for a fin-fish and sound exposure type as the reader should see their text for the reasoning and caveats behind the values presented.

B.10.4. Assessment Criteria

In assessing impacts of a noise source on fin-fish any EIA document should consider species which:

- are important for commercial fisheries,
- are listed as threatened, vulnerable or are endemic to an area,
- can be considered as important 'bait fish' or are important as prey species for higher order fauna,
- have limited ability to flee an intense noise source,
- utilize a noise impacted area for specific purposes such as feeding or spawning events.

In considering impacts of underwater noise on a species of fin-fish, factors which must be taken into account include:

- hearing capabilities of the species in question including knowledge of morphological adaptations to increase hearing capability, noting fin-fish primarily respond to motion of the water particles and less to measures of sound pressure. Fin-fish have a diverse range of morphological adaptations to improve hearing capability,
- studies of known impacts on this species,
- studies of known impacts on related species either taxonomically, morphologically or in general terms if no other comparison is available (ie. pelagic fishes, benthic fishes etc),
- particular spatial and temporal features which are critical to that fin-fish population's survival (ie. specific feeding areas or prey types, spawning locations and periods).

For migratory fin-fish impact assessment must consider if a noise producing action may cause a species to leave an area and if so, the consequences of this to the species in question, for other fauna and for commercial fisheries which target that species.

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B.11. Elasmobranchs

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Consider when assessing

- Military sonar
- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Offshore platforms
- Playback and sound exposure experiments
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- MOU on the Conservation of Migratory Sharks (Sharks)

Related modules

- Refer also to modules B.10 and B.12 when assessing impact to elasmobranchs

B.11.1. Species Vulnerabilities

Elasmobranchs as a group are poorly studied in relation to the potential impact of anthropogenic sounds, although several studies over time have been directed at particular species of shark to improve knowledge of their hearing mechanisms, abilities and implications for management. From as early as the 1960s (e.g. Nelson and Gruber, 1963), studies have shown that large sharks (*Carcharhinidae*, *Sphyrnidae*), in their natural environment, were attracted to low-frequency (predominantly 20 to 60 Hz) pulsed sounds, but apparently not to higher frequency (400 to 600 Hz) pulsed sounds, or to low-frequency continuous sounds. More recent research has established the hearing range of sharks to be between 40 Hz to approximately 800 Hz (Myrberg 2001), with possible limits for elasmobranchs in general at 20–1000 Hz (Casper and Mann, 2006, 2010).

Noise within the sharks' audible range may be produced by several anthropogenic sources such as shipping, underwater construction, pile driving, dredging, power stations and sonic surveys. It has been suggested that loud sounds in their audible range may repel sharks whereas low sounds may attract them (Francis and Lyon, 2013), probably as these latter mimics sounds emitted by struggling prey. Response likely depends on

its distance from the source and the volume of the source.

Although more recent research in elasmobranch hearing and impacts in the wild have been sparse at best, and nonexistent for most species, there is evidence of habituation or at least no negative reaction to noise levels and frequencies from small boats operating recreational diving or from SCUBA divers' noises, even when these are regularly present and arising from many sources (Lobel, 2009 and personal observations by the author of this summary).

It is likely that elasmobranchs might suffer more impacts from noise through the effects it has on its prey species (Popper and Hastings, 2009, Carlson, 2012), and perhaps through acute events that impact concentration sites such as social groupings of hammerhead sharks, *Sphyrna* spp., and white sharks, *Carcharodon carcharias*, around offshore islands, as well as those gathering at coral reef habitats, in these cases, displacement may occur, either temporary or permanent, although again lack of adequate field research prevents any definitive conclusions. Several studies (eg Klimley and Myrberg 1979, Banner 1972, Myrberg *et al* 1978) indicate that elasmobranchs show consistent withdrawal from sources that are at close range and when confronted with sudden onset of transmissions. However they may habituate to these too if events become frequent (Myrberg, 2001). Seismic activities, pylon-driving operations, explosive construction work and activities involving similar pulsed sound emissions are likely therefore to have the most impact on elasmobranch species directly.

B.11.2. Habitat Considerations

Several species of elasmobranchs exhibit some type of site-fidelity, either permanent or seasonal. This has been observed in particular regarding species of interest to the dive industry. Some species of shark (eg whitetip, *Triaenodon obesus*, blacktip, *Carcharinus melanopterus*, and grey reef, *Carcharhinus amblyrhynchos*) and the reef manta, *Manta alfredi*, are particularly attached to coral reef environments, while others exhibit seasonal concentration around offshore islands (eg hammerheads, *Sphyrna lewini*, at Galápagos, Cocos and Malpelo Islands, white sharks, *Carcharodon carcharias*, at Guadalupe and Farallon Islands, whale sharks, *Rhincodon typus*, at Holbox, Mexico, and several other sites). Giant mantas *Manta birostris* also can be found in seasonal concentrations such as in Revillagigedo Islands in Mexico, Laje de Santos in Brazil and La Plata in Ecuador.

Seasons for these aggregations vary from site to site and by species and need to be assessed on a case by case basis.

Acoustic impacts which might severely affect vulnerable or complex habitats such as coral reefs or mangrove forests (essential nursery areas for some shark and ray species) are certain to have an effect on its elasmobranch fauna if it includes displacement or damage to prey species and any physical disruption of the habitat. Seasonal concentration areas for sharks and rays can be particularly vulnerable to acute acoustic disturbance, which may result in abandonment of the area or disruption of gregarious behaviour whose implications are yet not fully understood. Acute acoustic disturbances such as seismic or sonic surveys and any activity involving explosives in or around these critical habitats (coral reefs, offshore islands and other known seasonal concentration sites, key feeding grounds) are likely to have serious impacts on elasmobranch populations.

Although migration paths are still poorly understood for most species, recent satellite tagging research (e.g. Domeier and Nasby-Lucas, 2008) has begun to reveal some consistent patterns and as yet unknown concentration areas away from above-water topographic features. These areas likely represent additional vulnerability corridors where protection from acute acoustic disturbance should be incorporated into management actions.

B.11.3. Impact of Exposure Levels

As a group, elasmobranchs have been poorly represented in field studies on acoustics, with most knowledge available for more “visible” species such as large sharks. For these, observed impacts refer mostly to short-term avoidance responses to loud, sudden bursts of sound in their audible range, although there’s evidence that the regularity of such sounds might lead to habituation (see references above).

Given that bony fish, which make the majority of prey species for most sharks, may be severely impacted by sound (Slabekoorn et al., 2010), especially in loud bursts (eg Carlson, 2012), it is perhaps this indirect effect on prey that holds the most severe potential for generating impacts on shark populations.

There is insufficient information to assess long-term impacts or behavioral changes in elasmobranchs from anthropogenic noise that might affect survivability of species. Existing studies indicate that the most direct negative impact on the animals seems to be displacement by sonic outbursts, while longer-

term exposure often seems to lead to habituation (Lobel, 2009; Myrberg, 2001; Myrberg et al., 1972).

B.11.4. Assessment Criteria

From available data it seems that there are two main aspects of potential impacts on elasmobranchs that merit particular consideration: displacement or elimination of prey species and displacement or disruption of behaviour associated with specific sites by sound bursts. Given that detailed studies are mostly lacking, a precautionary approach to the exposure of elasmobranchs to noise, especially at key habitats and aggregation sites, is warranted. In particular activities involving the use of equipment or methods that generate loud sonic outbursts near known or estimated aggregation areas, or which might physically injure or displace prey, need to be carried out with adequate assessment (including baseline surveys for elasmobranch species and their prey) and mitigation measures as feasible and appropriate. Also, proposed activities that alter or impact key habitats such as coral reefs, mangroves or offshore islands with known aggregations of elasmobranch species should be carried out with extreme caution and this group of species should be explicitly considered in studies and proposed management measures to reduce potential impacts.

B.11.5. Species not listed on the CMS Appendices that should also be considered during assessments

In general, listed species include those for which several acoustic and hearing studies exist, but as for the entire group detailed acoustic impact studies are lacking. The development and collation of more detailed data on a species by species basis could greatly help improve our understanding of the impacts of anthropogenic noise on their physiology and life cycles. Lack of information on most elasmobranch species is an impediment to the provision of any meaningful advice on species not listed on the CMS Appendices,

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B.12. Marine Invertebrates

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Consider when assessing

- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Offshore platforms
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- Agreement on the Conservation of Cetaceans of the Black Seas Mediterranean Seas and Contiguous Atlantic Area (ACCOBAMS)
- Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)
- MOU for the Conservation of Cetaceans and their Habitats in the Pacific Islands Region (Pacific Islands Cetaceans)
- MOU Concerning the Conservation of the Manatee and Small Cetaceans of Western Africa and Macaronesia (West African Aquatic Mammals)
- Agreement on the Conservation of Seals in the Wadden Sea (Wadden Sea seals)
- MOU Concerning Conservation Measures for the Eastern Atlantic Populations of the Mediterranean Monk Seal (*Monachus monachus*) (Atlantic monk seals)
- MOU Concerning Conservation Measures for Marine Turtles of the Atlantic Coast of Africa (Atlantic marine turtles)
- MOU on the Conservation and Management of Marine Turtles and their Habitats of the Indian Ocean and South-East Asia (IOSEA)
- MOU on the Conservation of Migratory Sharks (Sharks)

Related modules

- Refer also to modules B.10 when assessing impact to marine invertebrates

B.12.1. Species Vulnerabilities

Very little is known about effects of anthropogenic noise on invertebrates (Morley *et al* 2014). This includes more than 170,000 described species of multicellular marine

invertebrates in spite of their ecological and economic importance worldwide (Anderson *et al* 2011). Most research targets molluscs (e.g. cephalopods, shellfish) and crustaceans (e.g. crabs, shrimps, barnacles) (reviewed in Aguilar de Soto, 2016).

Molluscs:

Two atypical mass-strandings involving nine giant squids, *Architeuthis dux*, were associated with seismic surveys co-occurring in nearby underwater canyons where this species concentrates (Guerra *et al* 2004, 2011). Two specimens suffered extensive multiorgan damage to internal muscle fibres, gills, ovaries, stomach and digestive tract. Other squids were probably disoriented due to extensive damage in their statocysts. Damage to the sensory epithelium was also observed in four species of coastal cephalopods (*Sepia officinalis*, *Loligo vulgaris*, *Illex coindetii* and *Octopus vulgaris*) by exposure to two hours of low-frequency sweeps at 100 per cent duty cycle (André *et al* 2011, Solé, 2012, Solé *et al* 2013). Fewtrell and McCauley (2012) reported that squid, *Sepioteuthis australis*, exposed to seismic pulses from a single air gun showed signs of stress such as significant increases in the number of startle and alarm responses, with ink ejection in many cases, increased activity and changing position in the water column.

Delayed and abnormal development as well as an increase in mortality rates in eggs and larvae of shellfish exposed to noise have been recorded in two species. New Zealand scallop larvae, *Pecten novaezelandiae*, exposed to playbacks of low frequency pulses in the laboratory showed significant developmental delays and developed body abnormalities (Aguilar de Soto *et al* 2013). The number of eggs of sea hares, *Stylocheilus striatus*, that failed to develop at the cleavage stage, as well as the number that died shortly after hatching, were significantly higher in a group exposed to boat noise playback at sea compared with playback of ambient noise (Nedelec *et al* 2014). In contrast, playbacks of ship-noise enhanced larval settlement in the mussel, *Perna canaliculus* (Wilkins *et al* 2012) while seemed to increase biochemical indicators of stress in adult mussels (*Mytilus edulis*) (Wale *et al* 2016).

Crustaceans:

Stress responses were observed in aquarium-dwelling brown shrimp, *Crangon crangon*, exposed to ambient noise of some 30 dB higher than normal at 25–400 Hz (Lagardere, 1982, Regnault and Lagardere, 1983). Shrimps did not seem to habituate

throughout the experiment. Similarly, shore crabs, *Carcinus maenas*, increased metabolic consumption and showed signals of stress when exposed to playbacks of ship noise in the laboratory. Crustacean larvae seem to differ in their sensitivity to noise: larval dungeness crabs, *Metacarcinus magister*, did not show significant differences in survival nor in time-to-moult when exposed to a single pulse from a seven air gun array, even at the higher received level of 231 dB re 1 μ Pa (Pearson *et al* 1994). In contrast, larvae of other crab species, *Austrohelice crassa* and *Hemigrapsus crenulatus* megalopae, exposed to playbacks of noise from tidal turbines tended to suffer significant delays in time-to-moult (Pine *et al* 2012) and low-frequency noise exposure inhibited settlement of early larvae of barnacle, *Balanus amphitrite* (Branscomb and Rittschof, 1984). The apparent contradiction in the larval responses from different species of crustaceans may be due, among other things, to the experimental set-up (wild versus laboratory, one pulse versus a continuous exposure), the biology of the species, or the characteristics of the sound treatment. Cellular and humoral immune responses of marine invertebrates to noise have also been examined. In the European spiny lobster, *Palinurus elephas*, exposure to sounds resembling shipping noise in the laboratory affected various haematological and immunological parameters considered to be potential health or disease markers in crustaceans (Celi *et al* 2014).

B.12.2. Habitat Considerations

Marine invertebrates inhabit a range of habitats. Mainly, they may live associated to the seafloor (benthic or benthic-pelagic species) or free in the water column (pelagic). Many species have an initial pelagic phase as larvae, useful for dispersion, before finding suitable habitat for settling into their adult life. Sound from preferred habitats is one of the cues used by larvae to find a suitable location to settle (Stanley *et al* 2012). Once they settle, many species have limited capabilities to move fast enough at distances required to avoid noise exposure, due to morphological constraints or to territorial behaviour.

Species associated to the seafloor will be more exposed to ground-transmission of noise. This is especially relevant for intense low frequency sounds directed towards the seafloor, typical of seismic surveys. Seismic pulses coupled with the seafloor and low frequency vibrations can travel long distances through the ground and can re-radiate to the water depending on the structure and composition of the seafloor. Marine

invertebrates are sensitive to the particle motion component of sound, more than to the pressure wave, they are well suited to detect low frequency vibrations because these are used, for example, to identify predators and prey.

The variability in the extent of barotrauma experienced by different giant squid stranding at the same time, in coincidence with the same seismic survey (Guerra *et al* 2004, 2011), underlines the difficulties inherent in predicting noise-induced damage to animals in the wild. Here, some giant squid suffered direct mortality from barotrauma, while the death of others seemed to be caused by indirect effects of physiological and behavioural responses to noise exposure. Direct injury (barotrauma) can be explained by some animals being exposed to higher sound levels due to complex patterns of sound radiation creating zones of convergence (Urick, 1983) of the seismic sound waves reflected by the sea surface/sea floor, and possibly by the walls of the steep underwater canyons in the area where the seismic survey took place.

Marine invertebrates often have discrete spawning periods. It is unknown if eggs/larvae have a greater vulnerability to sound-mediated physiological or mechanical stress, or even particular phases of larval development when larvae undergo metamorphosis.

Metamorphosis involves selective expression of genes mediating changes in body arrangement, gene expression is susceptible to stress, including from noise. Spawning periods are key for the recruitment of marine invertebrates and thus should be considered when planning activities.

B.12.3. Impact of Exposure Levels

There are no data about thresholds of pressure or particle motion initiating noise impacts on marine invertebrates. Studies have found a range of physiological effects (reviewed in Aguilar de Soto and Kight 2016) but there are no dose-response curves identifying levels of impact onset. Moreover, most studies report only sound pressure level, while particle motion is relevant for the effects of noise on these species. At a distance from an acoustic source (in the far-field) the pressure and particle motion components of sound are easily predicted in a free homogeneous environment such as the water column. In contrast, in the near-field animals may experience higher particle motions than would be expected for the same pressure level in the far-field. Intense underwater sound sources such as air guns, pile driving, sonar

and blasting have back-calculated peak source levels ranging from 230 to, in the case of blasting, >300 dB re 1 μ Pa at 1m. These activities routinely ensoundify large areas with sound pressure levels higher than the thresholds of response observed in different studies of noise-impacts on marine invertebrates. For example, a seismic array with an equivalent source level of 260 dB pk-pk re 1 μ Pa at 1m will produce levels in excess of 160 dB_{rms} over hundreds of km-squared. This level was measured in an experiment reporting noise-induced developmental delays and malformations in scallop larvae (Aguilar de Soto *et al* 2013). But the particle velocities experienced by the larvae in the experiment (about 4-6 mm s⁻¹ RMS) imply higher far-field pressure levels of some 195-200 dB_{rms} re 1 μ Pa, reducing the potential impact zone to only short ranges from the source. However, there are several reasons why larvae in the wild may be impacted over larger distances than these approximate levels suggest. Given the strong disruption of larval development reported, weaker but still significant effects can be expected at lower exposure levels and shorter exposure durations. Moreover, low frequency sounds propagate in complex sound fields in which convergence zones and re-radiation of sound transmitted through the sea-floor can create regions with high sound levels far from the source (Madsen *et al* 2006). The sound field experienced by an organism is a complex function of its location with respect to the sound source and acoustic boundaries in the ocean necessitating *in situ* measurements to establish the precise exposure level.

B.12.4. Assessment Criteria

Benthic marine invertebrates often have little movement capabilities further than a few metres, limiting their options to avoid exposure to anthropogenic noise. In the case of intense low frequency noise, e.g. seismic or pile driving, it is essential to consider ground-transmission. For example, during a seismic survey animals will be exposed to sound received from the air gun array passing over the location of the animals, but these invertebrates will be receiving at the same time ground-transmitted vibrations originated by previous seismic pulses. Thus, animals will experience waves arising from the water and from the ground, differing in phase and other parameters. Complex patterns of wave addition mean that in some cases vibrations will sum, increasing the levels of sound exposure to the animals. Because ground vibrations may travel tens of kilometres or more, the time that benthic invertebrates will be exposed to a

given threshold of pressure or particle motion will be increased when we consider seafloor transmission. An alternative source for seismic surveys (©Vibroseis) is currently being tested. In contrast to usual seismic surveys transmitting pulses every 6 to 15 s from an air gun array towed by a ship near the sea-surface, Vibroseis is towed near the seafloor and emits continuously, but at lower peak level. Thus, duty cycle increases to 100 per cent. EIA of Vibroseis and other low frequency sound sources should include modelling particle motion in the target area and consider exposures to benthic fauna.

Results of experiments about effects of noise on catch rates of marine invertebrates have not shown significant effects: Andriguetto-Filho *et al* (2005) did not find changes on catches of shrimps after the passage of a small air gun array. No effects of seismic activities on catches of rock-lobsters were found either by Parry *et al* (2006) performing a long-term analysis of commercial data. In contrast, fishermen have blamed seismic sources for mortalities of scallops and economic losses due to reduced catch rates.

Despite uncertainties about how noise may affect marine fauna and fisheries, several countries have already implemented regulations that reduce overlap between seismic surveys and fishing activities (mainly of fin-fish). However, these regulations do not address concerns of noise effects on eggs and larvae, i.e. that noise might affect stock recruitment and thereby cause delayed reductions in catch rates.

Marine invertebrates form the base of the trophic-web in the oceans, providing an important food source for fish, marine mammals and humans. In addition to direct effects to adults, noise exposure during critical growth intervals may contribute to stock vulnerability, underlining the urgency to investigate potential effects of acoustic pollution on marine invertebrates at different ontogenetic stages. Moreover, recent results investigating the effects of noise on a range of marine invertebrate species call for applying the precautionary principle when planning activities involving high-intensity sound sources, such as explosions, construction, pile driving or seismic exploration, in spawning areas/times of marine invertebrates with high natural and economic value.

B.12.5. Species not listed on the CMS Appendices that should also be considered during assessments

Some large cephalopods are migratory, including the giant squid, *Architeuthis sp* (Winkelmann *et al* 2013). Given the vulnerability of this species to acoustic sources, it should also be considered during assessments.

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C. Decompression Stress

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Decompression sickness (DCS, ‘the bends’) is a disease associated with gas uptake at pressure. As hydrostatic pressure increases with depth, the amount of nitrogen (N₂) that is absorbed by the blood and tissues increases, resulting in higher dissolved gas tensions that could at maximum reach equilibrium with the partial pressure of N₂ in the lungs. This is a long-known problem for human divers breathing pressurized air, but has often been discounted as a problem for breath-hold divers since they dive on only a single inhalation (Scholander 1940). However, for free-diving humans and other air-breathing animals, tissues can become highly saturated under certain circumstances depending on the iterative process of loading during diving and washout at the surface (Paulev 1967, Lemaitre *et al* 2009). During decompression, if the dissolved gas tension in the tissues cannot equilibrate fast enough with the reducing partial pressure of N₂ in the lungs, tissues will become supersaturated, with the potential for gas-bubble formation (Francis and Mitchell 2003).

Breath-hold diving vertebrates were previously thought to be relatively immune to DCS due to their multiple anatomical, physiological and behavioural adaptations (Fahlman *et al* 2006, Fahlman *et al* 2009, Hooker *et al* 2012). However, recent observations have shown that marine mammals and turtles may be affected by decompression sickness under certain circumstances (Jepson *et al* 2005, Dennison *et al* 2012, Van Bonn *et al* 2013, Garcia-Parraga *et al* 2014). Of most concern, however, are the beaked whales, which appear to be particularly vulnerable to anthropogenic stressors that may cause decompression sickness (Jepson *et al* 2003, Cox *et al* 2006, D’Amico *et al* 2009, Hooker *et al* 2009, Hooker *et al* 2012).

C.1.1. Bubble Formation

Among marine mammals, both acute and chronic gas emboli have been observed. The formation of bubbles has been suggested as a potential explanation for lesions coincident

with intravascular and major organ gas emboli in beaked whales that mass stranded in conjunction with military exercises deploying sonar (Jepson *et al* 2003, Fernandez *et al* 2005). There is some controversy about the exact behaviour leading to the gas emboli (Hooker *et al* 2012). However it is widely agreed that this outcome was linked to man-made acoustic disturbance. These types of lesions have also been reported in some single-stranded cetaceans for which they do not appear to have been immediately fatal (Jepson *et al* 2005, Bernaldo de Quirós *et al* 2012, Bernaldo de Quirós *et al* 2013). Looking at species-specific variability in bubble presence among stranded animals, the deeper divers (Kogia, Physeter, Ziphius, Mesoplodon, Globicephala, and Grampus) appeared to have higher abundances of bubbles, suggesting that deep-diving behaviour may lead to a higher likelihood of decompression stress (Bernaldo de Quirós *et al* 2012).

In addition, osteonecrosis-type surface lesions have been reported in sperm whales (Moore and Early 2004). These were hypothesized to have been caused by repetitive formation of asymptomatic N₂ emboli over time and suggest that sperm whales live with sub-lethal decompression induced bubbles on a regular basis, but with long-term impacts on bone health. Bubbles have also been observed from marine mammals bycaught in fishing nets, which died at depth (Moore *et al* 2009, Bernaldo de Quirós *et al* 2013). These bubbles suggested the animals’ tissues were supersaturated sufficiently to cause bubble formation when depressurized (as nets were hauled). B-mode ultrasound has detected bubbles in stranded (common and white-sided) dolphins, which showed normal behaviour after release and did not re-strand, and so appeared to tolerate this bubble formation (Dennison *et al* 2012). Cerebral gas lesions have also been observed using Magnetic Resonance Imaging in California sea lions, *Zalophus californianus*, admitted to a rehabilitation facility (Van Bonn *et al* 2011, Van Bonn *et al* 2013).

It therefore appears that gas supersaturation and bubble formation may occur more routinely than previously thought. These cases highlight a growing body of evidence that marine mammals are living with blood and tissue N₂ tensions that exceed ambient levels (Moore *et al* 2009, Bernaldo de Quirós *et al* 2013). However, our understanding of how marine mammals manage their blood gases during diving, and the mechanism causing these levels to become dangerous is very rudimentary (Hooker *et al* 2012). Some perceived threats appear to cause a behavioural response that may override normal N₂ management, resulting in decompression sickness, stranding and death.

C.1.2. Sources of Decompression Stress

Most evidence for both beaked whale fatalities and for behavioural modification (thought to be the precursor to further effects) has suggested an anthropogenic sound source. There is a documented association between naval active sonar exercises (particularly mid-frequency active sonar) and beaked whale mass strandings (Frantzis 1998, Evans and England 2001, Jepson *et al* 2003). Spatial and temporal correlations between active sonar and beaked whale strandings support this conclusion but suggest a role for specific bathymetric topography leading some areas to show correlations while others do not (Filadelfo *et al* 2009). A comprehensive review of beaked whale mass strandings (D'Amico *et al* 2009) suggested that some strandings might be associated with other source events. However, the evidence is less comprehensive in support for high-intensity underwater sounds other than mid-frequency sonar causing fatalities for these species (Taylor *et al* 2004; Barlow and Gisiner 2006). In terms of other sources causing behavioural modification, ship-noise appears to cause a behavioural response disrupting foraging behaviour in Cuvier's beaked whales, *Ziphius cavirostris* (Soto *et al* 2006).

Another form of decompression stress is the oxidative stress caused by diving (Hermes-Lima and Zenteno-Savin 2002). Episodic regional lack of oxygen and abrupt reperfusion upon re-surfacing creates a situation where post-ischemic reactive oxygen species (ROS) and physiological oxidative stress are likely to occur. Decompression sickness likely has a multifactorial origin, but this oxidative stress could be a contributor (Wang *et al* 2015).

C.1.3. Source Frequency, Level and Duration

Understanding the responses of cetaceans to noise is a two-stage process: (1) understanding the noise required to cause the behavioural modification and (2) understanding the physiological mechanism by which that behavioural modification causes harm to the animal. At present, almost all research has focussed on the first of these, i.e. work evaluating playback and response, and almost nothing is known about how this response then leads to decompression stress.

Several recent studies have found similar behavioural responses of a small number of beaked whales to sonar signals (Tyack *et al* 2011, DeRuiter *et al* 2013, Stimpert *et al* 2014, Miller *et al* 2015). These studies have shown that beaked whales respond behaviourally to sonar and other human and natural stimuli, typically showing a combination of avoidance and cessation of noise-production associated with foraging (Table 8). Responses to simulated sonar have started at low received levels. These types of behavioural changes were also documented in work monitoring vocal activity using Navy range hydrophones (Tyack *et al* 2011, Moretti *et al* 2014).

C.1.4. Assessment Criteria

At the planning stage, the primary mitigation method to reduce issues of decompression stress would be to reduce the interactions of stressor and animals (i.e. to reduce the number of "takes"). Acknowledging that there might be other planning issues that limit flexibility, this could be done by placing high-intensity noise into areas without high densities of species of concern. Thus proposals should take account of all survey and modelling information sources to predict areas of likelihood of high/low species density, and attempt to reduce the number of impacted animals by designing operations within areas of lower animal density.

To supplement this, or in areas in which such species densities are unknown, baseline studies will be needed. Beaked whales are particularly difficult to monitor visually (surfacing for as little as 8 per cent of the time), but have more reliable detection acoustically (vocalising for 20 per cent of the time, de Soto *et al* 2012). Hydrophone arrays can detect animals at 2-6km distances (eg Moretti *et al* 2010, Von Benda-Beckmann *et al* 2010).

During the activity, real-time monitoring of animal presence should be conducted using visual and acoustic monitoring, with detections within a specified range of the activity

resulting in cessation of the sound source. Mitigation measures such as 'ramp-up' may be effective, although some beaked whale species show curiosity toward novel sounds which may increase the likelihood of impact (Miller *et al.* 2015).

Monitoring over a wider area can sometimes be achieved using hydrophone arrays on the seafloor (Moretti *et al.* 2010). Such hydrophone arrays allow detection over a wide but static area. Dynamic monitoring over a wide area is not currently feasible.

Modelling of animal likelihood and distance from the source should be carried out in order to minimize received levels (Table 8), thus reducing the risk of animals receiving too high a dose which might incur DCS/death.

C.1.5. Species not listed on the CMS Appendices that should also be considered during assessments

Beaked whales, *Ziphius cavirostris* (Appendix I) and *Hyperoodon* spp and *Berardius* spp (Appendix II) require additional consideration. These species appear particularly vulnerable to noise impacts. 20 species of *Mesoplodon* are currently missing from the CMS Appendices and yet are likely to also be vulnerable to noise impacts. All of these species are likely to be particularly sensitive to decompression stress.

Of other deep diving species which may potentially be at increased risk of decompression stress, *Kogia* are currently not listed on either of the CMS Appendices, *Physeter* is listed on Appendices I and II, *Globicephala* on Appendix II, and *Grampus* should also be considered during assessments.

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Table 8: Responses of beaked whales to sound sources

Species	Sound source	Response observed at received level (dB re. 1µPa)
Cuvier's beaked whale, <i>Ziphius cavirostris</i> (DeRuiter <i>et al</i> 2013)	30 min playback of 1.6s MFA sonar signal repeated every 25 sec. Initial source level of 160 dB re 1 mPa-m was increased ('ramped up') by 3 dB per transmission to a maximum of 210 dB re 1 mPa-m.	89-127
Cuvier's beaked whale, <i>Ziphius cavirostris</i> (Soto <i>et al</i> 2006)	Maximum broadband (356 Hz–44.8 kHz) level received during the ship passage was 136 dB _{rms} re 1 µPa, approx. 700m away.	106 (in click frequency range)
Northern bottlenose whale, <i>Hyperoodon ampullatus</i> (Miller <i>et al</i> 2015)	104 1-s duration 1–2 kHz upswing pulses (naval sonar signals) at 20s intervals. The source level of the sonar pulses increased by 1 dB per pulse from 152 to 214 dB re 1 µPam over 20min (61 pulses), and the remaining pulses were transmitted for 15min at a source level of 214 dB re 1 µPa m.	107
Baird's beaked whale, <i>Berardius bairdii</i> (Stimpert <i>et al</i> 2014)	Simulated mid-frequency active (MFA) military sonar signal at 3.5-4 kHz, transmitting 1.6 s signal every 25 s. The initial source level of 160 dB re: 1 mPa was increased by 3 dB per transmission for the first 8 minutes to a maximum of 210 dB for 22 additional minutes (72 transmissions total over 30 minutes).	127
Blainville's beaked whale, <i>Mesoplodon densirostris</i> (Tyack <i>et al</i> 2011)	Simulated 1.4 s MFA sonar, killer whale and noise signals. MFA sonar had both constant frequency and frequency modulated tonal components in the 3–4 kHz band repeated every 25 s. Initial source level of 160 dB re 1 mPa-m was increased ('ramped up') by 3 dB per transmission to a maximum of 210 dB re 1 mPa-m.	138

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D. Exposure Levels

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D.1. Impact of Exposure Levels and Exposure Duration

One of the first comprehensive definitions of exposure criteria for noise impact on marine mammals considering two types of impacts, namely auditory injury and behavioural disturbances by three sound types (single pulse, multiple pulse and nonpulse) has been published by Southall *et al* (2007). Just recently, the National Oceanic and Atmospheric Administration (NOAA) compiled and synthesized best available science to guide the assessment of effects of anthropogenic noise on marine mammals (NOAA, 2016). Both guidance documents consider cetaceans and pinnipeds assigned to five functional hearing groups (i.e. low-frequency cetaceans, mid-frequency cetaceans, high-frequency cetaceans, pinniped in water, pinnipeds in air and low-frequency cetaceans, mid-frequency cetaceans, high-frequency cetaceans, phocid pinnipeds underwater, otariid pinnipeds underwater respectively). The assignment to functional hearing groups was based on functional hearing characteristics of the species (e.g. frequency range of hearing, auditory morphology) and with reference to Southall *et al* as well the medium in which the amphibious living pinnipeds were exposed to sound. The developed noise exposure criteria do not address polar bears, sirenians, and sea otters due to the absence of necessary data in these species. To account for different hearing bandwidths and thus differences in impacts of identical noise exposure frequency-weighting functions were developed for each functional hearing group and considered in the formulation of the noise exposure criteria. Southall *et al* and NOAA applied dual criteria for noise exposure using peak sound pressure level (SPL) and sound exposure level (SEL) in each of the considered functional hearing groups in order to account for all relevant acoustic features such as sound level, sound

energy, and exposure duration that influence the impacts of noise on marine mammals.

The onset of a permanent threshold shift (PTS-onset) has been considered as the onset of auditory injury (Southall *et al* 2007, NOAA 2016, Finneran 2015). PTS-onset estimates are applied in order to formulate dual noise exposure levels. The PTS-onset thresholds were estimated from measured TTS-onset thresholds (=threshold where temporary change in auditory sensitivity occurs without tissue damage) in very few mid-frequency odontocetes (i.e. bottlenose dolphin and beluga) and pinnipeds (i.e. California sea lion, northern elephant seal, and harbour seal) and extrapolated to other marine mammals due to the scarcity of available TTS data. It has been noted, that this extrapolation from mid-frequency cetaceans and the subsequent formulation of exposure criteria may be delicate in particular for high-frequency cetaceans due to their generally lower hearing threshold as compared to other cetaceans. The growth rates of TTS were estimated based on data in terrestrial and marine mammals exposed to increasing noise levels. Noise exposure levels for single pulse, multipulse and nonpulse sounds were expressed for SPL and SEL whereby the latter has been frequency weighted to compensate for the differential frequency sensitivity in each functional marine mammal hearing group as described above. No noise exposure criteria were developed by Southall *et al* (2007) or NOAA (2016) for the occurrence of non-auditory injuries (e.g. altered immune response, energy reserves, reproductive efforts due to stress, tissue injury by gas and fat emboli), due to a lack of conclusive scientific data to formulate quantitative criteria for any other than auditory injuries caused by noise.

Additionally to auditory injuries Southall *et al* (2007) presented also explicit sound exposure levels for noise impacts on behaviour resulting in significant biological responses (e.g. altered survival, growth,

reproduction) for single pulse noise. For the latter it has been assumed that given the nature (high peak and short duration) of a single pulse behavioural disturbance may result from transient effects on hearing (i.e. TTS). Therefore, TTS values for SPL and SEL were proposed as noise exposure levels. In contrast, for multiple and nonpulse sounds it has been taken into account that behavioural reactions to sounds are highly context-dependent (e.g. activity animals are engaged at the time of noise exposure, habituation to sound) and depending also among others on environmental conditions and physiological characteristics such as age and sex. Thus noise impact on behaviour is less predictable and quantifiable than effects of noise on hearing. Moreover, adverse behavioural effects are expected to occur below noise exposure levels causing temporary loss of hearing sensitivity. Therefore, a descriptive method has been developed by Southall *et al.* (2007) to assess the severity of behavioural responses to multipulse and nonpulse sound. This method encompasses a quantitative scoring paradigm which numerically ranks (scores) the severity of behavioural responses. Noise exposure levels have been identified in a scoring analysis based on a thorough review of empirical studies on behavioural responses of marine mammals to noise. Reviewed cases with adequate information on measured noise levels and behavioural effects were then considered in a severity scoring table with the two dimensions, severity score and received SPL.

In contrast to former sound exposure assessment attempts Southall *et al.* (2007) and NOAA (2016) account for differences in functional hearing bandwidth between marine mammal groups through the developed frequency-weighting functions. Thus, this approach allows to assess the effects of intense sounds on marine mammals under the consideration of existing differences in auditory capabilities across species and groups respectively. Furthermore, as compared to the widely used RMS sound pressure Southall *et al.* (2007) and NOAA (2016) propose dual criteria sound metrics (SPL and SEL) to assess the impact of noise on marine mammals, accounting not only for sound pressure but also for sound energy, duration and high-energy transients.

All these aspects are certainly major accomplishment as compared to earlier attempts to assess noise effects on marine mammals. However, it has also to be noted that due to the absence of data noise exposure criteria had to be based on extrapolations and

assumptions and therefore, as Southall *et al.* (2007) and Finneran (2015) pointed out, caution is needed regarding the direct application of the criteria presented and that it is expected that criteria would change as better data basis becomes available.

D.2. Species Vulnerabilities

The best documented vulnerabilities to noise in marine mammals in terms of number of studies and species involved are certainly behavioural responses to noise. Only a few studies considering a few species exist regarding noise impacts on hearing and hearing sensitivity and physiology in marine mammals and therefore the respective knowledge on specific vulnerabilities of noise is rather scarce.

Auditory effects resulting from intense noise exposure comprise temporary threshold shift (TTS) and permanent threshold shift (PTS) in hearing sensitivity. For marine mammals TTS measurements exist for only a few species and individuals whereas for PTS no such data exist (Southall *et al.* 2007, Finneran 2015). Furthermore, noise may cause auditory masking, the reduction in audibility of biological important signals, as has been shown for pinniped species in air and water (Southall *et al.* 2000, 2003) and in killer whales (Foote *et al.* 2004) for example.

Physiological stress reactions induced by noise may occur in cetaceans as has been shown for few odontocete species where altered neuro-endocrine and cardiovascular functions occurred after high level noise exposure (Romano *et al.* 2004, Thomas *et al.* 1990c). Furthermore, regarding noise-related physiological effects it has to be noted that scientific evidence indicates that in particular beaked whales experience physiological trauma after military sonar exposure (Jepson *et al.* 2003, Fernandez *et al.* 2004, 2005) due to in vivo nitrogen gas bubble formation.

The magnitude of the effects of noise on behaviour may differ from biological insignificant to significant (= potential to affect vital activities such as foraging and reproduction). Noise-induced behaviour response may not only vary between individuals but also intra-individually and depends on a great variety of contextual (e.g. biological activity animals are engaged in such as feeding, mating), physiological (e.g. fitness, age, sex), sensory (e.g. hearing sensitivity), psychological (e.g. motivation, previous history with the sound) environmental (e.g. season, habitat type, sound transmission characteristics) and operational (e.g. sound

type, sound source is moving / stationary, sound level, duration of exposure) variables (Wartzok *et al* 2004).

Observable behavioural responses to noise include orientation reaction, change in vocal behaviour or respiration rates, changes in locomotion (speed, direction, dive profile), changes in group composition (aggregation, separation), aggressive behaviour related to noise exposure and/or towards conspecifics, cessation of reproductive behaviour, feeding or social interaction, startle response, separation of females and offspring, anti-predator response, avoidance of sound source, attraction by sound source, panic, flight, stampede, stranding, long term avoidance of area, habituation, sensitization, and tolerance (Richardson *et al* 1995, Gordon *et al* 2004, Nowacek *et al* 2007, Wartzok *et al* 2004).

Studies have shown that in mysticetes the reaction to the same received level of noise depends on the activity in which whales are engaged in at the time of exposure. For migrating bowhead whales strong avoidance behaviour to seismic air gun noise has been observed at received levels of noise around 120 dB re 1 μ Pa while engaged in migration. In contrast, strong behavioural disturbance in other mysticetes such as gray and humpback whales as well as feeding bowhead whales has been observed at higher received levels around 150-160 dB re 1 μ Pa (Richardson *et al* 1985, 1999, Malme *et al* 1983, 1984, Ljungblad *et al* 1988, Todd *et al* 1996, McCauley *et al* 1998, Miller *et al* 2005). Furthermore, in different dolphin species reactions to boat noise varied from avoidance, ignorance and attraction dependant on the activity state during exposure (Richardson *et al* 1995).

Noise-induced vocal modulation may include cessation of vocalization as observed in right whales (Watkins 1986), sperm whales and pilot whales (Watkins and Schevill 1975, Bowles *et al* 1994) for example. Furthermore, vocal response may include changes in output frequency and sound level as well as in signal duration (Au *et al* 1985, Miller *et al* 2000, Biassoni *et al* 2000).

Noise-induced behaviour depends on the characteristics of the area where animals are during exposure and/or of prior history with that sound. In belugas for example a series of strong responses to ship noise such as flight, abandonment of pod structure and vocal modifications, changes in surfacing, diving and respiration patterns has been observed at relatively low received sound levels of 94-105 dB re 1 μ Pa in a partially confined area but the animals returned after some days while ship

noise was higher than before (LGL and Greeneridge 1986, Finley *et al* 1990).

The distance of a noise source or its movement pattern influences the nature of behavioural responses. For instance, in sperm whales, changes in respiration and surfacing rates has been observed in the vicinity of ships (Gordon *et al* 1992) and dependant on whether a ship is moving or not different reactions of bowhead whales and other cetaceans have been observed (Richardson *et al* 1995, Wartzok *et al* 2004).

D.2.1. Species not listed on the CMS Appendices that should also be considered during assessments

- Deep-diving cetaceans, in particular beaked whales need special consideration regarding noise exposure levels due to the risk for tissue trauma due to gas and fat emboli under certain noise conditions.
- Due to their lower overall hearing thresholds, high-frequency hearing cetaceans (true porpoises, river dolphins, *Pontoporia blainvillei*, *Kogia breviceps*, *Kogia sima*, *cephalorhynchids*) may need additional consideration as their sensitivity to absolute levels of noise exposure may be higher than other cetacean hearing groups.
- Southall *et al* pointed out that due to a lack of data they could not formulate noise exposure levels for polar bears, sea otters, and sirenians. Certainly a point which needs consideration when dealing with areas where these marine mammal taxa occur.

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E. Marine Noise-generating Activities

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Wild Migration

E.1. Military Sonar

E.1.1. Low-Frequency Active Sonar

The evolution of lower frequency active (LFA) sonar came from two needs. First, to increase detection ranges to overcome passive sonar systems and second, to compensate for the improvements of stealth designs in submarine hulls, part of which was an anechoic coating that absorbed incident waves. It was discovered this coating was less efficient when exposed to longer wave lengths.

LFA sonars work below the 1kHz range. For transmitting long distances efficiently, high-powered modulated signals, typically 240 dB in water at 1m, peak value, (240 dB re 1μPa @ 1m peak) are produced lasting from tens of seconds to sometimes minutes. An example of this technology is the SURTASS-LFA of the US navy that operates within 100-500Hz range. (Lurton, 2010)

E.1.2. Mid-Frequency Active Sonar

Mid-frequency active (MFA) sonar is used for detecting submarines at moderate range, typically less than 10km.

MFA operates between 1-5 KHz range, with a sound intensity level typically 235 dB in water at 1m, peak value, (235 dB re 1μPa @ 1m peak) with a pulse duration of 1-2 seconds. (Hildebrand, 2009, Fildelfo *et al* 2009)

E.1.3. Continuous Active Sonar

The concept of continuous active sonar (CAS) is generating interest in the anti-submarine warfare community, largely due to its 100 per cent duty cycle offering the potential for rapid, continuous detection updates. CAS operates between 500Hz to 3KHz range with sound intensity levels typically 182 dB in water at 1m, peak value, (182 dB re 1μPa @ 1m peak) with a signal duration of 18 seconds (Murphy and Hines, 2015)

E.1.4. Mine Counter Measures Sonar

Underwater mines have proven, over time, to be very effective. Their prevalence led to the development of the Mine Counter Measures (MCM) sonar. This system works at very high frequency, usually between 100-500kHz, to achieve high-quality acoustic imaging of the sea floor and water column. Targets, semi-buried or suspended from the sea floor, are easily identified. (Lurton, 2010)

E.1.5. Acoustic Minesweeping Systems

Acoustic Minesweeping Systems are another mine counter-measure that produces a low-frequency broadband transmission, mimicking the sound produced by certain vessels whereby detonating the mine. (Lurton, 2010)

E.2. Seismic Surveys

The commonly used surveying method for offshore petroleum exploration is 'seismic reflection'. This is simply sound energy emitted from a sound source (air gun array) several metres below the sea surface that penetrates subsurface layers of the seabed and is reflected and refracted to the surface where it is detected by acoustic receivers (accelerometers and geophones).

These surveys are typically conducted using specially equipped vessels that tow one or more cables (streamers) with geophones at constant intervals. Air guns vary in size, and in conjunction with the charge pressure, determine the sound intensity level and frequency.

Frequencies used for seismic surveys are between 10-200Hz and down to 4-5Hz for the larger air guns. However, there are unused high-frequency components up to 150kHz, with a very high discharge at the onset of the pulse. (Goold and Coates, 2006)

The typical discharge sound intensity level of each pulse of an air gun array is around 260-262 dB in water at 1m, peak to peak value, (260-262 dB re 1μPa @ 1m p-p)

(OSPAR, 2009) every 10-15 seconds, and surveys typically run more or less continuously over many weeks. (Urick, 1983, Clay and Medwin, 1997, Caldwell and Dragoset, 2000, Dragoset, 2000, Lurton, 2010, Prideaux and Prideaux, 2015)

E.3. Civil High Power Sonar

Seafloor mapping sonar systems are probably one of the most prolific forms of underwater noise generation. The main application is coastal navigation for the production of bathymetric charts. Other applications include geology, geophysics, underwater cables and oil industry exploration. Three examples are Single Beam Sounders (SBES), Sidescan Sonars and Multibeam Echosounders (MBES).

E.3.1. Single Beam Sounders

Single beam sounders point vertically below the vessel and transmit a short signal, typically 0.1ms. The frequencies vary on their application. For deep water, the frequency would be around 12kHz and increase to 200, 400 and even 700KHz for shallow water. The sound intensity level is usually around 240 dB in water at 1m, peak value (240 dB re 1 μ Pa @ 1m peak). (Lurton, 2010)

E.3.2. Sidescan Sonar

Sidescan sonar system structures are similar to single-beam sonars. This sonar differs as it is installed on a platform or “towfish” and towed behind a vessel close to the seabed. Two antennae are placed perpendicularly to the body of the towfish, pointing fractionally to the sea floor. The transmission of the sidescan sonar insonifies the sea floor with a very narrow perpendicular band. The echo received along time reflects the irregularities of the sea floor. A simple analogy is the scan mechanism of a photo copier. The operating frequency is usually in the range of many hundreds of kHz with the pulse duration 0.1ms or less. (Lurton, 2010)

E.3.3. Multibeam Echosounder

Multibeam echosounders are the major tool for seafloor mapping, for hydrography and offshore industry applications. The transmission and receiving arrays are mounted on the vessel to create a narrow beam, fan-like 150° spread, perpendicular to the keel.

Multibeam sounders can be put into three main categories depending on their system structure and varied uses:

- deep water systems, designed for regional mapping, 12khz for deep ocean, 30khz for continental slopes;
- shallow water systems designed for

mapping continental shelves, 70-200kHz; and

- high-resolution systems for hydrography, shipwreck location and underwater structural inspection, 300-500khz.

The attraction for multibeam systems is the scale of area that can be covered over time. For instance, a deep water configured multibeam sounder with a 20km fan/spread can cover 10,000km² per day. (Lurton, 2010)

E.3.4. Boomers, Sparkers and Chirps

Sparkers and boomers are devices used to determine shallow features in sediments. These devices may also be towed behind a survey vessel, with their signals penetrating several tens (boomer) or hundred (sparker) of metres of sediments. Typical sound intensity levels of sparkers are approximately 204-210 dB in water at 1m, rms value (204-210 dB re 1 μ Pa @ 1 m). Deep-tow boomer sound intensity levels are approximately 220 dB in water at 1m, rms value (220 dB re 1 μ Pa @ 1 m). The frequency range of both is 80Hz-10kHz, and the pulse length is 0.2 ms. (Aiello *et al* 2012, OSPAR, 2009)

Chirps produce sound in the upper-frequency range around 20Hz-20 kHz. (Mosher and Simpkin, 1999) The sound intensity level for these devices is about 210-230 dB in water at 1m, peak value, (210-230 dB re 1 μ Pa @ 1 m) and the pulse length is 250ms. (Dybedal and Boe, 1994, Lee *et al* 2008, OSPAR, 2009)

E.4. Coastal and Offshore Construction Works

E.4.1. Explosions

Explosions are used in construction and for the removal of unwanted seabed structures. Underwater explosions are one the strongest anthropogenic sound sources and can travel great distances. (Richardson *et al* 1995) Sound intensity levels vary with the type and amount of explosive used and the depth to which it is detonated. TNT, 1-100lbs, can produce a sound intensity level from 272-287 dB in water at 1m, zero to peak value, (272-287 dB re 1 μ Pa 0 to peak @ 1m) with a frequency range of 2-~1000Hz for a duration of <1-10ms. The core energy is between 6-21Hz. (Richardson *et al* 1995, NRC, 2003)

E.4.2. Pile driving

Pile driving is associated with harbour work, bridge construction and wind farm foundations. Sound intensity levels vary depending on pile size and type of hammer. There are two types of hammers, an impact

type (diesel or hydraulic) and vibratory type. Vibratory type hammers generate lower source levels, but the signal is continuous, where impact hammers are louder and impulsive. The upper range is around 228 dB in water at 1m, peak value or 248-257 dB in water at 1m, peak to peak value, (228 dB re 1µPa peak @ 1 m/248-257 dB re 1µPa peak to peak @ 1m) with frequencies ranging within 20Hz-20kHz and a duration of 50ms. (Nedwell *et al* 2003, Nedwell and Howell, 2004, Thomsen *et al* 2006, OSPAR, 2009)

E.4.3. Dredging

Dredging is used to extract sand and gravel, to maintain shipping lanes and to route pipelines. The sound intensity level produced is approximately 168-186 dB in water at 1m, rms value, (168-186 dB re 1µPa @ 1m_{rms}) with frequencies ranging from 20Hz->1kHz with the main concentration below 500Hz.

The majority of this sound is constant and non-impulsive. (Richardson *et al* 1995, OSPAR, 2009)

E.5. Offshore Platforms

E.5.1. Drilling

Drilling can be done from natural or manmade islands, platforms, drilling vessels, semi-submersibles or drill ships.

For natural or manmade islands, the underwater sound intensity level has been measured at 145 dB in water at 1m, rms value, (145 dB re 1µPa @1m_{rms}) with frequencies below 100Hz. (Richardson *et al* 1995)

The sound intensity level transmitted down the caissons with platform drilling has been measured at approximately 150 dB in water at 1m, rms value, (150 dB re 1µPa_{rms} @ 1m) at 30-40Hz frequency. (Richardson *et al* 1995)

Drill ships seem to emit the highest sound intensity level, 190 dB in water at 1m, rms value, (190 dB re 1µPa @ 1m_{rms}) with the frequencies ranging between 10Hz-10kHz, due to the efficient transmission of sound through the ship's hull. Additionally, ships use their location thrusters to keep them on target, combining propeller, dynamic positioning transponder (placed on the hull and sea floor) pingers (see below), and drill noise. (Richardson *et al* 1995, OSPAR, 2009, Kyhn *et al* 2014)

E.5.2. Positioning Transponders

Positioning transponders are used to dynamically position drill ships and other offshore platforms. Each system uses a concatenation of master and slave transponders. These systems have been recorded to have a sound intensity level of 100

dB in water at 2km, rms value (100 dB re 1µPa @ 2km_{rms}) with the frequencies ranging between 20kHz to 35kHz. (Kyhn *et al* 2014)

E.5.3. Related Production Activities

During production, noise sources include seafloor equipment such as separators, injectors and multi-phase pumps operating at very high pressures.

There have also been studies to measure the sound intensity levels during production maintenance operations. Sound intensity levels of 190dB rms from the drill ship (distance unknown) with a frequency range between 20Hz-10kHz were recorded. (Kyhn *et al* 2014) In another instance, well head (choke valves) were recorded as producing continuous noise 159 dB re 1 µPa @ 1m from the source (RMS) (McCauley, 2002)

There have been few systematic studies to measure the source levels of production maintenance. It is likely the sound intensity level is high. This is an area that needs focused attention.

E.6. Playback and Sound Exposure Experiments

Ocean science uses a variety of sound sources. These include explosives, air guns and underwater sound projectors.

Where studies involve the intentional exposure of animals to a particular noise source, the impact assessments (and ethics requirements) should refer to the information available in this Technical Background Information about the noise-generating activity and the species concerned (Modules B-D).

E.6.1. Ocean Tomography

Ocean tomography measures the physical properties of the ocean using frequencies between 50-200Hz with a sound intensity level of 165-220 dB in water at 1m (165-220 dB re 1µPa @ 1m). The *Acoustic Thermometry of Ocean Climate* research programme emitted a sound source of 195 dB in water at 1m, peak value, (195 dB re 1µPa @ 1m peak) at a frequency of 75Hz.

Geophysical research activities, one of which is the study of sediments in shallow water, also use typical mid or low-frequency sonar systems or echo-sounders. (OSPAR, 2009) These are discussed under Civil High Power Sonar.

E.7. Shipping and Vessel Traffic

Marine vessels, small to large, contribute significantly to anthropogenic noise in the oceans. The trend is usually, the larger

the vessel, the lower the frequencies produced resulting in the noise emitted travelling greater distances. The sound characteristics produced by individual vessels are determined by the vessels class/type, size, power plant, propulsion type/design and hull shape with relation to speed. Also, the vessel's age regarding mechanical condition and the cleanliness of the hull: Less drag means less noise.

E.7.1. Small Vessels

Small vessels (leisure and commercial) for this paper are vessels up to 50m in length. These include planing hull designs such as jet skis, speed boats, light commercial runabouts as well as displacement hull designs like motor yachts, fishing vessels and small trawlers.

The greater portion of sound produced by these vessels is mainly above 1kHz mostly from propeller cavitation. Factors that generate frequencies below 1kHz are engine and gearbox noise as well as propeller resonance. The sound intensity level produced is approximately 160-180 dB in water at 1m, rms value, (160-180 dB re 1µPa @ 1m_{rms}) with frequencies ranging 20Hz ->10kHz. This, however, is dependent on the vessel's speed in relation to hull efficiency and economic speed to power settings. (Richardson *et al* 1995, OSPAR, 2009)

E.7.2. Medium Vessels

Medium vessels for this paper are vessels between 50-100m, such as tugboats, crew-boats, larger fishing/trawler and research vessels. These vessels tend to have slower revving engines and power trains. The frequencies produced tend to mimic large vessels with the majority of sound energy below 1kHz. The sound intensity level produced is approximately 165-180 dB in water at 1m, rms value (165-180 dB re 1µPa @ 1m_{rms}). (Richardson *et al* 1995, OSPAR, 2009)

E.7.3. Large Vessels

Large vessels for this paper are vessel lengths greater than 100m, such as container/cargo ships, super-tankers and cruise liners.

Large vessels, depending on type, size and operational mode, produce their strongest sound intensity level of approximately 180-190 dB in water at 1m, rms value, (180-190 dB re 1µPa @ 1m_{rms}) at a few hundred Hz. (Richardson *et al* 1995, Arvenson and Vendittis, 2000) In addition, a significant amount of high-frequency sound, 150 dB in water @ 1m, rms value, (150 dB re 1µPa @ 1m_{rms}) or broadband frequencies, 0.354-44.8

kHz of 136 dB in water at 700m distance, rms value, (136 dB re: 1µPa @ >700m_{rms}) can be generated through propeller cavitation. This near-field source of high-frequency sound is of concern particularly within shipping corridors, shallow coastal waters, waterways/canals and/or ports. (Arveson and Vendettis, 2000, Aguilar Soto *et al* 2006, OSPAR, 2009)

E.8. Pingers

E.8.1. Acoustic Navigation Beacons

Acoustic navigation beacons mark the position of an object and measure its height above the seabed. Most underwater beacons emit a short continuous wave tone, commonly 8-16 kHz octave band, with a stable ping rate. Typical sound intensity levels are around 160-190 dB in water at 1m, peak value (160-190 dB re 1µPa @ 1m peak). They are designed to be omnidirectional to be heard from any direction. Simple systems are programmed to transmit a fixed ping rate while more sophisticated systems transmit after receiving an interrogating signal. (Lurton, 2010)

E.8.2. Acoustic Deterrent Devices

Acoustic Deterrent Devices (ADDs) are a low powered device, 130-135 dB in water at 1m, peak value, (130-135 dB re 1µPa @ 1m peak) designed to deter fish from entering places of harm such as water inlets to power stations. The frequencies range from 9-15kHz for a duration 100-300ms every 3-4 seconds. (Carretta *et al* 2008, Lepper *et al* 2004, Lurton, 2010, OSPAR Commission, 2009)

E.8.3. Acoustic harassment devices

Acoustic Harassment Devices (AHDs) are a higher powered device, 190 dB in water at 1m, peak value, (190 dB re 1µPa @ 1m peak) originally designed to keep marine mammals away from fish farms by causing them pain. Frequencies range from 5-20kHz for repelling pinnipeds and 30-160kHz for delphinids. (Carretta *et al* 2008, Lepper *et al* 2004, Lurton, 2010, OSPAR, 2009)

E.9. Other Noise-generating Activities

E.9.1. Acoustic Data Transmission

Acoustic modems are used as an interface for subsurface data transmission. Frequencies range around 18-40kHz with a sound intensity level around 185-196dB in water at 1m (185-196 dB re 1µPa @ 1m). (OSPAR, 2009)

E.9.2. Offshore Tidal and Wave Energy Turbines

Offshore tidal and wave energy turbines are new, so acoustic information is limited. However, they appear to emit a frequency range of 10Hz-50kHz and a sound intensity level between 165-175dB in water at 1m, rms value, (165-175 dB re 1 μ Pa @ 1m_{rms}) depending on size. (OSPAR, 2009)

E.9.3. Wind turbines

The operational sound intensity levels for wind generators depend on construction type, size, environmental conditions, type of foundation, wind speed and the accumulative effect from neighbouring turbines. A 1.5MW turbine in 5-10m of water with a wind speed of 12m/s has been recorded producing 90-112 dB in water at 110m, rms value, (90-112 dB re 1 μ Pa @ 110m_{rms}) with frequencies ranging 50Hz-20kHz. (Thomsen *et al* 2006, OSPAR, 2009)

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Table 9: Noise-generating activity, sound intensity level, bandwidth, major amplitude, duration and directionality (summary of E.1-E.9)

Sound	Sound Intensity Level (dB re1 μ Pa)	Bandwidth	Major Amplitude	Duration	Directionality
Military					
Military Low-Frequency Active Sonar	240 Peak @ 1m	<1kHz- 1kHz	[unknown]	600-1,000ms	Horizontally focused
Military Mid-Frequency Active Sonar	235 Peak @ 1m	1-5kHz	[unknown]	1-2s	Horizontally focused (3 degrees down)
Continuous Active Sonar	182 Peak @ 1m	500Hz – 3kHz	[unknown]	18 seconds	Horizontally focused
Military Mine Counter Measures Sonar	[unknown]	100kHz-500kHz	[unknown]	[unknown]	[unknown]
Seismic Surveys					
Seismic Surveys	260-262 Peak to Peak @ 1m	10Hz-150kHz	10-120Hz also 120dB up to 100kHz	30-60ms	Vertically focused
Civil High Power Sonar					
Single Beam Sounders	240 Peak @ 1m	12kHz-700kHz depending on the application	[unknown]	0.1ms	Vertically focused
Sidescan Sonar	240 Peak @ 1m	12kHz-700kHz depending on the application	[unknown]	0.1ms	Vertically focused fan spread
Multibeam Echosounders	240 Peak @ 1m	12kHz-30kHz, 70kHz-200kHz, 300kHz-500kHz depending on the application	[unknown]	0.1ms	Vertically focused fan spread
Sparkers and Boomers	204-220 _{rms} @ 1m	80Hz-10kHz	[unknown]	0.2ms	[unknown]
Chirps	210-230 Peak @ 1m	20Hz-20kHz	[unknown]	250ms	[unknown]
Coastal and Offshore Construction Works					
Explosions, TNT 1-100lbs	272-287 Peak @ 1m	2Hz-~1,000Hz	6-21Hz	<1-10ms	Omnidirectional
Pile Driving	248-257 Peak to Peak @ 1m	20Hz-20kHz	100Hz-500Hz	50ms	Omnidirectional
Dredging	168-186 _{rms} @ 1m	20Hz-1kHz	500Hz	Continuous	Omnidirectional
Offshore Platforms					
Platform Drilling	150 _{rms} @1m	30Hz-40Hz	[unknown]	Continuous	Omnidirectional
Drill Ships (including maintenance)	190 _{rms} @ 1m	10Hz-10kHz	[unknown]	Continuous	Omnidirectional
Positioning transponders	100 _{rms} @ 2km	20kHz – 35kHz	[unknown]	Continuous	Omnidirectional

Sound	Sound Intensity Level (dB re 1 iPa)	Bandwidth	Major Amplitude	Duration	Directionality
Playback and Sound Exposure Experiments					
Ocean Tomography	165-220 Peak @ 1m	50Hz-200Hz	[unknown]	[unknown]	Omnidirectional
Shipping and Vessel Traffic					
Small Vessels	160-180 _{rms} @ 1m	20Hz-10kHz	[unknown]	Continuous	Omnidirectional
Medium Vessels	165-180 _{rms} @ 1m	Below 1kHz	[unknown]	Continuous	Omnidirectional
Large Vessels	Low Frequency 180-190 _{rms} @ 1m High Frequency 136 _{rms} @ 700m	Low Frequency A few hundred Hz High Frequency 0.354kHz-44.8kHz	[unknown]	Continuous	Omnidirectional
Pingers					
Acoustic Navigation Beacons	160-190 Peak @ 1m	8kHz-16kHz	[unknown]	[unknown]	Omnidirectional
Acoustic Deterrent Devices	130-135 Peak @ 1m	9kHz-15kHz	[unknown]	100-300ms	Omnidirectional
Acoustic Harassment Devices	190 Peak @ 1m	5kHz-20kHz, 30kHz-160kHz depending on the application	[unknown]	[unknown]	Omnidirectional
Other Noise-generating Activities					
Acoustic Data Transmission	185-196 @ 1m	18kHz-40kHz	[unknown]	[unknown]	Omnidirectional
Offshore Tidal and Wave Energy Turbines	165-175 _{rms} @ 1m	10Hz-50kHz	[unknown]	Continuous	Omnidirectional
Wind Turbines	90-112 _{rms} @ 110m	50Hz-20kHz	[unknown]	Continuous	Omnidirectional

F. Related Decisions of Intergovernmental Bodies or Regional Economic Organisations

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A series of relevant intergovernmental decisions have already determined the direction for regulating anthropogenic marine noise through EIAs. The following decisions are the latest from each of Multi-lateral Environment Agreement (MEA).

F.1.1. CMS

‘CMS Resolution 9.19: Adverse Anthropogenic Marine/Ocean Noise Impacts on Cetaceans and Other Biota’ encourages Parties to:

‘...to endeavour to control the impact of emission of man-made noise pollution in habitat of vulnerable species and in areas where marine mammals or other endangered species may be concentrated, and where appropriate, to undertake relevant environmental assessments on the introduction of systems which may lead to noise associated risks for marine mammals.’

‘CMS Resolution 10.24: Further Steps to Abate Underwater Noise Pollution for the Protection of Cetaceans and Other Migratory Species’ encourages CMS Parties to:

‘...prevent adverse effects on cetaceans and on other migratory marine species by restricting the emission of underwater noise, understood as keeping it to the lowest necessary level with particular priority given to situations where the impacts on cetaceans are known to be heavy’ and

“[u]rges Parties to ensure that Environmental Impact Assessments take full account of the effects of activities on cetaceans and to consider potential impacts on marine biota and their migration routes ...’

‘Resolution 10.24’ further articulates that CMS Parties should ensure that Environmental Impact Assessments take full account of the impact of anthropogenic marine

noise on marine species, apply Best Available Techniques (BAT) and Best Environmental Practice (BEP), and integrate the issue of anthropogenic noise into the management plans of marine protected areas. ‘Resolution 10.24’ also ‘invites the private sector to assist in developing ...alternative techniques and technologies for coastal, offshore and maritime activities’.

F.1.2. ACCOBAMS

‘ACCOBAMS Resolution 5.13: Conservation of Cuvier's beaked whales in the Mediterranean’ and ‘Resolution 5.15: Addressing the impact of anthropogenic noise’ reinforces the commitments made in ‘Resolution 4.17: Guidelines to Address the Impact of Anthropogenic Noise on Cetaceans in the ACCOBAMS Area (ACCOBAMS Noise Guidelines)’ that urges ACCOBAMS Parties to:

‘[r]ecogniz[e] that anthropogenic ocean noise is a form of pollution, caused by the introduction of energy into the marine environment, that can have adverse effects on marine life, ranging from disturbance to injury and death.’

This Resolution also encourages ACCOBAMS Parties to:

‘... address fully the issue of anthropogenic noise in the marine environment, including cumulative effects, in the light of the best scientific information available and taking into consideration the applicable legislation of the Parties, particularly as regards the need for thorough environmental impact assessments being undertaken before granting approval to proposed noise-producing activities.’

The ACCOBAMS Noise Guidelines provide further comprehensive detail-specific considerations relating to military sonar,

seismic surveys and offshore drilling, shipping and offshore renewable energy developments.

F.1.3. ASCOBANS

‘ASCOBANS Resolution 5.4: Adverse Effects of Sound, Vessels and other Forms of Disturbance on Small Cetaceans’, urges ASCOBANS Parties to:

‘... develop, with military and other relevant authorities, effective mitigation measures including environmental impact assessments and relevant standing orders to reduce disturbance of, and potential physical damage to, small cetaceans, and to develop and implement procedures to assess the effectiveness of any guidelines or management measures introduced.’

‘ASCOBANS Resolution 6.2: Adverse Effects of Underwater Noise on Marine Mammals during Offshore Construction Activities for Renewable Energy Production’, further recommends that Parties:

‘... include Strategic Environmental Assessments and Environmental Impact Assessments carried out prior to the construction of marine renewable energy developments and taking into account the construction phase and cumulative impacts’

and to:

‘... introduce precautionary guidance on measures and procedures for all activities surrounding the development of renewable energy production in order to minimise risks to populations ... [that include] measures for avoiding construction activities with high underwater noise source levels during the periods of the year with the highest densities of small cetaceans, and in so doing limiting the number of animals exposed, if potentially significant adverse effects on small cetaceans cannot be avoided by other measures; [to include] Measures for avoiding construction activities with high underwater noise source levels when small cetaceans are present in the vicinity of the construction site; [and] technical measures for reducing the sound emission during construction works, if potentially significant adverse effects on small cetaceans cannot be avoided by other measures.’

F.1.4. CBD

‘CBD Decisions VIII/28: CBD Voluntary Guidelines on Biodiversity-inclusive Impact Assessment’ provides detailed guidance on whether, when and how to consider biodiversity in both project level and strategic levels assessments. The document articulates screening, scoping, assessment and evaluation of impacts, development and alternatives; transparency and consultation, reporting, review and decision-making. The guidelines suggest that environmental impact assessments should be mandatory for activities in habitats for threatened species and activities resulting in noise emissions in areas that provide key ecosystem services.

‘CBD Decision XII/23: Marine and coastal biodiversity: Impacts on marine and coastal biodiversity of anthropogenic underwater noise’ encourages CBD Parties and others:

‘... to take appropriate measures, as appropriate and within competencies and in accordance with national and international laws, such as gathering additional data about noise intensity and noise types; and building capacity in developing regions where scientific capacity can be strengthened.’

In ‘Decision XII/23’ CBD Parties have agreed to a significant list of technical commitments, including gathering additional data about noise intensity and noise types, and building capacity in developing regions where scientific capacity can be strengthened.

The CBD Parties also encouraged Parties to take appropriate measures, including:

*‘... (e) Combining acoustic mapping with habitat mapping of sound-sensitive species with regard to spatial risk assessments in order to identify areas where those species may be exposed to noise impacts,
(f) Mitigating and managing anthropogenic underwater noise through the use of spatio-temporal management of activities, relying on sufficiently detailed temporal and spatial knowledge of species or population distribution patterns combined with the ability to avoid generating noise in the area at those times,
(g) Conducting impact assessments, where appropriate, for activities that may have significant adverse impacts on noise-sensitive species, and carrying out monitoring, where appropriate.’*

‘Decision XII/23’ urges the transfer to quieter technologies and applying the best available practice in all relevant activities.

F.1.5. IMO

The International Maritime Organization (IMO), through ‘Resolution A 28/Res.1061’, has requested that the Marine Environment Protection Committee (MEPC) keep under review measures to reduce adverse impact on the marine environment by ships, including developing:

‘[g]uidance for the reduction of noise from commercial shipping and its adverse impacts on marine life’

F.1.6. IWC

The Scientific Committee of the International Whaling Commission (IWC) continues to monitor and discuss the impacts of noise on cetaceans.

F.1.7. OSPAR

The Convention for the Protection of the Marine Environment of the North-East-Atlantic (OSPAR) has reached agreement on an ‘OSPAR Monitoring Strategy for Ambient Underwater Noise’.

The OSPAR Intersessional Correspondence Group on Noise (ICG-NOISE) is currently working closely with the International Council for the Exploration of the Sea (ICES) data team to produce the 2017 OSPAR Intermediate Assessment for impulsive noise. This is the first regional assessment of its kind and will give policy-makers and regulators a regional overview of cumulative impulsive noise activity in the Northeast Atlantic, including the noise source type (e.g. pile driver, explosion) and intensity. The 2017 Intermediate Assessment will serve as a ‘roof report’ to inform the subsequent 2018 MSFD assessments of EU Member States within the OSPAR region.

F.1.8. Espoo (EIA) Convention

In ‘Decision II/8’ Espoo Parties endorsed the Good Practice Recommendations on Public Participation in Strategic Environmental Assessment set out in document ‘ECE/MP.EIA/SEA/2014/2’, including and requirement that

‘... the public to be given an opportunity to comment on draft plans or programmes and the associated environmental reports,’
and that:

‘[p]eople who are affected by a plan or programme and are interested in participating must be given access to all necessary information and be able to participate in meetings and hearings related to the SEA process.’

This applies during the different stages of the assessment, including screening, scoping, availability of the draft plan/programme and environmental report, opportunity for the public to express its opinions and decision.

F.1.9. HELCOM

The Baltic Marine Environment Protection Commission - Helsinki Commission (HELCOM) has two important programmes in development. The Baltic Sea Information on the Acoustic Soundscape Project surveyed national needs and requirements of information on noise and will recommend monitoring of ambient noise in the Baltic Sea. A registry of impulsive sounds project is also being considered.

F.1.10. Regional Seas Programmes

Most of the six UNEP administered Regional Seas Programmes including the Wider Caribbean Region, East Asian Seas, Eastern Africa Region, Mediterranean Region, North-West Pacific Region and the Western Africa Region and seven non-UNEP Administered Regional Seas Programmes including the Black Sea Region, North-East Pacific Region, Red Sea and the Gulf of Aden, ROPME Sea Area, South Asian Seas, South-East Pacific Region and the Pacific Islands Region suggest some form of impact assessment should be conducted to mitigate threats to the marine environment.

F.1.11. European Union Legislation and Implementation

Some pieces of EU legislation on environmental impact assessment and nature protection are relevant and contain specific references to the marine environment and wildlife and noise.

Recital 12 of Directive 2014/52/EU of the European Parliament and the Council, which amends Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment, specifically mentions the marine environment and gives the example of one source of noise-generating activity:

‘With a view to ensuring a high level of protection of the marine environment, especially species and habitats, environmental impact assessment and screening procedures for projects in the marine¹ environment should take into account the characteristics of those projects with particular regard to the technologies used (for example seismic surveys using active sonars).’

In addition, Recital 33 of this Directive also requires that:

‘Experts involved in the preparation of environmental impact assessment reports should be qualified and competent. Sufficient expertise, in the relevant field of the project concerned, is required for the purpose of its examination by the competent authorities in order to ensure that the information provided by the developer is complete and of a high level of quality.’

The marine environment is mentioned in Annex III paragraph 2 (ii) related to legal article 4(3), and noise and vibration are listed in Annex IV paragraphs 1 (d) and 5 (c) among information to be supplied according to Article 5 (1).

The EIA Directive applies to all Member States and requires that, for certain types of projects listed in its Annexes, public and private projects likely to have significant effects on the environment by virtue *inter alia* of their size, nature or location are made subject to an assessment of their environmental effects.

Under the EIA Directive “project” means *‘the execution of construction works or of other installations or schemes’* and *‘other interventions in the natural surroundings and landscape including those involving the extraction of mineral resources’*.

For projects listed in Annex I of the EIA Directive an assessment should always be carried out, whereas, for projects listed in Annex II, Member States have to determine whether an assessment is to be carried out through a case-by-case examination or according to thresholds or criteria set by the Member State.

The so-called EU nature directives (Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitats Directive) and Council and European Parliament Directive 2009/147/EC on the conservation of wild birds (Birds Directive) are also relevant. For the Natura 2000 sites designated for the protection of features such as marine animal species listed in Annex II of the Habitats Directive, measures are required under Art. 6(2) to avoid any significant disturbance of those species, while different human activities that are likely to have a significant effect on Natura 2000 sites need to be properly assessed and authorized in accordance with the provisions of article 6 (3) and (4) of the Habitats Directive. This provision also includes the obligation to assess the cumulative impacts of different activities on the conservation objectives of the site. Furthermore, the provisions of Article 12 of the Habitats Directive, which includes an obligation to prohibit deliberate disturbance of strictly protected species, are also particularly relevant in such situation, as all species of cetaceans and a number of marine vertebrates and invertebrates listed in Annex IV(a) benefit from a system of strict protection.

The Commission guidance document on *‘establishing Natura 2000 sites in the marine environment’*¹ contains a specific section on noise pollution.

There is specific legislation on the marine environment. In 2008 the European Parliament and the Council adopted the Marine Strategy Framework Directive² which requires the Member States to achieve or maintain ‘good environmental status’ of European Union marine waters by 2020, by developing marine strategies. Marine strategies contain five main elements: the initial assessment, the determination of good environmental status, the establishment of environmental targets, the monitoring programmes and the programme of measures.

When determining ‘good environmental status’, the Member States shall determine a set of characteristics on the basis of 11 qualitative descriptors. One of these descriptors state:

¹ Guidelines for the establishment of the Natura 2000 network in the marine environment: Application of the Habitats and Birds Directives (pp. 94-96)

² Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive); Commission Directive (EU) 2017/845 of 17 May 2017 amending Directive 2008/56/EC of the European Parliament and of the Council as regards the indicative lists of elements to be taken into account for the preparation of marine strategies

“Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.”

This is further specified in Commission Decision (EU) 2017/848³. Two types of criteria elements are defined for Descriptor 11: (a) anthropogenic impulsive sound in water and (b) anthropogenic continuous low-frequency sound in water. The primary criteria for both types are that the spatial distribution, temporal extent, and the levels of anthropogenic impulsive sound or continuous low-frequency sound sources do not affect populations of marine animals. In both cases the Member States shall establish threshold values for these levels through cooperation at Union level, taking into account regional and subregional specificities.

Methodological standards, as well as specifications and standardised methods for monitoring and assessment, are given in detail for both types of sound sources.

Within the context of the Marine Strategy Framework Directive, the Member States sharing a marine region or sub-region are also encouraged to cooperate to deliver on the objectives of the Directive.

³ Commission Decision (EU) 2017/848 of 17 May 2017 laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment, and repealing Decision 2010/477/EU.

G. Principles of EIAs

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The principle of Environmental Impact Assessment (EIA) was developed and introduced in the 1960s during a time where there was a growth of modern environmental concern, a drive for more rational, scientific and objective environmental decision-making and a desire for more public involvement in environmental decision-making. (Weston, 2002)

Conducting EIAs is now a well-established governance and environmental management process, institutionalised in most of the 193 United Nations Member States (Glasson *et al* 2013, Morrison-Saunders and Retief, 2012).

Some intergovernmental bodies have elaborated the principles of what EIAs should present (see Module F).

Through the process of their adoption, governments have individually committed to reflecting these decisions in their domestic law. The 'weight' of these decisions taken by governments at an international level is considerable and provides significant clarity about the expectations to conduct EIAs and effectively manage impacts of marine noise-generating activities.

Some jurisdictions have already developed national and regional operational guidelines about mitigating anthropogenic noise on marine fauna during activities. These began with the United Kingdom's Joint Nature Conservation Committee guidelines. Similar guidelines have been iteratively developed in the United States of America, Brazil, Canada, Australia and New Zealand (Castellote 2007, Weir and Dolman 2007). The European Espoo Convention also provides guidance. These are important and necessary operational guidelines. They form a part of but are not the totality of what should be considered within an EIA.

This Module provides some general principles to ensure environmental impacts (broadly defined to include the physical, life and social sciences) are an explicit and

fundamental consideration both during the design of an activity and in the project authorisation by a regulator. (Cashmaore, 2004)

It is clear that there is sufficient international agreement that EIAs should be conducted. There are widespread national legal commitment and some detail in a few jurisdictions. What is now required is a change of practice: by regulators to insist thorough EIAs are presented, and by proponents to accept the same. (Morrison-Saunders and Retief, 2012, Prideaux and Prideaux, 2015)

G.1. The importance of early Strategic Environmental Assessment

There is strong value in governments' undergoing a level of assessment before inviting proponents to propose activities. Conducting proactive and early assessment of groups of activities, in the context of broader governmental vision, goals or objectives, can serve as a decision-support instrument that shapes as a process. (Morgan, 2012) Commonly called Strategic Environmental Assessments (SEA), these exercises can highlight the likely outcomes of anticipated activities and reduce stakeholder conflict by restricting or directing activity development before any commercial investment has been made. (Alshuwaikhat, 2005, Fundingsland Tetlow and Hanusch, 2012).

SEAs have the potential to act as a mediating instrument, bridging problem perceptions with technical solutions and steering the assessment to facilitate the integration of environmental values into decision-making processes. (Therivel, 2012, Fundingsland Tetlow and Hanusch, 2012)

SEA can enhance communication between different stakeholders, enabling discussion and agreement independently of different beliefs, convictions, social roles,

values, accumulated experiences, individual needs or other factors. (Vicente and Partidário, 2006) SEAs can also guide regulators about the institutional requirements needed to assess proposals properly. This will include their internal organisational structure, staffing and capacity. (Therivel, 2012, Fundingsland Tetlow and Hanusch, 2012)

SEA design should reflect the core principles of the EIAs and the ‘CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities’.

G.2. Basic Principles of EIAs

It is broadly accepted that the basic intent of EIAs is to anticipate the significant environmental impacts of development proposals before any commitment to a particular course of action. Often, the detail required within EIAs is poorly defined. Many legislative provisions for EIAs have been introduced without consideration of the institutional requirements, organizational structure, staffing and capacity development (Cashmore *et al* 2004, Devlin and Yap 2008, Jay *et al* 2007). Often the scientific basis and methods need sophisticated understanding.

Defensible EIAs, representing the Best Available Techniques (BAT) and Best Environmental Practice (BEP), should provide regulators with decision-making certainty by ensuring:

- Appropriate transparency
- Natural justice
- Independent peer-review
- Appropriate consultation

Each of these elements complements and supports the others.

G.2.1. Transparency and Commercial Sensitivity

Transparency is necessary for well-informed consultation, natural justice and independent peer-review.

The extent of transparency should complement the goals of natural justice and consultation, but does not need to provide information that is genuinely commercially or personally sensitive. However, far too often commercial sensitivity is a veil that industry proponents hide behind. (DiMento and Ingram, 2005, Sheaves *et al* 2015) Currently, a large body of data about public resources (the marine environment) is claimed as commercial-in-confidence with little justification. (Costanza *et al* 2006, Sheaves *et al* 2015)

The technical details of proposal for activities that generate noise should be fully and transparently available for comment before plans are submitted for approval to regulators.

Broadly, the information provided should include:

- a comprehensive description of the noise to be generated and the equipment to be used, including elements of the sound that is auxiliary to the need,
- a comprehensive description of the direct and surrounding area where the noise-generating activity is proposed and the species within this area,
- independent, scientific modelling of sound propagation of expected sound intensity levels and sound dispersal, the timeframe of the noise-generation,
- scientific monitoring programmes conducted during and after noise-generating activity.

The full extent of information that should be transparently available is detailed in the ‘CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities’.

While there is some information that is, and should remain, commercially sensitive, none of the information listed above should be considered commercially sensitive, and proponents should not seek to hide it from view.

G.2.2. Natural Justice

Natural justice is both a legal and common concept with two parts: it ensures there is no bias, increasing public confidence, and enshrines a right to a fair hearing so that individuals are not unfairly impacted (penalised) by decisions that affect their rights or legitimate expectations.

In the case of decisions for activities in the marine environment, confidence that there is no hidden bias can be developed by ensuring there is full transparency and that all stakeholders are given reasonable notice of the plans, a fair opportunity to present their concerns and that these concerns will factor in the final decision that is made. (DiMento and Ingram, 2005)

Stakeholders with a rightful interest in the marine environment include: traditional communities with cultural or spiritual connections, marine users such as fishermen (commercial and recreational), shipping and boating and tourism operators, scientists, conservation organizations, and general marine users such as tourism and recreation, who advocate for the conservation of marine

wildlife or marine ecosystems. Their interest must be considered.

G.2.3. Independent Peer-review

There is a concern in many countries over the poor quality of EIA information. Depending on the circumstance, this might reflect problems with institutional arrangements, low levels of commitment by proponents, or issues with the nature, extent and quality of training and capacity-building in the impact assessment, or elements of all of these. (Morgan, 2012) There is often a significant gap between the best practice thinking represented in the research and practice literature and the application of EIAs on the ground. (Morgan, 2012)

Proponent-funded independent peer-review of EIA proposals, before submission to regulators for assessment, is an important tool of BEP. (Sheaves *et al* 2015) Comprehensive, independent peer-review is a logical requirement for ensuring alignment of EIAs with scientific understanding and standards and ensuring that scientific understanding takes precedence over short-term benefits and political considerations. (Morrison-Saunders and Bailey, 2003, DiMento and Ingram, 2005, Sheaves *et al* 2015)

In the case of marine noise-generating activities, independent peer-reviewers should include species experts and expert sound modellers and acousticians, who can declare full and verifiable independence from the proposal. Their peer-review reports should be fully transparent and submitted to regulators, without influence from proponents.

G.2.4. Consultation and burden of proof

True consultation has two key components: participation in the outcome of a decision and that the burden of proof rests with the proponent.

Development actions may have wide-ranging impacts on the environment, affecting many different groups in society. There is increasing emphasis by governments at many levels on the importance of consultation and participation by key stakeholders in the planning and development of projects.

An EIA is an important vehicle for engaging with communities and stakeholders, helping those potentially affected by a proposed development to be much better informed and to influence the direction and precautions put in place by the proponent. This requires an appropriate exchange of information and a willingness by the proponent

to be transparent about their likely impact. (O'Faircheallaigh, 2010, Glasson *et al* 2013)

The burden of proof is often associated with the Latin maxim *semper necessitas probandi incumbit ei qui agit*, which broadly means “the necessity for proof always lies with the person who makes the claim”. In the case of proponents of marine noise-generating activities, they claim that the activities they propose to undertake – in a shared marine environment – will cause minimal harm. To satisfy the burden of proof, the proponent must provide sufficient evidence to demonstrate that there is a limited danger of damaging the marine environment or any species that have been highlighted as having importance.

Other stakeholders do not carry the burden of proof but instead carry the benefit of assumption, meaning they need no evidence to support their position of concern. It is up to the proponent to provide the assurance and bear all financial costs for doing so.

Despite the international consensus for robust EIA described in Module F, in many circumstances the burden of proof has been shifted to stakeholders. The CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities and these Modules of Technical Support Information provide regulators with the needed information to redress this imbalance.

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H. CMS-Listed Species Potentially Impacted by Anthropogenic Marine Noise

Pinnipeds				
Scientific name	Common name	App I	II	CMS Instruments
<i>Arctocephalus australis</i>	South American fur seal		1979	CMS
<i>Halichoerus grypus</i>	Grey seal		1985	CMS
<i>Monachus monachus</i>	Mediterranean monk seal	1979	1979	CMS, Monk Seal in the Atlantic
<i>Otaria flavescens</i>	South American sea lion		1979	CMS
<i>Phoca vitulina</i>	Harbour seal		1985	CMS, Wadden Sea Seals

Cetaceans				
Scientific name	Common name	App I	II	CMS Instruments
<i>Balaena mysticetus</i>	Bowhead whale	1979		CMS
<i>Balaenoptera bonaerensis</i>	Antarctic minke whale		2002	CMS, Pacific Cetaceans
<i>Balaenoptera borealis</i>	Sei whale	2002	2002	CMS , ACCOBAMS , Pacific Cetaceans
<i>Balaenoptera edeni</i>	Bryde's whale		2002	CMS , Pacific Cetaceans
<i>Balaenoptera musculus</i>	Blue whale	1979		CMS, ACCOBAMS, Pacific Cetaceans
<i>Balaenoptera physalus</i>	Fin whale	2002	2002	ACCOBAMS, CMS, Pacific Cetaceans
<i>Berardius bairdii</i>	Baird's beaked whale		1991	CMS, Pacific Cetaceans
<i>Caperea marginata</i>	Pygmy right whale		1979	CMS, Pacific Cetaceans
<i>Cephalorhynchus commersonii</i>	Commerson's dolphin		1991	CMS
<i>Cephalorhynchus eutropia</i>	Chilean dolphin		1979	CMS
<i>Cephalorhynchus heavisidii</i>	Heaviside's dolphin		1991	CMS, Western African Aquatic Mammals
<i>Cephalorhynchus hectori</i>	Hector's dolphin			Pacific Cetaceans
<i>Delphinapterus leucas</i>	Beluga		1979	CMS
<i>Delphinus capensis</i>	Long-beaked common dolphin			Western African Aquatic Mammals, Pacific Cetaceans
<i>Delphinus delphis</i>	Common dolphin	2005	1988	CMS, ASCOBANS, ACCOBAMS, Western African Aquatic Mammals, Pacific Cetaceans
<i>Eubalaena australis</i>	Southern right whale	1979		CMS, Pacific Cetaceans
<i>Eubalaena glacialis</i>	Northern right whale	1979		CMS, ACCOBAMS
<i>Eubalaena japonica</i>	North Pacific right whale	1979		CMS
<i>Globicephala melas</i>	Long-finned pilot whale		1988	CMS, ACCOBAMS, ASCOBANS, Pacific Cetaceans, Western African Aquatic Mammals
<i>Grampus griseus</i>	Risso's dolphin		1988	CMS, ACCOBAMS, ASCOBANS, Western African Aquatic Mammals, Pacific Cetaceans
<i>Hyperoodon ampullatus</i>	Northern bottlenose whale		1991	CMS, ASCOBANS, Western African Aquatic Mammals
<i>Lagenodelphis hosei</i>	Fraser's dolphin		1979	CMS , Western African Aquatic Mammals, Pacific Cetaceans
<i>Lagenorhynchus acutus</i>	Atlantic white-sided dolphin		1988	CMS , ASCOBANS
<i>Lagenorhynchus albirostris</i>	White-beaked dolphin		1988	CMS , ASCOBANS
<i>Lagenorhynchus australis</i>	Peale's dolphin		1991	CMS
<i>Lagenorhynchus obscurus</i>	Dusky dolphin		1979	CMS, Western African Aquatic Mammals, Pacific Cetaceans
<i>Megaptera novaeangliae</i>	Humpback whale	1979		CMS, ACCOBAMS, Pacific Cetaceans
<i>Monodon monoceros</i>	Narwhal		1991	CMS
<i>Neophocaena phocaenoides</i>	Finless porpoise		1979	CMS, Pacific Cetaceans
<i>Orcaella brevirostris</i>	Irrawaddy dolphin	2009	1991	CMS, Pacific Cetaceans
<i>Orcaella heinsohni</i>	Australian snubfin dolphin		1979	CMS, Pacific Cetaceans

<i>Orcinus orca</i>	Killer whale	1991		CMS, ACCOBAMS, ASCOBANS, Western African Aquatic Mammals, Pacific Cetaceans
<i>Phocoena dioptrica</i>	Spectacled porpoise	1979		CMS, Pacific Cetaceans
<i>Phocoena phocoena</i>	Harbour porpoise	1988		CMS, ASCOBANS, ACCOBAMS, Western African Aquatic Mammals
<i>Phocoena spinipinnis</i>	Burmeister porpoise	1979		CMS
<i>Phocoenoides dalli</i>	Dall's porpoise	1991		CMS
<i>Physeter macrocephalus</i>	Sperm whale	2002	2002	CMS, ACCOBAMS, Pacific Cetaceans
<i>Platanista gangetica</i>	Ganges River dolphin	2002	1991	CMS
<i>Pontoporia blainvillei</i>	Franciscana	1997	1991	CMS
<i>Sotalia fluviatilis</i>	Tucuxi		1979	CMS
<i>Sousa chinensis</i>	Indo-Pacific hump-backed dolphin		1991	CMS, Pacific Cetaceans
<i>Sousa teuszii</i>	Atlantic hump-backed dolphin	2009	1991	CMS, Western African Aquatic Mammals
<i>Stenella attenuata</i>	Pantropical spotted dolphin		1999	CMS, Western African Aquatic Mammals, Pacific Cetaceans
<i>Stenella clymene</i>	Clymene dolphin		2009	CMS, Western African Aquatic Mammals
<i>Stenella coeruleoalba</i>	Striped dolphin		2001	CMS, ASCOBANS, ACCOBAMS, Western African Aquatic Mammals, Pacific Cetaceans
<i>Stenella longirostris</i>	Spinner dolphin		1999	CMS, Western African Aquatic Mammals, Pacific Cetaceans
<i>Tursiops aduncus</i>	Indian bottlenose dolphin		1979	CMS
<i>Tursiops truncatus</i>	Bottlenose dolphin	2009	1991	CMS, ASCOBANS, ACCOBAMS, Western African Aquatic Mammals, Pacific Cetaceans
<i>Ziphius cavirostris</i>	Cuvier's Beaked whale	2014		CMS, ACCOBAMS

Sirenians

Scientific name	Common name	App I	II	CMS Instruments
<i>Dugong dugon</i>	Dugong		1979	CMS, Dugong
<i>Trichechus manatus</i>	Manatee	1999	1999	CMS
<i>Trichechus senegalensis</i>	West African manatee	2009	2002	CMS, Western African Aquatic Mammals

Sea turtles

Scientific name	Common name	App I	II	CMS Instruments
<i>Caretta caretta</i>	Loggerhead turtle	1985	1979	CMS, IOSEA Marine Turtles, Atlantic Turtles
<i>Chelonia mydas</i>	Green turtle	1979	1979	CMS, IOSEA Marine Turtles, Atlantic Turtles
<i>Dermochelys coriacea</i>	Leatherback turtle	1979	1979	CMS, IOSEA Marine Turtles, Atlantic Turtles
<i>Eretmochelys imbricata</i>	Hawksbill turtle	1985	1979	CMS, IOSEA Marine Turtles, Atlantic Turtles
<i>Lepidochelys kempii</i>	Kemp's ridley turtle	1979	1979	CMS, Atlantic Turtles
<i>Lepidochelys olivacea</i>	Olive ridley turtle	1985	1979	CMS, IOSEA Marine Turtles, Atlantic Turtles
<i>Natator depressus</i>	Flatback turtle		1979	CMS, IOSEA Marine Turtles

Fish, Crustaceans and Cephalopods

Fish, crustaceans and cephalopods are considered as listed CMS species as well as prey to CMS listed species.

Scientific name	Common name	App I	II	CMS Instruments
<i>Carcharodon carcharias</i>	Great white shark	2002	2002	CMS, Sharks
<i>Cetorhinus maximus</i>	Basking shark	2005	2005	CMS, Sharks
<i>Isurus oxyrinchus</i>	Shortfin mako shark		2008	CMS, Sharks
<i>Isurus paucus</i>	Longfin mako shark		2008	CMS, Sharks
<i>Lamna nasus</i>	Porbeagle		2008	CMS, Sharks
<i>Alopias pelagicus</i>	Pelagic thresher shark		2014	CMS
<i>Alopias superciliosus</i>	Bigeye thresher shark		2014	CMS
<i>Alopias vulpinus</i>	Common thresher shark		2014	CMS
<i>Carcharhinus falciformis</i>	Silky shark		2014	CMS
<i>Sphyrna lewini</i>	Scalloped hammerhead shark		2014	CMS
<i>Sphyrna mokarran</i>	Great hammerhead shark		2014	CMS
<i>Manta alfredi</i>	Reef manta ray	2014	2014	CMS
<i>Manta birostris</i>	Manta ray	2011	2011	CMS
<i>Manta alfredi</i>	Reef manta ray	2014	2014	CMS
<i>Mobula eregoodootenkee</i>	Pygmy devil ray	2014	2014	CMS
<i>Mobula hypostoma</i>	Atlantic devil ray	2014	2014	CMS

<i>Mobula japanica</i>	Spinetail mobula	2014	2014	CMS
<i>Mobula kuhlii</i>	Shortfin devil ray	2014	2014	CMS
<i>Mobula mobular</i>	Giant devil ray	2014	2014	CMS
<i>Mobula munkiana</i>	Munk's devil ray	2014	2014	CMS
<i>Mobula rochebrunei</i>	Lesser Guinean devil ray	2014	2014	CMS
<i>Mobula tarapacana</i>	Box ray	2014	2014	CMS
<i>Mobula thurstoni</i>	Bentfin devil ray	2014	2014	CMS
<i>Squalus acanthias</i>	Spiny dogfish		2008	CMS, Sharks

Otters				
<i>Scientific name</i>	<i>Common name</i>	<i>App I</i>	<i>II</i>	<i>CMS Instruments</i>
<i>Lontra felina</i>	Marine otter	1979		CMS

Polar bear				
<i>Scientific name</i>	<i>Common name</i>	<i>App I</i>	<i>II</i>	<i>CMS Instruments</i>
<i>Ursus maritimus</i>	Polar bear		2002	CMS





**CONVENTION ON
MIGRATORY
SPECIES**

UNEP/CMS/COP13/Inf.8

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**ADVISORY NOTE: FURTHER GUIDANCE ON INDEPENDENT, SCIENTIFIC MODELLING
OF NOISE PROPAGATION**

(Prepared by OceanCare)

Summary:

The CMS Family Noise EIA Guidelines are accompanied by expert-authored Technical Support Information, which was presented to COP12 as UNEP/CMS/COP12/Inf.1, and welcomed in Resolution 12.14.

When promoting these Guidelines, it has become apparent that there are some difficulties with interpretation of the guidance related to noise modelling. OceanCare contracted the lead author of the Guidelines to draft an additional advisory note specifically on this topic.

UNEP/CMS/COP13/Doc.26.2.2 recommends that this Advisory Note be added to the Technical Support Information provided online.

Advisory Note: Further guidance on independent, scientific modelling of noise propagation

Geoff Prideaux
June 6, 2019

It is evident, after a period of two years since the *CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities* (CMS Noise EIA Guidelines) were endorsed by CMS COP12, further clarity about **independent, scientific modelling** is required.

The precision of acoustic modelling depends on accurate parameters defining the sound propagation environment. This takes both skill and the choice of the appropriate scientific model/s for each sound generating activity and proposal.

The model/s should reflect: the activity to be modelled, location, environmental conditions, biological relevance, topographic/bathymetric features (underwater canyons and seafloor composition), Sound Speed Profiles that are seasonally relevant factoring temperature, salinity and depth. There is no single model capable of accommodating all noise generating activities in all circumstances.

Using a reputable model is not enough. Modellers need expert knowledge and experience of the model/s they are using. This requires understanding of the physics of underwater acoustic propagation, knowledge to select the right model/s, and to choose the appropriate input parameters and adjust them accordingly, so that the outcome of the modeling process makes physical sense. Finally, time investment in ground-truthing feedback is necessary to confirm the validity of the model.

The following table elaborates important detail about the CMS Noise EIA Guidelines advice on **independent, scientific modelling** (column 2) and is complimented by additional details from the New Zealand 'Sound Propagation and Cumulative Exposure Models Technical Working Group' report (column 3). This Technical Working Group advised the Department of Conservation for the revision of the NZ Code of Conduct for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations (2015-2016).

At all stages, the information provided below is intentionally conservative and does not embellish or add to the information from within each document.

	CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities	Sound Propagation and Cumulative Exposure Models Technical Working Group
1. Independent, scientific modelling of noise propagation should be impartially conducted	a) Models chosen should be peer-reviewed, scientific source models (as opposed to industry black box models) b) Modelers should have enough knowledge of, and experience with, the models they are using. Modellers should understand the physics of underwater noise propagation to ensure the correct models are used and that the results are accurate and make physical sense. c) Modelling results should be reviewed by subject matter experts, and experienced modellers with a strong theoretical understanding of underwater acoustics.	
2. Propagation models should be:	a) based on accurate input data, and for seismic surveys specifically the	c) specific to the source, region and environmental conditions.

	official calibration figures supplied by the survey vessel to be charted. b) able to accommodate the activity noise frequencies, the water depth, seabed topography, temperature and salinity, and spatial variations in the environment. Model methodology/s used should be stated.	d) based on accurate input data including seismic source data and environmental data, such as: - geo-acoustic properties including bottom sediment types and their layer depths for the region to be modelled, ideally down to several hundred metres into the bottom. - bathymetry mapping grid resolution greater than 450m - seasonally relevant Sound Speed Profiles (SSPs), salinity, temperature and depth data (in tabulated form). e) chosen based on the treatment of environmental conditions, with an appropriate rationale for the modelling choice provided in the modelling report. f) given special consideration for fiords and deep-water canyons and may require high-resolution 3D models. g) biologically relevant and able to handle a wide range of frequencies, including very high and very low frequencies, regardless of the proponent's frequency focus. The computational difficulty of modelling very high frequencies is not a reason for disregard.
3. Propagation modelling should include:	a) the received sound levels at given distances from the noise source to determine propagation loss. b) full frequency bandwidth of a proposed anthropogenic noise source. c) the intensity/pressure/energy output within that full range.	f) sound propagation and cumulative exposure data that is appropriate to the full range of concurrent noise-generating activities. These should include separate modelling of each noise-generating activity (ie. shipping, support vessels, sonar, seismic surveys), as well as a cumulative model

	d) the principal or mean/median operating frequency of the source(s). e) the same season/weather conditions as the proposed activity accounting for local propagation features (depth and type of sea bottom, local propagation paths related to thermal stratification, SOFAR or natural channel characteristics).	- of all these activities combined. g) appropriate single shot modelling that is correctly representative of the survey region. Biologically important sub-regions may require additional focus. h) representation of cumulative exposure over time (ie 24 hours) i) acoustic ground-truthing of the chosen model (to ensure model credibility).
4. Propagation modelling reports should demonstrate:	a) propagation from point source out to a radius where the noise levels generated are close to natural ambient sound levels¹ b) particle motion propagation² to assess the impact on invertebrates, and fish species. c) proposed exclusion zones designed for the protection of specific species and/or populations should be identified and mapped and should demonstrate how noise will not propagate into these areas, taking into consideration the local propagation features.	d) border thresholds will not be breached for exclusions zones and biologically important areas. e) that all modelling assumptions are clearly stipulated and comprehensively justified.

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¹ ISO 18405 refers to ambient sound as "sound that would be present in the absence of a specified activity" and "is location-specific and time-specific". The CMS Noise EIA Guidelines more specifically define ambient sound as the average ambient (non-anthropogenic) sound levels from biological (marine animals) and physical processes (earthquakes, wind, ice and rain etc) of a given area. It should be measured (including daily and seasonal variations of frequency bands), for each component of an activity, prior to an Environmental Impact Assessment (EIA) being developed and presented

² The detection of particle motion or particle displacement requires different types of sensors than those utilized by a conventional hydrophone. These sensors must specify the particle motion in terms of the particle displacement, or its time derivatives (particle velocity or particle acceleration).



**GUIDELINES TO ADDRESS THE IMPACT OF ANTHROPOGENIC NOISE
ON CETACEANS IN THE ACCOBAMS AREA**



GUIDELINES TO ADDRESS THE IMPACT OF ANTHROPOGENIC NOISE ON CETACEANS IN THE ACCOBAMS AREA

(Revisions highlighted in bold)

A. GENERAL GUIDELINES

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, 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 modelling; 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 consulted: the best tool currently available meeting this need is the International Noise Register developed by ACCOBAMS which is aimed at centralising data on positions and periods of occurrence of human activities producing impulsive noise.**
- f) Model the generated sound field in relation with oceanographic features (depth/temperature profile, sound channels, water depth, 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 modelled 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 behavioural 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.
- 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 behaviours 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 operators where appropriate) should be employed for the monitoring and reporting program including overseeing implemented mitigation rules.
- s) Cetacean observers and bio-acousticians in charge of the monitoring program must be qualified, dedicated and experienced, with suitable equipment. **To this end, ACCOBAMS has developed a certification system for Highly Qualified MMO and PAM operators. The goal of this certification is to guarantee, throughout the Agreement area, a high-quality standardized training of MMOs and PAM operators thanks to:**
 - a. The high-quality training of MMOs and PAM operators,
 - b. The standardization of training content,
 - c. The standardization and quality of the data collected,**More information on this certification system is available by the ACCOBAMS Permanent Secretariat.**
- t) Marine mammal observers should report to the National Focal Point **and** the ACCOBAMS Secretariat using a standardized reporting protocol. **This reporting protocol has been developed in the framework of the certification system for Highly Qualified MMO and PAM operators.** 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 **Environmental Impact Assessment (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.
- x) **Detailed data on the execution of the activities emitting impulsive noise should be reported to the International Noise Register developed by ACCOBAMS, especially the following: geographical position, start and end dates, source description, source level, frequency band.**
- y) **Procedures for reporting impulsive noise data to the International Noise Register developed by ACCOBAMS should follow national instructions related to Descriptor 11 of the Marine Strategy Framework Directive of the European Union, or Ecological Objective 11 of the Ecosystem-Approach being implemented by the Barcelona Convention.**

B. 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. **Guidelines concerning MMOs and PAM operators refer, as far as possible, to the high-quality standards defined in the certification system for Highly Qualified MMO and PAM operators developed by ACCOBAMS. Reporting of sonar activities to the International Noise Register should follow national instructions related to Descriptor 11 of the Marine Strategy Framework Directive of the European Union or to the corresponding Ecological Objective 11 of the Ecosystem-Approach process being implemented by the Barcelona Convention.**

- 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 unfavourable 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.

C. GUIDELINES FOR SEISMIC SURVEYS AND AIRGUN USES

Guidelines for mitigating the effects of seismic surveys have been **first** experimented in the context of academic seismic surveys conducted under NMFS permits. **Since then the diffusion of such guidelines and their adoption during commercial hydrocarbon exploration has not ceased to increase.** Most of the following guidelines are equivalent to those required for sonar operations and should apply in addition to general guidelines. **Guidelines concerning MMOs and PAM operators always refers to the high-quality standards defined in the certification system for Highly Qualified MMO and PAM operators developed by ACCOBAMS. Reporting of seismic surveys and airgun uses to the International Noise Register should follow national instructions related to Descriptor 11 of the Marine Strategy Framework Directive of the European Union or to the corresponding Ecological Objective 11 of the Ecosystem-Approach process being implemented by the Barcelona Convention.**

- 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)** Modelling 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 bio-acousticians 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.

D. 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 far and can ensonify large marine areas at distances of more than 100km; in such conditions alternative technologies should be used. **Updated information on the available mitigation technologies is maintained by the ACCOBAMS Secretariat.**

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.

Guidelines concerning MMOs and PAM operators always refers to the high-quality standards defined in the certification system for Highly Qualified MMO and PAM operators developed by ACCOBAMS. Reporting of coastal and offshore construction works to the International Noise Register should follow national instructions related to Descriptor 11 of the Marine Strategy Framework Directive of the European Union or to the corresponding Ecological Objective 11 of the Ecosystem-Approach process being implemented by the Barcelona Convention.

- 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 windfarms and oil extraction platforms produce their own noise and thus their environmental impact should be carefully evaluated and mitigated with dedicated rules.

E. GUIDELINES FOR OFFSHORE PLATFORMS

Offshore platforms may be used for a variety of different activities, such as seafloor drilling, oil/gas extraction, electricity production (windfarms), 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.

F. 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:

- a)** 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.
- b)** model sound propagation from the source to the targets based on local oceanographic features and background noise information.
- c)** 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.
- d)** design experiments so that monitored animals are those exposed to highest levels.
- e)** halt sound emission if adverse response or behavioural changes are observed on either target or non-target animals.
- f)** limit repeated exposures on the same target(s) unless required by the research protocol.
- g)** avoid enclosed areas, avoid blocking escape routes.
- h)** avoid “chasing” animals during playbacks; if they move away -- don’t modify the course to follow them with the playback source.

- i) 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.

G. GUIDELINES FOR 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. Guidelines for shipping, developed by IMO/ASCOBANS working group in 2014 and available online (*Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life*, IMO/ASCOBANS 2014 Circ.833), consider common technologies and measures that may be relevant for most sectors of the commercial shipping industry and can be applied to any commercial 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. 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.

For commercial shipping, the following guidelines and key concepts should apply in addition to the general guidelines:

- a) 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.
- b) Underwater noise should be measured to an objective standard for any meaningful improvements: ISO/PAS 17208-1, ISO/DIS 16554. Several research ships have been designed using the noise specification, designed for fishery research ships, proposed by the International Council for the Exploration of the Sea (ICES) Cooperative Research Report No.209 (CRR 209). Other underwater noise rating criteria are available and may prove useful as guidance.
- c) The optimal underwater noise mitigation strategy for any ship should at least consider all relevant noise sources.
- d) 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. For effective reduction of underwater noise, hull and propeller design should be adapted to each other. Propellers should be designed and selected in order to reduce cavitation, the ship hull form with its appendages should be designed such that the wake field is as homogeneous as possible. 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.
- e) 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.

- f) In addition to their use for new ships, the following technologies are known to contribute to noise reduction for existing ships: design and installation of new state-of-the-art propellers, installation of wake conditioning devices and installation of air injection to propeller (e.g. in ballast condition).
- g) 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: propeller cleaning, underwater hull surface, selection of ship speed, rerouting and operational decisions to reduce adverse impacts on marine life.
- h) 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.
- i) Noise from ships should be evaluated both at close range for its direct possible effects on local marine life and at long-range for the contribute 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).
- j) **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.**

H. 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 (**please refer to code of conduct of the ACCOBAMS HQWW[®] Certificate**) 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 a **commercial tourism activity through which people observe whales and dolphins in their natural environment from a boat. This activity** 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.

Created in 2014 to supervise an expanding tourism activity and guide volunteer operators, the High-Quality Whale-Watching® (HQWW) certificate is an ACCOBAMS trademark jointly developed with the Pelagos Sanctuary. This certification, created to frame and harmonize whale watching activity, have an international dimension with a naturalist approach: the label guarantees a whale and dolphin approach respectful of the code of good conduct for the observation of Mediterranean cetaceans. Any certified operator can provide educational information acquired during his formation. Finally, in the framework of responsible ethics certified operators commit to waste sorting on-board their vessels. Each of the member countries should mandate a private or public structure to animate the certification on its territory.

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.
- h)** 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.

Agenda Item 3.2.2

Review of New Information on Threats to Small
Cetaceans

Underwater Noise

Reports from Parties

Information Document 3.2.2.a

**Concept for the Protection of
Harbour Porpoises from Sound
Exposures during the Construction
of Offshore Wind Farms in the
German North Sea**

Action Requested

- Take note

Submitted by

Germany



**NOTE:
DELEGATES ARE KINDLY REMINDED
TO BRING THEIR OWN COPIES OF DOCUMENTS TO THE MEETING**

Secretariat's Note

The original, official and binding version of the Sound Protection Concept is in German. The English version has been prepared for international information.



Concept for the Protection of Harbour Porpoises from Sound Exposures during the Construction of Offshore Wind Farms in the German North Sea (Sound Protection Concept)

Contents

1. *Introduction*
2. *Scope, delimitation and updating of the Sound Protection Concept*
3. *Ecology and conservation status of the harbour porpoise*
4. *Foundation technologies for offshore wind farms, sound emissions and sound mitigation technologies*
5. *Impacts of impulsive sound events on harbour porpoises*
6. *Disturbances*
7. *Sound Protection Concept Guidelines*
 - 7.1. *Best available technology*
 - 7.2. *Species protection: prohibitions on injury and killing*
 - 7.3. *Species protection: prohibition of disturbance*
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 - 7.5. *Old licences*
 - 7.6. *Requests for variation*

1. Introduction

With the Energy Concept adopted in 2010 and its decisions on the transformation of Germany's energy system taken in June 2011, the German Federal Government has put forward for the first time a comprehensive strategy for the expansion of renewable energies in the decades to come. The intention is for the share of Germany's power supply provided by renewables to rise to at least 35% by 2020, and for them to become the main pillar of the country's energy supply by 2050, backed up with major progress in improving energy efficiency. Wind energy will be the cornerstone of the power system of the future. In particular, offshore wind energy holds out a great deal of potential for the future, given the high levels of capacity utilisation demonstrated at the turbines that have been installed to date.

However, the development of offshore wind energy is currently lagging markedly behind the original expectations. The German Federal Government has taken a large number of measures that will allow offshore wind energy to be expanded fur-



ther. They include the decisions to give the transmission grid operators responsibility for grid connections, the KfW banking group's lending programme, the 'acceleration model', under which generators are paid a higher feed-in tariff for a shorter period of time, and the regulation of liability issues that had previously been unclear concerning delays in the expansion of the grid and interruptions to grid availability. At the moment, work is being done to expand the 2013 Offshore Grid Development Plan (O-NEP), which prioritises the measures for the connection of wind farms set out in the Spatial Offshore Grid Plan. The O-NEP is updated annually and forms an essential part of the framework put in place for the gradual expansion of offshore wind energy.

The Concept for the Protection of Harbour Porpoises from Sound Exposures during the Construction of Offshore Wind Farms in the North Sea (Sound Protection Concept) presented in this document is intended to foster greater clarity with regard to the requirements placed on the construction of offshore wind farms by nature conservation law. This is also being done with a view to the goal set by the German Federal Government that the construction and use of renewable energy facilities should not be pursued at the expense of biological diversity (cf. National Strategy on Biological Diversity, 2007). The Sound Protection Concept therefore takes account of the precautionary principle.

The basis for the Sound Protection Concept is the evidence that has been gathered about the impacts of the use of offshore wind energy on harbour porpoises. It is rooted, in particular, in the new and more detailed findings of the ecological research that has accompanied the construction and operation of the first offshore wind farms. In order to close the gaps that exist in our knowledge with regard to the possible impacts of offshore wind energy on the marine environment, extensive funding has been made available by the German Federal Environment Ministry (BMU) for parallel ecological research activities. In the years 2001 to 2012, more than 40 individual projects were carried out in this field with total funding worth more than €27m. In the course of these projects, it has become apparent, in particular, that the underwater noise generated by the driving of pile foundations for offshore wind farms can have significant impacts on marine mammals. Individuals can be damaged or whole populations suffer significant adverse impacts, the implication of which is that restrictions under nature conservation law need to be taken into consideration in this field.

The Sound Protection Concept takes account of the specific national conditions that pertain to the expansion of offshore wind energy. For reasons of nature conservation law, shipping law and concerns about tourism, offshore wind farms can only be constructed in the German North Sea at a large distance from the coastline and in accordingly deep water, which has direct effects on the scale of the sound immisions.



This Concept for the assessment of the ecological impacts of underwater sound during the construction of offshore wind farms is intended to create greater security for all parties in future with regard to the interpretation of the imprecise legal terms found in the relevant nature conservation standards ('injury' and 'significant disturbance' in the context of the prohibitions on taking under species protection law, 'significant adverse impact' in the context of site protection). It is intended to give the developers of offshore wind farms guidance concerning the application of these standards during the construction phase as early as possible in their very long planning processes. This will make it possible for the requisite organisational or technical measures for sound protection to be integrated into planning processes early on, so allowing costs to be minimised. The Concept does not replace or modify any requirements or procedural steps under nature conservation law, such as that of the Appropriate Assessment under the Habitat Directive, but is intended to offer assistance in the interpretation of the requirements of harbour porpoise protection.

The Concept will take effect as of 1 December 2013 as a basis for the assessment of projects that have not been approved up until this point. In view of the still limited impacts of the first construction phase of offshore wind energy to date and in the interests of a reliable basis for planning, the intention is that it should establish a fair balance between the protection of harbour porpoises and the development of offshore wind energy.

In the period between November 2012 and June 2013, consultations on the Concept were held twice with representatives of the offshore wind power industry and the nature conservation associations, and once with the coastal Länder. It has been further developed into its current form on the basis of the comments that were received.

2. Scope, delimitation and updating of the Sound Protection Concept

In this Sound Protection Concept, the harbour porpoise is treated as an indicator species for the assessment of the impacts of exposure to underwater sound on marine mammals because to date there has not been enough scientific evidence available concerning the problems of sound protection in relation to other marine mammals and, in particular, other species groups (e.g. fish) that would be sufficient to underpin the development of a sound protection concept for these other species.

The Concept only deals with the German Exclusive Economic Zone (EEZ) in the North Sea, for which the German Federation possesses immediate competence. The geographical limitation to the North Sea is necessary because no comparable data are available at the moment on the occurrence and distribution of harbour porpoises in the German Baltic Sea. Without this information, however, the requisite technical basis is lacking for the species to be incorporated conceptually in an appropri-





ate manner into a sound protection concept that is intended, and able, to lay claim to validity for the Baltic Sea. It is therefore not possible for this Concept to be applied to the Baltic Sea.

Furthermore, only the generation of sound and exposure to noise during the construction of the foundations for offshore wind farms (wind turbines, transformer stations) and converter stations are dealt with within the framework set out in this Concept. The Concept addresses the cumulative effects caused by the multiple sound emissions from pile driving operations that usually involve more than a thousand strikes and the cumulative effects due to simultaneous activities at several construction sites. On account of the lack of data available, however, other sound sources that (may) lead to noise exposures, such as the noises emitted by offshore wind turbines during operation, noise from shipping activity, civilian and military sonar systems, and seismic explorations, are not examined in this Sound Protection Concept in terms of either their direct or their cumulative effects. Nevertheless, where they are known, the corresponding cumulative effects caused by these and other possible sound sources must be taken into consideration on a case-by-case basis as part of the Appropriate Assessment of projects' environmental impacts under the Habitats Directive provided for in Section 34(1) of the Federal Nature Conservation Act (BNatSchG), as is the case for all projects, including offshore wind turbines.

The complete coverage of the marine waters in Germany with their total spectrum of species, and the coverage of the entirety of sound sources and possible forms of noise pollution have been addressed in a European context (Marine Strategy Framework Directive).

The scientific evidence about the topics that are relevant here, such as the impacts of noise on harbour porpoises, the propagation of sound in the sea and foundation technologies, is based on recent advances in knowledge that are attributable, above all, to the experience gained from the construction of offshore wind farms in recent years and to the associated research projects funded by the Federal Environment Ministry. However, it may be assumed that even more will be learned over the next few years. In consequence, it will be indispensable for this Sound Protection Concept to be reviewed regularly and adjusted to take account of the latest findings.

Following an account of the ecology and conservation status of the harbour porpoises in the North Sea, this document discusses state-of-the-art foundation technologies and sound mitigation measures. Subsequently, the impacts of impulsive sound on harbour porpoises are set out. The last part of this document elaborates conventions for the assessment of the legal concepts found in nature conservation law that are to be formulated in concrete terms in this context.



3. Ecology and conservation status of the harbour porpoise

The population of harbour porpoises in the German marine waters of the North Sea is subject to major variations from year to year and is stated to be 55,000 animals. Harbour porpoises occur throughout the year in the German North Sea, but exhibit seasonal 'hot spots' in their spatial distribution (GILLES *ET AL.* (2008), (2009a)). In the spring, such hot spots are found off the Lower Saxon coast on the Borkum Reef Ground, while there is another area of high density on the Sylt Outer Reef. The major surveys of 2002-2006 found that the total population at this time was 55,000 animals ($n=55,048$). In the summer months and the main breeding season, harbour porpoises continue to occur extensively with just one pronounced hot spot area on the Sylt Outer Reef. During these months, the population in the German North Sea is 50,000 individuals ($n=49,687$). The most recent area-wide survey in June/July 2009 found no significant deviations from these population levels, counting 54,227 animals (95% confidence interval 30,079 – 104,186, coefficient of variation (CV) = 0.32) (GILLES *ET AL.* (2010)). In the autumn, the harbour porpoise population falls to 15,394 individuals (CV=0.33), and no recognisable population hot spots are evident. So far, the data published have been insufficient for an estimate of the population in the winter months to be attempted, but a large proportion of the animals evidently leave the German marine areas.

The harbour porpoises of the German North Sea belong to the subpopulation of the central and southern North Sea (EVANS, P. G. H. AND TEILMANN, J. (EDS.) (2009), INTERNATIONAL WHALING COMMISSION (2000)). For this reason and on account of the strong seasonal dynamics that have been described, the whole harbour porpoise population of the German North Sea is to be regarded as a local population that cannot be further subdivided.

According to recent findings, a female animal has approx. four to six calves during its lifetime (usually eight to ten years, rarely more than twelve years). In the North Sea, harbour porpoises give birth in the period from May to July (after an approx. ten to eleven month pregnancy). Renewed mating takes place immediately after the birth through to the beginning of August. The infants are nursed from the point of birth to the age of approx. eight to ten months. Harbour porpoises therefore find themselves in their reproduction and rearing period all year round.

Within the year-round breeding and rearing period, there is a particularly sensitive phase from May to August in the North Sea, during which disturbances have particularly high potential to worsen the conservation status of the local population because its reproductive success is immediately affected. This period includes the last few weeks before birth, the birth itself, the phase during which a stable mother-infant bond is formed and the parallel mating phase.

Harbour porpoises are classified as endangered on Germany's Red List (2009).





The harbour porpoise is a species of Community interest. It is included in both Annex II of the Habitats Directive (HD) (as a non-priority species for which Natura 2000 sites are to be designated) and Annex IV, which lists species for which a system of strict protection is to be established under Articles 12 ff. In German nature conservation law, it is covered by the provisions on site protection set out in Sections 32 ff. of the BNatSchG and the provisions on species protection set out in Sections 44 ff. of the BNatSchG (strictly protected species).

The conservation status of the harbour porpoise in the Atlantic Biogeographical Region (North Sea) is described as 'Unfavourable-Inadequate' in the German Federal Government's 2013 report under Article 17 of the Habitats Directive (cf. also GERMAN FEDERAL GOVERNMENT (2007)).

According to the Bern Convention and Annex II to the Convention, the harbour porpoise is one of the species that are to be strictly protected. Under the auspices of the Bonn Convention, a special Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS) has been concluded in order to protect small cetaceans (which include harbour porpoises). In the Agreement, the Parties made comprehensive commitments to protect and preserve these species.

The harbour porpoise is included in the lists of threatened and declining species and biotopes administered by the commissions of the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) and the Convention on the Protection of the Marine Environment of the Baltic Sea (HELCOM).

4. Foundation technologies for offshore wind farms, sound emissions and sound mitigation technologies

4.1. Foundation technology

When it comes to the foundations for offshore wind turbines, three types of foundations can be distinguished: foundations that are anchored in the seabed with piles or other supporting structures, foundations positioned on the seabed and structures that are capable of floating. The suitability of a particular type of foundation depends crucially on the water depth, the conditions on the seabed, the concepts for the turbine and its construction, and the costs that are incurred for the manufacture of the substructure.

4.1.1. Driving of pile foundations

To date, offshore wind turbines in the North Sea and Baltic Sea have predominantly been constructed on pile foundations or supporting structures that are anchored in the seabed with piles. Depending on the specific structural design, it is possible to



distinguish between 'monopiles' that consist of a single, large-diameter steel tube (pile), and multipile foundation structures erected on three or four piles (jackets, tripods, tripiles). All the different types of pile foundation possess a high degree of market maturity. As a rule, pile foundations are anchored in the seabed by means of hydraulic impact pile driving or – under certain preconditions – what is known as 'vibration pile driving', in which vertical vibrations are induced on the pile to drive it into the seabed.

a) Impact pile driving

The time taken to construct each foundation varies widely depending on the type of foundation and other factors. The driving process alone (net driving time) usually lasts between 30 and 100 minutes for monopiles. Approximately 30-60 minutes per pile are to be allowed for multipile foundation structures, i.e. between 90 and 240 minutes in total. The high impulsive sound emissions that arise during pile driving are believed to be problematic for harbour porpoises.

b) Vibration pile driving method

Subject to certain preconditions, foundation piles can be anchored into the seabed using vibration pile driving in soft and moderately firm sandy seabeds. Measurements show that the levels of noise generated by the vibration pile driving method are markedly lower than those from impact pile driving. By contrast to impact pile driving, continuous sound is emitted during vibration pile driving.

However, this installation method is subject to technical constraints.

When tripod or jacket foundations are installed, vibration pile driving usually remains limited to the upper eight to twelve metres, since vibrating the pile any further would require costly action to provide proof of the foundations' structural stability by conducting a dynamic pile load test. In order to ensure stability, foundation piles that have been vibrated for the upper metres of their length are driven to their final depth using impact pile driving. Subject to certain premises, as experiments at the Danish Anholt offshore wind farm have shown, monopiles can be driven to their final depth using the vibration pile driving method. In this case, the precondition is the provision of evidence that the bedding characteristics of the seabed are not altered disadvantageously and the structure is stable. Since no scientifically backed-up findings have been published on this topic to date, this method has not been applied for the installation of offshore wind farms in the German marine areas as yet.

4.1.2. Drilling methods

As a matter of principle, drilling methods also come into question for the installation of pile foundations. They represent a suitable alternative, in particular when seabed conditions are difficult and impact pile driving is not possible. Drilling methods are



appropriate for water depths of up to 80 metres. The centrepiece of the procedure is a vertical drilling machine, at the lower end of which a drilling head with a pivoted cutting cylinder is attached. Piles with diameters of up to ten metres and walls of any thickness can be installed with this method. Drilling technology has already been deployed in combination with the pile driving method for the construction of individual offshore wind turbines where substrate conditions are difficult (e.g. Barrow Offshore Wind Farm, UK). With a view to the possibility of its series application, however, this method does not yet have sufficient market maturity. Optimised concepts with more rapid advance rates and higher weather tolerance are currently the subject of research and development projects.

Apart from the method's technical practicality in the offshore sector, it is also still necessary to demonstrate its economic viability.

In contrast to impact pile driving, continuous sound emissions are generated when drilling methods are used. It is to be expected that the levels of sound emitted will be very markedly below those of pile driving methods. In consequence, this construction technology represents a low-noise option for the installation of foundations.

4.1.3. Suction bucket/suction can foundations

Foundations for offshore installations can be anchored in the seabed with low levels of noise using what are known as 'suction buckets' or 'suction cans', which are embedded in the seabed. This foundation concept is suited for the installation of supporting structures on sandy seabeds in water depths of up to 60 metres.

Although several transformer stations and service platforms for oil and gas extraction have already been installed on suction bucket foundations, they have played practically no role in the construction of offshore wind farms up until now.

Extensive further research and development efforts will be required if this method is to reach market maturity as a foundation technology for wind turbines.

The suction bucket represents a low-sound option for the construction of foundations with good prospects for the future.

4.1.4. Gravity foundations

Gravity foundations are concrete or steel structures that are positioned on the seabed and held in place by their own weight. The excavation that is required, gravity foundations' large footprint and their scour protection features take up comparatively large areas of the seabed.

To date, gravity foundations have been used for the construction of offshore wind farms in shallower areas of sea (e.g. Nysted Offshore Wind Farm, Lillegrund Offshore Wind Farm) and they possess a high degree of market maturity for these locations. In principle, this foundation concept is also regarded as suitable for the installation of offshore wind turbines in water depths of 30 to 40 metres, but further research and development will be needed in the immediate future. Apart from the method's technical suitability, it is also still necessary for the economic viability of this type of foundation to be proven.



High sound emissions are not generated when gravity foundations are installed, but problems are encountered in particular when work is undertaken in protected biotopes due to the large areas of the seabed that are occupied.

4.1.5. Floating foundations

Floating foundations are suited in particular for the construction of offshore wind farms in greater water depths (> 50 metres). However, there are various concepts that have hardly been trialled yet. A number of prototype floating foundation constructions have been tested, including Hywind since 2009 in Norway and Windfloat since 2011 in Portugal. However, it is apparent that major research and development efforts will still be required before floating foundations attain market maturity. Floating foundation concepts only come into question for the German marine areas to a limited extent due to the relatively gently sloping coastline and the prevailing water depths of up to 50 metres.

No large-scale sound emissions are generated when they are installed, making this a low-sound option for the construction of foundations.

Summary of foundation technologies

It is to be expected the offshore wind farms to be developed over the next few years will overwhelmingly be built on the tried-and-tested kinds of pile foundations and require the pile driving operations necessary for such structures. No alternative state-of-the-art foundation technologies for offshore wind turbines are yet available at present. Innovative concepts for the low-sound construction of foundations must be developed further in parallel research and development efforts, and continuously driven forward to become state-of-the-art technologies. Even if a procedure were to become the 'state of the art', other systems should continue to be researched and developed in the interests of diversifying the technological options that are available.

4.2. Sound emissions

In the quite overwhelming majority of cases, foundation piles are installed using hydraulic impact pile drivers. When these machines are in operation, the energy from the hammer is transmitted to the pile, with some of it being released as sound either directly from the pile or indirectly into the water via the seabed.

The indirect transmission of sound into the water column via the seabed has still not been researched comprehensively. The energy released from the pile into the marine environment in the form of impulsive sound represents the crucial variable for this Sound Protection Concept.

The fundamental principles of underwater sound propagation are well known. In practice, however, forecasting rapidly runs up against its limits because local parameters can heavily influence sound propagation. Among other things, the water depth, the marine substrate and the relief of the seabed are crucial. In addition to



this, reflections, superimposition and interference cancellation may occur. There is currently no spatially resolved model of sound propagation for the German North Sea. The development and validation of such a model is the subject of a research project funded by the Federal Environment Ministry (BORA, <http://www.bora.mub.tuHH.de/>). At present, therefore, simplified calculations are carried out using standard values for sound propagation, although this means the forecasts are affected by corresponding uncertainties. In this respect, the uncertainty of the forecasts rises with increasing distance from the sound source.

4.3. Sound mitigation measures

The sound emissions caused by the driving of foundation piles can be reduced by technical measures, but not prevented as a rule. It is possible to distinguish between primary sound mitigation measures, which allow a reduction of the sound that is generated to be achieved, and secondary sound mitigation measures that are aimed at limiting or preventing the propagation of sound emissions. By contrast, the use of deterrence techniques (seal scarers, pingers) prior to piling operations, as prescribed in the licenses for wind farms, is not a sound mitigation measure but a protective measure.

4.3.1. Primary sound mitigation measures

Primary sound mitigation measures include the reduction of strike energy, and the extension of the contact time between the hydraulic hammer and the pile that is being driven, the 'prolongation of impact contact time' as it is termed. For the most part, pile driving operations begin with reduced strike energy, what is known as a 'soft start', which is intended to have a deterrent effect on marine mammals. As far as the prolongation of impact contact time is concerned, this approach to sound mitigation is based on the insertion of a 'soft' intermediate layer (e.g. a steel cable) between the hammer and pile to prolong the contact time and so reduce the 'energy peaks' of the strike impact. Its effectiveness has been proven, but there is still considerable need for research.

4.3.2. Secondary sound mitigation measures

Secondary sound mitigation measures are considerably more significant and effective. The Federal Environment Ministry's research projects are therefore concentrated on this field. At present, the following sound mitigation measures are being deployed or are in development and trial operation:

- Bubble curtains
 - 'Little' or 'small' bubble curtains
 - 'Big' or 'large' bubble curtains
- Pile sleeves
- Hydro sound dampers
- Cofferdams

a) Bubble curtains





The most common sound mitigation measures in Germany at the moment are bubble curtains of various designs. Bubble curtains involve compressed air being fed into perforated pipe or hose systems that are laid on the seabed or arranged in the water body. Ideally, the bubbles that rise from the openings form an unbroken barrier that extends the whole height of the water column. The reduction in sound depends, among other things, on the volume of compressed air that is used, the density of the bubble curtain and the size of the bubbles.

The following bubble curtain designs are being deployed or trialled at present in Germany:

- 'big' or 'large' bubble curtain: rising bubbles are generated using a system of pipes or hoses laid on the seabed at a relatively large distance around the location where the noise is generated,
- 'little' or 'small' bubble curtain: rising bubbles are generated using a number of small-diameter rings arranged one above the other directly around the pile to be driven or the foundation structure,
- guided bubble curtain: the air bubbles rise up along a membrane or a wall, which detaches them from the potential influences of flowing water.

Bubble curtains have been deployed in the last few years for various purposes, including sound mitigation during port and bridge construction works. Engineers have started to gain experience of their use during the construction of offshore wind turbines. It has been possible for important evidence to be gathered about these systems in the course of BMU-funded research projects.

The effectiveness of a big bubble curtain during pile driving work on foundations in the offshore sector was evaluated for the first time in 2008 while the FINO 3 research platform was being constructed. On this occasion, it was possible for an attenuation effect of 7 to 12 dB re 1 μ Pa (SEL) or up to 14 dB re 1 μ Pa (SPL) to be achieved (GRIEBMANN *ET AL.* (2010)).

A technically optimised big bubble curtain suitable for series deployment was trialled and evaluated for the first time under real construction conditions during the construction of the Borkum West II offshore wind farm in 2012 (PEHLKE *ET AL.* (2013)). The centrepiece of the sound protection system was a perforated hose laid by automated machinery, which was used successfully on 31 of 40 tripod foundations. The results of the measurements taken show that an attenuation effect of 9 to 13 dB re 1 μ Pa (SEL) or 10 to 17 dB re 1 μ Pa (SPL) can be achieved at water depths of around 30 m with a single-row 'big bubble curtain'. The mean attenuation effect was 11 dB re 1 μ Pa (SEL) or 14 dB re 1 μ Pa (SPL). Tests conducted with a two-row configuration indicate there is the potential for greater reductions. The sound protection system that was used allowed the sound protection threshold set by the authorities to be complied with at 12 out of 40 foundations on the Borkum West II site. The reduction of underwater sound in these cases made it possible for



a clear lessening in the disturbance effect on harbour porpoise by up to 90% to be achieved (PEHLKE ET. AL. 2013).

However, compliance with sound protection thresholds cannot currently be guaranteed because the degree of sound mitigation attained to date is sometimes not sufficient in other circumstances at particular locations with greater water depths, unfavourable weather conditions and larger piles.

The BMU's ongoing research and development projects are focussed on improving the effectiveness of these technologies, minimising the time required to lay out and gather in the hose or pipe system, and developing durable materials and robust technical components.

b) Pile sleeves

Pile sleeves decouple the pile acoustically from the water body as far as possible. Pile sleeves are suitable for the construction of monopiles. Some concepts also permit their application for multipile foundation structures. As far as their design is concerned, they can be configured as double-wall or single-wall designs with some form of insulation in place along the whole length of the pile (air, foams, bubble curtains).

It is possible to distinguish several concepts for the operational deployment of pile sleeves in the construction process:

- A crane is used to place the pile sleeve over the pile to be driven, which has already been positioned on the seabed, and raise it back to the offshore installation vessel after the conclusion of the pile driving.
- The pile to be driven is inserted into the pile sleeve on the installation vessel and positioned together with it on the seabed, then the sleeve is lifted back up once the pile driving has been completed.
- The installation vessel lowers a pile sleeve mechanically onto the seabed, into which the pile to be driven is inserted. After the pile driving, the sleeve is raised again and the installation vessel moved to the next driving location.
- A pile sleeve consisting of two halves is attached to the pile on the installation vessel. The sleeve is mechanically closed once the pile to be driven has been positioned, then opened again after the conclusion of the driving.
- The foundation piles consist of an inner tube and an outer tube. After the pile driving of the inner tube ('tube-in-tube piling'), which serves to anchor the outer tube in the seabed, the turbine is constructed on the outer tube.

The practicality of pile sleeve technology was demonstrated during the construction of the Riffgat offshore wind farm. The 30 monopile foundations were driven using a 30-m-long, 10-m-wide, double-walled steel tube with an internal bubble curtain.

The deployment of pile sleeves as a sound minimisation measure is dependent on particular preconditions being satisfied as far as logistics are concerned because



sufficient capacities for the storage of the pile sleeve and an appropriately configured crane must be kept available.

Further need for development is seen with regard to the deployment of these systems in greater water depths and experimental work to optimise them.

c) Hydro sound dampers

Hydro sound dampers (HSDs) are air-filled balloons with a thin, highly elastic skin that are fastened together in a net-like structure. The cylindrical net is placed over the pile to be driven and lowered to the seabed. This is intended to shield the noise source from the environment to a large extent. By contrast to bubble curtains, the hydro sound damper concept allows the shape, size, number and arrangement of the 'artificial air bubbles' to be precisely predetermined. This means the attenuation effect can be tailored so as to target it at the frequency range relevant for the sound from the pile driving operations.

After it was possible for its suitability to be confirmed in the course of the ESRa project (WILKE *ET AL.* (2012)), an HSD prototype was trialed at the London Array off-shore wind farm in August 2012. It was found the system offered an attenuation effect of 8 to 12 dB re 1 μ Pa (SEL) or 8 to 14 dB re 1 μ Pa (SPL). As far as its level of development is concerned, the hydro sound damper is to be characterised as a highly promising sound mitigation method, but one that has undergone little trialing. The development of a concept suitable for series deployment is currently the focus of ongoing research activities.

d) Cofferdams

A 'coffer dam' is generally a structure that can be used to create a dry, accessible area at the bottom of a water. For example, a coffer dam can be designed as a steel tube, which is placed on the bed of the water and drained using pumps. Construction works – such as the driving of a pile – can then be carried out in the drained area. When this approach is taken, a considerable reduction in sound can be achieved by decoupling the pile from the body of water. In an experiment with a test pile that was conducted in December 2011 in the Danish Belt Sea at a water depth of approx. 20 m, it was found the coffer dam principle had an attenuation potential of 22 dB (SEL) or 18 dB (SPL). One conceptual study has suggested the development of a telescopically extendable coffer dam that would also be suitable for the construction of wind turbine foundations in greater water depths. At present, however, no empirical data have yet been published on this topic.

4.4 Research and development

In order to overcome the problems caused by the impacts of construction-induced sound emissions on harbour porpoises, the BMU has funded diverse projects with



the following priorities under its Future Investment Programme, the 5th and 6th Energy Research Programmes and the Environmental Research Plan (UFOPLAN):

- surveying the impacts of sound emissions on harbour porpoises,
- developing and trialling (new) low-noise options for the construction of foundations,
- developing and trialling efficient, practical, economic (new) noise minimisation measures.

Apart from this, wide-ranging projects designed to augment scientists' knowledge of the fundamental principles of acoustic engineering, model sound propagation and evaluate deterrence methods have been, and are being, funded.

Most of the projects on low-sound options for the construction of foundations and sound minimisation technologies, in particular, have been conducted with participation from the private sector and industry. If the diverse foundation technologies and sound minimisation measures that are being researched and trialled are to be converted into state-of-the-art methods in the near future, it will also be necessary for the offshore industry to continue its committed involvement in both development work, and the application and optimisation of technologies during concrete offshore projects. The Federal Environment Ministry would like to support these activities. According to the current funding regulations for research and development in the renewable energies sector promulgated on 13 December 2011 (<http://www.erneuerbare-energien.de/die-themen/forschung/foerderbekanntmachung/>), the research funding disbursed by the Federal Environment Ministry will continue to be focussed on the funding priorities discussed above.

Conclusions

In view of the current state of the art, it is not possible to dispense with pile driving technology when installing the foundations for offshore wind farms, even though innovative low-sound or sound-reducing technologies are in development and some of them are already well advanced. At present, however, no state-of-the-art technology has become established that guarantees compliance with the sound exposure level (L_E) threshold of 160 dB re $1\mu\text{Pa}^2 \text{ s}$ or the peak sound pressure level ($L_{\text{peak-peak}}$) threshold of 190 dB re $1\mu\text{Pa}$ (at a distance of 750 m), irrespective of the diameter of the pile. The improvement of sound protection technologies is being driven further ahead, thanks in part to the research funding provided by the BMU. However, given the technological advances that have been made, it is indispensable at present for the consequences of the impacts of impulsive sound events due to pile driving activities during the construction of offshore wind farms to be dealt with in this Sound Protection Concept.



5. Impacts of impulsive sound events on harbour porpoises

Harbour porpoises can suffer temporary or permanent damage to their hearing as a result of impulsive sound. On the one hand, it may trigger a raising of their hearing threshold for a limited period, i.e. a temporary lowering of hearing sensitivity (temporary threshold shift, TTS). On the other hand, there may be a permanent raising of their hearing threshold (permanent threshold shift, PTS) that can go as far as complete deafness. When this happens, the rise in the hearing threshold may be limited to certain frequency ranges or occur over the whole hearing curve. Damage to hearing is to be regarded as an injury within the meaning of Section 44(1) of the BNatSchG. An injury within the meaning of the prohibition on taking under species protection law is an impairment of an animal's physical welfare or damage to its health. This encompasses any impairment of its physical integrity.

According to the latest academic findings, a threshold shift is triggered among harbour porpoises by impulsive sound events with a broadband single event sound pressure level (L_E) above 164 dB re $1\mu\text{Pa}^2 \text{ s}$ combined with a peak level ($L_{\text{peak-peak}}$) of 199 dB re $1\mu\text{Pa}$ (LUCKE *ET AL.* (2009)). The single event sound pressure level (L_E) is identical with the sound exposure level (SEL). The peak level ($L_{\text{peak-peak}}$) is identical with the peak sound pressure level ($\text{SPL}_{\text{peak-peak}}$).

Recent progress in the research and the thresholds set on the basis of these findings, a sound exposure level (L_E) of 160 dB re $1\mu\text{Pa}^2 \text{ s}$ and a peak sound pressure level ($L_{\text{peak-peak}}$) of 190 dB re $1\mu\text{Pa}$ (at a distance of 750 m), are based on the effects of a single acoustic event. When a driven foundation structure is installed, several thousand hammer strikes are required for each pile (multiple sound emissions from pile driving). Models of the corresponding cumulative sound exposure caused by multiple sound emissions of this kind suggest that the thresholds may not be sufficient (e.g. AUSTRALIAN GOVERNMENT (2008), FINNERAN AND SCHLUNDT (2004), FINNERAN *ET AL.* (2002)).

Even at an impulsive sound exposure of markedly less than an SEL of 164 dB re $1\mu\text{Pa}^2 \text{ s}$, harbour porpoises respond with pronounced avoidance behaviour and behavioural changes, which are visible in particular in the form of flight responses away from the sound source that can result in them leaving the space affected by strong sound emissions (habitat loss). Other behavioural changes such as the interruption of feeding or resting phases, and the prevention of or interference with communication are currently not recorded. Since the space gradually comes into use again once the sound exposure has ceased, this disturbance lasts for a limited period (BRANDT *ET AL.* (2011)).

Flight responses and avoidance behaviour at distances up to over 20 km from pile driving have been demonstrated among harbour porpoises in the North Sea where no sound mitigation technologies are deployed (LUCKE *ET AL.* (2010); TOUGAARD *ET AL.* (2006)).





If an impulsive sound exposure causes a flight response on the part of a mother-calf pair, the mother may lose contact with the calf, while mating may be significantly disrupted or fail on account of the relatively short conception period (just a few days for each individual). Scientifically backed-up findings on the level of sound pressure that leads to these responses have not been published to date.

Behavioural effects can result in harbour porpoises being driven away temporarily or permanently from ecologically important areas. Harbour porpoises have a high digestion rate and need to consume food frequently in the course of the day. If a harbour porpoise consumes no food for just a few days, it may suffer hypothermia and die. There are no scientifically backed-up findings about the level of sound pressure that leads to behavioural responses of this kind either.

Looked at in isolation, the impulsive sound inputs attributable to the driving of piles into the seabed for the foundations of offshore wind turbines are temporary events that are limited to the construction phase of an offshore wind farm. In view of the large number of turbines at each wind farm (up to 80 turbines in the current pilot phases), combined with the number of planned offshore wind farms that have already been licensed or are going through the approval process, it is to be expected that temporary sound exposures of this kind could well be occurring in the German North Sea for a period of about 30 years. This is far longer than the approx. 8-10 years a harbour porpoise generation lasts.

6. Disturbances

The concept of disturbance is of central significance if the impacts of sound generated by pile driving activities during the construction of offshore wind farms are to be assessed properly because the Federal Nature Conservation Act takes the term as its starting point. It is for this reason that this section sets out in detail the basis on which the concept of disturbance has been developed for the Sound Protection Concept presented in this document.

Sound as disturbance: What behavioural changes may be triggered by sound among harbour porpoises?

Harbour porpoises are essentially reliant on their hearing. Sound events provoke various responses among harbour porpoises. Above a certain threshold, the sound becomes noise and has a disturbance effect. Noise is a recognised stress factor and provokes stress responses among harbour porpoises. At present, the threshold as of which sound becomes noise cannot be determined exactly for harbour porpoises and, furthermore, varies depending on the condition of the individual animal, the stage it has reached in its biological cycle (infant, rearing, mating) and the activity it is engaged in at a particular time. Apart from the strength of the noise, the frequency range also plays a crucial role because harbour porpoises' hearing ability



and noise sensitivity differ depending on the frequency of the sound to which they are exposed.

There have been no scientific studies aimed at conducting a complete survey of disturbances among marine mammals. Hitherto, findings on individual aspects of the issue have merely been recorded for certain individual species. Nevertheless, it has been possible to synthesise these data to arrive at a sufficiently robust overview. The following behavioural patterns among harbour porpoises are evidence of the presence of an acoustic disturbance:

- directed swimming away from the sound source (evasion, flight),
- interruption of feeding,
- interruption of communication,
- interruption of resting behaviour.

Apart from this, their location and communication signals may be 'masked' (reduced perception of acoustic signals as a result of the superimposition of other loud acoustic signals) (NRC (2005)). This prevents or interferes with

- feeding (location of food),
- communication between harbour porpoises,
- orientation.

What can be detected?

In order to be able to detect disturbances to harbour porpoises with some degree of precision, the specified impacts would have to be recorded for each individual animal. However, such individual observations or measurements can only be carried out with a justifiable amount of effort in a few cases. The comprehensive determination of the impacts of sound on harbour porpoises therefore comes up against its limits, and such impacts can only be determined approximately at present.

Attempts are currently being made to survey the impacts of sound generated by pile driving activities on harbour porpoises using porpoise detectors (PODs). PODs permit changes in the acoustic activity of harbour porpoises and their precise timing to be recorded continuously and correlated with the times of sound-intensive pile driving operations. These alterations are either to be attributed to behavioural changes in the animals that are present (e.g. 'falling silent'), a change in the number of animals present (immigration or emigration) or a combination of both effects. None of the other impacts of disturbances discussed above can be determined with this method. This methodological limitation is important for the classification of the results from these investigations.

The consequences of sound-induced disturbances, both for individual animals and also at the population level, can only be traced with difficulty among harbour porpoises, not only on account of the inaccessibility of wild harbour porpoises for in-



vestigations in their real surroundings, but above all in view of the complexity and large number of the factors to be analysed.

In 2005, the US National Research Council (NRC) developed what is known as the Population Consequences of Acoustic Disturbance (PCAD) model as a tool for the analysis of population-relevant effects that occur due to acoustic disturbances. The model, which is organised in a series of manageable stages, shows a causal chain from the original source of the (sound) exposure to the impacts on mammals' individual behaviour, the vital functions affected, the exposure's impacts on the vitality rate and the population effect in which they result (see Figure 1). There is insufficient knowledge of, in particular, the interactions and linkages between the different individual stages.

[Abbildung 1:

Schall = Sound

Quelle = Source

Pegel = Level

Frequenz = Frequency

Dauer = Duration

Zyklus = Cycle

Stunde – Saison = Hour – Season

Verhaltensänderung = Behavioural change

Orientierung = Orientation

Atemfrequenz = Breathing frequency

Vokalisation = Vocalisation

Tauchen = Diving

Ruhen = Resting

Mutter-Jungtier-Beziehung (räuml.) = Mother-infant spatial relationships

Meidung = Avoidance

Saison – Jahr = Season – Year

Betroffene Lebensfunktionen = Life functions affected

Überleben = Survival

Wanderung = Migration

Fressen = Feeding

Aufzucht = Rearing

Reaktion auf Fraßfeinde = Response to predators

Jahr – Generation = Year – Generation

Vitalitätsrate = Vitality rate

Abh. v. Altersklasse = Stage-specific

Überlebensrate = Survival rate

Geburtenrate = Birth rate

Fortpflanzungsrate = Reproduction rate

eine – mehrere Generationen = One – Several Generations

Populationseffekt = Population effect



Wachstumsrate d. Pop. = Population growth rate
Populationsstruktur = Population structure
Austauschdynamik = Transient dynamics
Empfindlichkeit = Sensitivity
Elastizität (Resilienz) = Elasticity (resilience)
NRC 2005 (abgewandelt) = NRC 2005 (adapted)]

Figure 1

Key: Indicator scale

+++	Well known
++	Comparatively well known
+	Some knowledge
o	Unknown

The use of PODs to survey the impacts of sound from pile driving activities on harbour porpoise currently represents a practical, well established method for the observation of disturbance effects, provided it is taken into consideration when this is done that only some of the actual disturbances can be recorded.

What is the spatial range of disturbances?

If the distances around a sound source at which disturbances can still be expected are to be determined, it becomes necessary, among other things, to appraise sound propagation characteristics. According to measurements taken by the German Wind Energy Institute (ISD, DEWI, ITAP (2004)), the decrease in the sound level as the distance from the sound source increases can be calculated with what is known as the 'Thiele formula' (THIELE (2002) AND THIELE, R. AND SCHELLSTEDE, G. (1980)), which was developed for application in the sandy coastal areas of the North Sea and the Baltic Sea. However, the frequency of the sound is factored into the calculation and the attenuation values calculated are accordingly frequency-dependent as well. As far as broadband sound from pile driving operations in the North Sea is concerned, DEWI (ISD, DEWI, ITAP 2004) determined a decrease in the sound level by 4.5 dB for every doubling of the distance from the sound source (does not apply for the near-field).

Using measurements of sound exposure levels taken during the pile driving for the met mast at the Amrumbank West offshore wind farm, ELMER *ET AL.* (2007) were able to show that the decrease in the sound level became greater as the distance from the sound source increased and, in particular, clearly diverged from the forecast values at greater distances from the location of the pile driving operations. The investigations by PEHLKE *ET AL.* (2013) also demonstrate sound immissions from pile driving activities at greater distances are overestimated when geometrical propagation loss is calculated in accordance with the BSH's *Measuring Instruction* and the semi-empirical approximation of propagation loss put forward by THIELE AND SCHELLSTEDE (1980) is applied. In consequence, use is not made of the Thiele formula below, but a formula derived from ELMER *ET AL.* that depicts a faster rate of



propagation loss at greater distances. These authors used measurements of peak sound pressure level taken at various distances from the met mast to determine the distance-dependent transmission loss (TL) for broadband sound from pile driving operations (sound pressure level):

$$(1) \quad TL = (14 + r \cdot 0.0002) \cdot \text{LOG}(r).$$

Here, TL states how many dB the sound level has fallen by in comparison to the level at a distance of one metre from the location of the pile driving operations, in which respect it is merely the distance r (in metres) that is factored into the calculation.

After the pile driving for the Amrumbank West met mast, sound measurements were taken at different distances during the pile driving for the FINO 3 research platform and the installation of the foundations for the Horns Rev II, alpha ventus and BARD Offshore I wind farms, which were conducted by the same group of authors (BETKE (2008), GRIEBMANN *ET AL.* (2010), BETKE AND MATUSCHEK (2009)). In order to examine whether the distance-dependent falls in the sound exposure level (SEL) measured at the specified installations can also be depicted with sufficient precision by Formula (1), the values measured were standardised. The first step was to calculate a sound curve (T 1) that followed Formula (1) and showed exactly 160 dB re 1 $\mu\text{Pa}^2 \text{ s}$ (SEL) at a distance of 750 m from the sound source. Furthermore, the measured sound levels for each individual project were standardised so that the value measured closest to 750 m in each case came to lie on the sound curve (T 1) calculated in the first step. The only measurements that diverged from this had been taken at alpha ventus 2 because a sound exposure level (SEL) of 166 dB re 1 $\mu\text{Pa}^2 \text{ s}$ had been measured at distances of both 500 m and 1,500 m. Here, the individual values were reduced by 6 dB in each case. The approach taken allowed the use of Formula (1) to arrive at a sufficiently good approximation of the distance-dependent sound exposure level caused by pile driving events that comply precisely with the thresholds set for a distance of 750 m. This method means forecasting is possible, in particular for the area of interest here up to a distance of approx. 20 km from the pile driving site.

However, as already explained in section 4.2, exact forecasting is not possible because the propagation of sound in the sea is dependent on, among other things, the water depth, the water temperature, the morphology of the seabed and swell conditions. Nevertheless, the Elmer formula (1) is used below for reasons of practicality and in the absence of more exact bases for the calculations.

In contrast to visual investigations, POD-supported measurements allow very much more detailed evidence to be gathered about flight and avoidance responses. Various parameters (encounters, porpoise positive 10 minutes/day (PP10min/d), porpoise positive minutes/hour (PPM/h), waiting time between detections) can be ana-



lysed to illuminate harbour porpoises' acoustic activity and so supply evidence about the behaviour and/or occurrence of animals in the vicinity of the PODs. The POD investigations at Horns Rev II mentioned above found reduced PPM/h values, which suggested disturbance effects were occurring at distances of up to 17.8 km (meaned) from the pile driving site. The authors state that the increased values recorded at a distance of 21.2 km (meaned) actually point to an aggregation of animals caused by the dispersal effect (BRANDT *ET AL.* (2011)). If Equation 1 is used (see above), it can be calculated from the sound levels quoted by BETKE (2008) that the sound exposure level (SEL) values at this distance were 138 dB re $1\mu\text{Pa}^2 \text{ s}$ or 134 dB re $1\mu\text{Pa}^2 \text{ s}$. At alpha ventus, DIEDERICHS *ET AL.* (2010) used waiting times to demonstrate significant effects up to 16.4 km, while no more significant impacts were to be found at a distance of 21 km. BETKE AND MATUSCHEK (2011) measured a sound exposure level of 140 dB re $1\mu\text{Pa}^2 \text{ s}$ (SEL) at 16.4 km, while a value of 134 dB was calculated for 21 km. The above-mentioned POD data indicate that disturbances are demonstrable even at sound exposure levels of 138-140 dB re $1\mu\text{Pa}^2 \text{ s}$ (SEL) while at 134 dB re $1\mu\text{Pa}^2 \text{ s}$ it is not possible to identify any further dispersal effects, at least. These figures are clearly lower than the results found in the investigations by LUCKE *ET AL.* (2009), in which the harbour porpoise that was studied displayed a startle response and corresponding behavioural avoidance in the direction of the location of the sound source when exposed to a single sound event at 145 dB re $1\mu\text{Pa}^2 \text{ s}$ (SEL). However, LUCKE *ET AL.* (2009) point out the animal that was studied lived in an environment in which it experienced intense exposures to sound and may have displayed an unnaturally high level of tolerance to underwater sound, so the actual level at which behavioural responses start to occur could be markedly lower. PEHLKE *ET AL.* (2013) found a significant detection threshold for disturbance at 144 dB re $1\mu\text{Pa}^2 \text{ s}$ (SEL) for the hours during which pile driving was taking place (p. 162) and highly to extremely highly significant disturbance during the following 24 hours at up to 140 dB re $1\mu\text{Pa}^2 \text{ s}$ (SEL) (PEHLKE *ET AL.* (2013), p. 165). Highly significant disturbances occurred only temporarily at levels between 135 and 140 dB re $1\mu\text{Pa}^2 \text{ s}$ (SEL) (PEHLKE *ET AL.* (2013), p. 165).

At present, it is not possible to set an exact sound threshold for disturbances on the basis of the observations discussed above. Rather, in the interests of simplicity, it is therefore assumed below that if the 160 dB (SEL) threshold is complied with, measured at a distance of 750 m, disturbances will occur within a radius of eight kilometres around the sound source, in particular avoidance and flight behaviour. Back-calculation using Equation 1 shows that at this distance the sound exposure level would be 140 dB re $1\mu\text{Pa}^2 \text{ s}$ (S_E), a figure that is to be described as plausible in the light of the studies that have been published. This value is also confirmed by the new results and still incomplete evaluations of NEHLS and DIEDERICHS (2013), who also assume a disturbance radius of eight kilometres.

Provided the sound exposure level (SEL) is lower than the threshold of 160 dB re $1\mu\text{Pa}^2 \text{ s}$ at a distance of 750 m, it may be posited that the radius around the sound source within which a disturbance of the kind described above is to be assumed is



also reduced accordingly. This means it is possible to derive immediately from the measured sound exposure the corresponding disturbance radiuses up to the point at which acoustic attenuation has reduced the sound level to approx. 140 dB. In order to anchor this effect within the framework put in place by the Sound Protection Concept, disturbance radiuses have been determined in conformity with the method for their derivation using Equation 1. By way of illustration, Table 1 shows the corresponding disturbance radiuses for two other values (155 dB re $1\mu\text{Pa}^2 \text{ s}$ and 150 dB re $1\mu\text{Pa}^2 \text{ s}$ at a distance of 750 m).

Table 1:
Disturbance radiuses dependent on sound exposure

dB SEL at a distance of 750 m	Disturbance radiuses
160	8 km
155	5 km
150	3 km

The disturbance radiuses derived in this way form the basis for the interpretation of the relevant provisions of nature conservation law within the framework of the Sound Protection Concept presented in this document. Areas where different disturbance radiuses overlap are only counted once (and not cumulated), because the disturbance is triggered by the first increase in noise levels.

7. Sound Protection Concept Guidelines

7.1. Best available technology

The principle applies that the best available technology in each case is to be used in order to implement the most ecologically appropriate option, and therefore minimise sound exposures and other negative impacts on the marine environment as far as possible overall. An explicit decision has been taken not to stipulate a specific foundation technology. Rather, the Sound Protection Concept and the research activities funded by the BMU are intended to incentivise and support the development and rapid deployment of innovative, low-noise technologies.

Since it is currently not yet possible to dispense with pile driving technology, at least for the construction of offshore wind farms, the individual requirements of nature conservation law concerning species protection under Section 44(1) of the BNatSchG and site protection under Sections 32 ff. of the BNatSchG are formulated in concrete terms below in the form of appropriate conventions for the assessment of impulsive sound inputs attributable to pile driving activities during the construction of offshore wind farms.



7.2. Species protection: prohibitions on injury and killing

According to point 1 of Section 44(1) of the BNatSchG, it is prohibited to kill or injure harbour porpoises. Damage to an animal's hearing is to be regarded as injury within the meaning of Section 44(1) of the BNatSchG. The noise prevention values recommended by the UBA and established with binding force by the BSH, consisting of the twin criteria of a sound exposure level (SEL) of 160 dB re 1 μ Pa² s (un-weighted) and a peak sound pressure level (SPL_{peak-peak}) of 190 dB re 1 μ Pa at a distance of 750 m, are to be complied with in this regard. In areas where higher levels of sound pressure occur, suitable measures are to be taken to ensure that no animals are present there at the time of the sound event (deterrence). This is to be proven by the monitoring of noise emissions and harbour porpoises using methods that are to be formulated in concrete terms during the licensing process.

7.3. Species protection: prohibition of disturbance

Not all disturbances to the harbour porpoise population are prohibited during their all-year-round breeding and rearing periods by point 2 of Section 44(1) of the BNatSchG: this is only the case for significant disturbances (see section 3 above). A significant disturbance occurs if the conservation status of the local population is worsened. In the North Sea, the reference variable 'local population' is equivalent to the whole population of harbour porpoises in the German part of the North Sea.

Conservation status of species under the Habitats Directive

Conservation status is characterised by the sum of the influences acting on the species concerned that may affect the long-term distribution and abundance of its populations within the territory referred to. The conservation status is taken as 'favourable' when population dynamics data on the species concerned indicate that it is maintaining itself on a long-term basis as a viable component of its natural habitats, the natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future, and there is, and will probably continue to be, a sufficiently large habitat to maintain its populations on a long-term basis.

The following criteria are drawn on to assess the conservation status of species covered by the Habitats Directive for the national reports provided for in Article 17 of the Habitats Directive:

1. current natural range (extent, trend),
2. population (population size, reproduction, age structure, mortality, health status),



3. habitat for the species (area and quality, incl. structures and functions),
4. future prospects (as regards to population, range and habitat availability, incl. pressures and threats, and long-term viability).

Sources: GERMAN FEDERAL GOVERNMENT (2007); EUROPEAN UNION, DG ENVIRONMENT B2 (2005): DocHab 04-03/03-rev.3; SACHTELEBEN, J. AND BEHRENS, M. (2010)

It is therefore not the disturbance of an individual animal that is relevant under species protection law. Rather, the proposed conventions elaborated below imply that, as a rule, it is only the presence of several pile driving sites with the associated disturbance radiuses at the same time that results in disturbances that are population-relevant and therefore significant. Only then are they relevant under species protection law. Among other things, of course, the significance of a disturbance to a local population is also connected conceptually with the question of the proportion of the population of harbour porpoises that may be disturbed in a particular temporal context. However, the proposed conventions set out below relate to spatial factors (number of disturbance radiuses, distance from protected site, etc.) in order to ensure the conventions are manageable, allow licensing authorities and developers to plan efficiently, and can therefore be implemented in practice. This is possible because the spatial and temporal distribution patterns and densities in the German North Sea are essentially well known and can be taken into consideration appropriately in modelling. The harbour porpoise densities in question are therefore factored into the evaluation criteria accordingly.

In order to simplify the process of determining the impacts attributable to a whole project (construction of an offshore wind farm), the project's individual wind turbines are not looked at separately, but the geographical centrepiece of the area to be occupied by the offshore wind farm is taken as the basis for the calculation of the disturbance radius in each individual case.

The circannual rhythm of harbour porpoise breeding and rearing phases discussed in section 3 means that during the particularly sensitive part of the breeding period (North Sea: May-August) the significance threshold set in point 2 of Section 44(1) of the BNatSchG is reached by disturbances of lower intensity than outside this period because the population's reproductive success is immediately affected. The prohibition on disturbance is therefore to be interpreted in a differentiated fashion, depending on the season.

7.3.1. Assessment convention for the prohibition on disturbance outside the particularly sensitive period

In order to rule out significant, population-relevant disturbances in the German North Sea now and in future, sufficient areas unaffected by sound from pile driving





must be available for harbour porpoises, in particular. It is assumed that sufficient areas of this kind are certainly always available if no more than ten per cent of the area of the EEZ in the German North Sea falls within the disturbance radiuses of the offshore wind farms that are under construction, and there is compliance with the impulsive sound thresholds set for compliance with the prohibitions on killing and injuring (broadband sound exposure level (SEL) of 160 dB re 1 μPa^2 s or peak sound pressure level ($\text{SPL}_{\text{peak-peak}}$) of 190 dB re 1 μPa at a distance of 750 m from the location where the sound is generated). As far as this is concerned, the location of the individual sound sources remains disregarded. If the thresholds are complied with, it is possible to rule out significant disturbance to the local harbour porpoise population.

7.3.2. Assessment convention for the prohibition of disturbance during the particularly sensitive period

In the German North Sea, the harbour porpoise goes through its most sensitive reproduction phase during the period from May to August. At the same time, the population displays a clear aggregation in an area north west of Sylt (main area of concentration). Furthermore, when consideration is given to the sometimes significant year-on-year fluctuations in density among the harbour porpoises in the German North Sea, the outstanding significance of this area within the German EEZ in the North Sea is apparent across all the years when studies were conducted (Fig. 2). In areas with high harbour porpoise densities, exposures have greater potential to cause population-relevant disturbance than in areas with lower densities.

[Abbildung 2:

Flugzählungen zur Erfassung von Schweinswalen = Aerial counts to survey harbour porpoises

Datenquelle: Mai bis August (gepoolt über die Jahre 2005-2010) = Data source: May to August (pooled over the years 2005-2010)

effektive Flugstrecke = 27.100 km (an 43 Flugtagen) = Effective distance flown: 27,100 km (on 43 flight days)

Anzahl gesichteter Schweinswalgruppen 2.960 mit 3.583 Individ. = Number of harbour porpoise groups sighted: 2,960 with 3,583 individuals

mittlere Schweinswaldichte (Ind./km^2) = Mean harbour porpoise density (ind./km^2)

Zellen: 10x10 km = Cells: 10x10 km

Mutter-Kalb Paar = Mother-calf pair]

Figure 2: Raster grid of the distribution of harbour porpoises in the German North Sea and sightings of mother-calf pairs (Gilles, unpublished), Habitats Directive special protection ar-



areas in the EEZ and boundaries of the main area of concentration on the Sylt Outer Reef (black, dotted line)

In addition to this, in order to ensure harbour porpoises permanently have sufficient opportunities to evade exposures and in order to limit the disturbances to the population to technically justifiable and legally permissible levels, in the particularly sensitive phase it is necessary to keep the main area of concentration free of sound-intensive construction activities during which a cumulative area of more than one per cent of the site is located within the disturbance radius. The areas of the disturbance radii for all projects in which the foundation construction phase has already begun and has not yet been concluded are cumulated.

All projects licensed as of 1 December 2013 are to be subject to this Concept. The developers of these projects can therefore organise their construction schedules accordingly at the point in time when the license is granted and allow for a period when pile driving will potentially be ruled out during the particularly sensitive phase. The principles laid down in section 7.5., 'Old licences', apply for projects that have been licensed in the past.

The main area of concentration is shown with its coordinates in Annex 1.

7.4. Site protection

The harbour porpoise is a conservation target for all Habitats Directive special protection areas in the German EEZ in the North Sea (Table 2). However, it is only in the Sylt Outer Reef and Dogger Bank Habitats Directive special protection areas that the reproduction of harbour porpoises is also an explicit conservation target.

Table 2: Conservation targets

Special protection area	Harbour porpoise is conservation target	Harbour porpoise reproduction is conservation target
Sylt Outer Reef	X	X
Borkum Reef Ground	X	-
Dogger Bank	X	X

The criteria for the assessment of an adverse impact on a site are the constitutive elements of the protective purpose or conservation target. The functions of a site for the population of harbour porpoises found at that site are to be protected.

Under the premise that the driving of piles for the foundations of offshore wind turbines constructed at distances greater than eight kilometres from a Habitats Directive special protection area complies with the thresholds specified in section 7.2 and could not result in any other significant adverse effects within the meaning of



Section 34(2) of the BNatSchG, there is no necessity for an Appropriate Assessment under the Habitats Directive to be conducted for these projects.

The constitutive elements of the protective purposes or conservation targets for Habitats Directive special protection areas must not suffer significant adverse impacts due to underwater sound. A significant adverse impact on a Habitats Directive special protection area is usually presumed if there is a permanent loss of one per cent of a habitat found within the site (LAMBRECHT *ET AL.* (2004)). Since the sound exposure caused by pile driving activities occurs for limited periods of time, it is justifiable here from a technical, nature conservation perspective for ten times this figure, i.e. ten per cent, to be defined as the significance threshold for a temporary, reversible loss of function in the area described by the disturbance radiuses.

A significant adverse impact on a site is therefore to be presumed if at least ten per cent of the area of the site is located within the disturbance radius (provided there is compliance with the sound exposure level (SEL) threshold of 160 dB re 1 μPa^2 s or the peak sound pressure level (SPL) threshold of 190 dB re 1 μPa at a distance of 750 m). Sound events caused by various sound sources are to be cumulated for analysis as follows. The areas of the disturbance radiuses for all projects whose foundation construction phase has already begun and has not yet been concluded are cumulated.

Habitats Directive special protection areas in which harbour porpoise reproduction is a conservation target (Table 2) require an enhanced level of protection, and no more than one per cent of the area of the site may be impinged upon by disturbance radiuses in the particularly sensitive phase from May to August discussed above (provided there is compliance with the sound exposure level (SEL) threshold of 160 dB re 1 μPa^2 s or the peak sound pressure level (SPL) threshold of 190 dB re 1 μPa at a distance of 750 m). The same cumulation rule as above applies.

7. 5. Old licences

The aim of the Sound Protection Concept is to manage the future expansion of offshore wind energy in order to protect harbour porpoises on the basis of assessment criteria that are well known in good time. This can only be implemented appropriately and successfully if it is possible for these assessment criteria to be integrated into the planning process at an early stage, which means there is no expectation this concept will be applied for previously licensed projects. Licenses granted in the past are final and absolute, and remain unaffected by the evaluation criteria laid down in the Sound Protection Concept. The same applies for projects whose licences are extended unchanged.

The legal options open to the BSH to take recent scientific findings into consideration under the Ordinance on Offshore Installations Seaward of the Limit of the German Territorial Sea remain unaffected by this arrangement. Old licences are to



be factored into the cumulative analysis of sound events caused by various sound sources that occur simultaneously.

7. 6. Requests for variation

On account of the long lead times involved in the planning of offshore wind farms, it is still common, and frequently necessary, to make modifications to a project after the license for the construction of an offshore wind farm has been obtained. This is done by submitting requests for variation. In some cases, depending on the modifications planned, requests for variation require the project's environmental impacts to be assessed once again.

However, only modifications that could cause additional, previously unconsidered adverse impacts as a result of a change in the scale of the sound emitted are relevant to the application of the Sound Protection Concept. This is to be examined in the concrete individual case.



Sources and further reading:

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Abbreviations

ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BNatSchG	German Federal Nature Conservation Act
BSH	German Federal Maritime and Hydrographic Agency
CV	coefficient of variation
dB	decibel
DEWI	German Wind Energy Institute
EEZ	Exclusive Economic Zone
HD	European Habitats Directive
Helcom	Commission of the Convention on the Protection of the Marine Environment of the Baltic Sea
HSD	hydro sound damper
ISD	Institute of Structural Analysis
ITAP	Institute for Technical and Applied Physics GmbH
IWC	International Whaling Commission
L_E	sound exposure level
$L_{\text{peak-peak}}$	peak sound pressure level
NERI	Danish National Environmental Research Institute
NRC	US National Research Council
O-NEP	German Offshore Grid Development Plan
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
Pa	pascal
PCAD	Population Consequences of Acoustic Disturbance model
POD	porpoise detector
PP10min/d	porpoise positive 10 minutes/day
PPM/h	porpoise positive minutes/hour
PTS	permanent threshold shift
SEL	sound exposure level
SPL	sound pressure level
TL	transmission loss
TTS	temporary threshold shift



Annex 1

ENTWURF = DRAFT

Hauptkonzentrationsgebiet der Schweinswale in der deutschen AWZ von Mai bis August = Main concentration area for harbour porpoises in the German EEZ from May to August

Bundesamt für Naturschutz (BfN), Fachgebiet II 5.2 Meeres- und Küstennaturschutz = Federal Agency for Nature Conservation Section II 5.2 Marine and Coastal Nature Conservation

Stand: Juni 2013 = June 2013

Punkt 1 = Point 1

geographische Länge (WGS84): 6.324038 = Geographical longitude (WGS84): 6.324038

geographische Breite (WGS84): 55.400854 = Geographical latitude (WGS84): 55.400854

Punkt 2 = Point 2

geographische Länge (WGS84): 7.551322 = Geographical longitude (WGS84): 7.551322

geographische Breite (WGS84): 55.166951 = Geographical latitude (WGS84): 55.166951

Punkt 3 = Point 3

geographische Länge (WGS84): 8.044337 = Geographical longitude (WGS84): 8.044337

geographische Breite (WGS84): 55.099176 = Geographical latitude (WGS84): 55.099176

Punkt 6 = Point 6

geographische Länge (WGS84): 6.324038 = Geographical longitude (WGS84): 6.324038

geographische Breite (WGS84): 54.947240 = Geographical latitude (WGS84): 54.947240

Punkt 5 = Point 5

geographische Länge (WGS84): 7.020467 = Geographical longitude (WGS84): 7.020467

geographische Breite (WGS84): 54.538849 = Geographical latitude (WGS84): 54.538849

Punkt 4 = Point 4

geographische Länge (WGS84): 7.530935 = Geographical longitude (WGS84): 7.530935

geographische Breite (WGS84): 54.241864 = Geographical latitude (WGS84): 54.241864

Punkt = Point

geog. Länge (WGS84) = Geog. Longitude (WGS84)

geogr. Breite (WGS84) = Geog. Latitude (WGS84)

ACHTUNG: = WARNING:



Für die Grenzpunkte sowie die Grenzverläufe des Hauptkonzentrationsgebiets, die zwischen den Punkten 1 bis 4 den Seegrenzen entsprechen, ist der proklamierte Grenzverlauf mit den entsprechenden Koordinaten in ED 50 maßgeblich. = The proclaimed course of the border with the corresponding coordinates in ED 50 is authoritative with regard to the boundary points and the course of the boundaries of the main concentration area where they coincide with maritime borders between Points 1 and 4.

Die hier genannten Koordinaten in WGS 84 können den Grenzverlauf nur näherungsweise wiedergeben. = The coordinates in WGS 84 quoted here can only represent the course of the border approximately.

Legende = Key

Hauptkonzentrationsgebiet Schweinswale = Main concentration area for harbour porpoises

Vogelschutzgebiet = Bird protection area

FFH-Gebiete = HD special protection areas

Deutsche AWZ = German EEZ

Deutsches Küstenmeer = German neritic zone

Seemeilen = Sea miles

Bezugssystem: WGS 84 = Datum: WGS 84

Projektion: Mercator (54°) = Projection: Mercator (54°)



AUGUST 31 2023

Temporary threshold shift in bottlenose dolphins exposed to steady-state, 1/6-octave noise centered at 0.5 to 80 kHz^{a)} **FREE**

James J. Finneran ; Carolyn E. Schlundt; Jason Mulsow 



J. Acoust. Soc. Am. 154, 1324–1338 (2023)

<https://doi.org/10.1121/10.0020728>



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Temporary threshold shift in bottlenose dolphins exposed to steady-state, 1/6-octave noise centered at 0.5 to 80 kHz^{a)}

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ABSTRACT:

Temporary threshold shift (TTS) was measured in bottlenose dolphins after 1-h exposures to 1/6-octave noise centered at 0.5, 2, 8, 20, 40, and 80 kHz. Tests were conducted in netted ocean enclosures, with the dolphins free-swimming during noise exposures. Exposure levels were estimated using a combination of video-based measurement of dolphin position, calibrated exposure sound fields, and animal-borne archival recording tags. Hearing thresholds were measured before and after exposures using behavioral methods (0.5, 2, 8 kHz) or behavioral and electrophysiological [auditory brainstem response (ABR)] methods (20, 40, 80 kHz). No substantial effects of the noise were seen at 40 and 80 kHz at the highest exposure levels. At 2, 8, and 20 kHz, exposure levels required for 6 dB of TTS (onset TTS exposures) were similar to previous studies; however, at 0.5 kHz, onset TTS was much lower than predicted values. No clear relationships could be identified between ABR- and behaviorally measured TTS. The results raise questions about the validity of current noise exposure guidelines for dolphins at frequencies below ~1 kHz and how to accurately estimate received noise levels from free-swimming animals. <https://doi.org/10.1121/10.0020728>

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I. INTRODUCTION

Numerous studies have shown that marine mammals have sensitive hearing and are susceptible to noise-induced hearing loss (NIHL), as revealed by measurements of temporary threshold shift (TTS) after controlled noise exposures [e.g., see Finneran (2015) and Southall *et al.* (2019)]. As in terrestrial mammals, TTS in marine mammals is heavily influenced by species-specific hearing characteristics, hearing test frequency, and exposure level, duration, frequency, and temporal pattern [see Finneran (2015)].

To account for effects of exposure frequency, recent efforts to predict and mitigate the effects of underwater noise have utilized auditory weighting functions (Southall *et al.*, 2007; National Marine Fisheries Service, 2016, 2018; Southall *et al.*, 2019). Weighting functions are essentially bandpass filters applied to a noise exposure before a single, weighted sound pressure level (SPL) or sound exposure level (SEL) is calculated (Houser *et al.*, 2017). The goal of the weighting function is to emphasize noise at frequencies where animals are more susceptible to NIHL and de-emphasize noise at frequencies where animals are less susceptible. In humans, auditory weighting functions for NIHL were derived from equal loudness contours, which show combinations of frequency and SPL resulting in sounds

perceived to be equally loud (Houser *et al.*, 2017). Human equal loudness contours are obtained from perceptual loudness comparison tasks, which are difficult to mimic with animals [but see Finneran and Schlundt (2011)]. As a result, marine mammal weighting functions for NIHL have typically been based on the manner in which the SEL required for the onset of TTS (typically defined as the exposure level producing 6 dB of TTS) varies with exposure frequency (Southall *et al.*, 2007; National Marine Fisheries Service, 2016, 2018; Southall *et al.*, 2019). As a result, the accuracy and validity of the resulting marine mammal weighting functions is limited by the relatively sparse data showing the effects of noise frequency on marine mammal TTS (e.g., few species, individuals, exposure scenarios).

The primary goal of the present study was to measure TTS in bottlenose dolphins (*Tursiops truncatus*) at a number of different exposure frequencies, to increase the available data for developing an auditory weighting function for predicting TTS onset. Bottlenose dolphins are one of the few species of marine mammals for which such measurements are possible, and have been used to represent other toothed whale species with known or suspected similarities in hearing ability and susceptibility to noise [e.g., National Marine Fisheries Service (2016)].

The exposure paradigm was similar to that previously employed in some studies with harbor porpoises (*Phocoena phocoena*), harbor seals (*Phoca vitulina*), and California sea lions (*Zalophus californianus*), where free-swimming animals were exposed to relatively long duration (60 min),

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1/6-octave noise, and exposure levels were estimated by combining estimates of animal position with sound field measurements [e.g., Kastelein *et al.* (2019b), Kastelein *et al.* (2020c), and Kastelein *et al.* (2021)]. The present study differed from these studies in the species involved, use of netted ocean enclosures rather than pools, and use of animal-borne archival audio recording tags to supplement estimates of received exposure levels on the moving animals. The use of free-swimming animals during exposures differs from other studies where animals were (nearly) stationary during exposures [e.g., Kastak *et al.* (1999) and Schlundt *et al.* (2000)], and was adopted to accommodate the long-duration exposures necessary to induce TTS given the limited SPLs that could be generated at lower frequencies using the available equipment. Though not a goal of the study, the availability of received levels estimated from animal positions and sound field measurements, and those estimated from animal-borne tags allowed a limited comparison between exposure estimates from the two methods.

TTS was assessed by comparing hearing thresholds measured in individual dolphins before and after noise exposure. Thresholds were measured using behavioral (psycho-physical) methods at lower frequencies and both behavioral and electrophysiological [auditory evoked potential (AEP)] measurements at higher frequencies. The specific type of AEP measured was the transient auditory brainstem response (ABR), a short-latency AEP reflecting summed neural activity from the auditory nerve to the inferior colliculus (Ridgway *et al.*, 1981). ABR measurements were limited to frequencies > 10 kHz, where they retain cochlear place specificity in dolphins (Finneran *et al.*, 2016). A number of studies have used AEPs to measure TTS in marine mammals [e.g., Nachtigall *et al.* (2004), Mooney *et al.* (2009), Popov *et al.* (2011b), and Popov *et al.* (2011a)]; however, behavioral- and AEP-based TTS measurements have only been directly compared in two studies (Finneran *et al.*, 2007; Finneran *et al.*, 2015). Both studies involved dolphins and utilized measurements of the auditory steady-state response (ASSR) obtained when transient AEPs to rapid stimuli overlap (Stapells *et al.*, 1984). Both studies showed larger amounts of TTS for equal noise exposure conditions when measured with AEPs compared to those measured behaviorally, with one study (Finneran *et al.*, 2007) showing much higher AEP-measured TTS. AEP measurements were therefore included in the present study to

help ensure that TTS-inducing exposures were identified; i.e., the previous data suggest that exposures might affect ABR morphology, amplitudes, or latencies at levels below those capable of causing behavioral threshold shifts. Transient ABR measurements were used, rather than ASSR measurements, because transient ABRs can be obtained very rapidly and allow identification of individual waves (corresponding to different neural generators) in the response [e.g., Finneran (2017)]. A secondary goal of the study was therefore to compare behavioral- and AEP-based TTS measures from the same exposure, to augment the limited available data on this topic in marine mammals.

II. METHODS

A. Overview

A single test session (exposure or control) was conducted each day. Each session consisted of three phases: (1) pre-exposure hearing test, (2) exposure to narrowband (1/6-octave) noise presented for 1 h (exposure session), or a mock exposure consisting of exposure to ambient noise only for 1 h (control session), and (3) post-exposure hearing test(s). Noise exposures were limited to a maximum of three per week. Noise exposure center frequencies were 0.5, 2, 8, 20, 40, and 80 kHz (Table I), tested in three phases: (1) 80, 40, and 20 kHz exposure frequencies tested in descending order; (2) 8, 2, and 0.5 kHz exposure frequencies tested in descending order; (3) additional exposures at 2–80 kHz with one dolphin wearing two archival acoustic recording tags (see below).

Hearing thresholds were measured using behavioral methods (all phases) and ABR measurements (phase 1 only). At each exposure frequency, hearing tests were conducted at the center frequency of the exposure (f_0) and/or 1/2-octave above ($f_{0.5}$). Both frequencies were tested because of uncertainties as to where the largest TTS would appear: previous studies suggested that at lower exposure levels maximum TTS occurs at the exposure frequency, but for increasing exposure levels/larger amounts of TTS the maximum TTS spreads upwards towards 1/2-octave above the exposure frequency (Finneran, 2015; Kastelein *et al.*, 2019a). At each exposure frequency, testing began with relatively low SPLs and gradually increased over successive exposure sessions. Testing at a single exposure frequency

TABLE I. Fatiguing sound (FS) and hearing test parameters, pooled across the two dolphins. f_0 : FS frequency, $f_{0.5}$: 1/2-octave above FS frequency.

Order tested	FS freq. (kHz)	FS SELs (dB re 1 μPa^2 s)	Total exposures	Hearing test frequencies (kHz)		Maximum TTS (dB)	Controls	
				f_0	$f_{0.5}$		f_0	$f_{0.5}$
6	0.5	166–197	16	0.5	0.7	7.2	20	20
5	2	172–202	16	2	2.8	9.8	20	11
4	8	160–197	15	8	11.3	18.3	10	14
3	20	161–193	20	20	28	9.3	29	8
2	40	153–187	27	40	57	4.6	31	21
1	80	161–192	25	80	113	5.6	23	37

persisted until TTS of ~ 20 dB was obtained or the maximum achievable exposure source SPL was reached.

Two dolphins were tested at exposure frequencies < 80 kHz. To reduce the total number of noise exposures, both dolphins participated in the same test session each day. When one dolphin was taking a hearing test, the other dolphin quietly waited at the surface a short distance away. After a 2–3 min time interval, the dolphins were signaled to switch places, so the dolphin that had been taking a hearing test began a wait period and the other dolphin began a hearing test. The process was then repeated as necessary. At the conclusion of pre-exposure threshold testing, both dolphins swam freely in the test enclosure while the fatiguing noise exposure or mock exposure occurred. Immediately after cessation of the exposure, post-exposure testing began in a similar fashion as pre-exposure testing.

As dolphins were free-swimming during the exposures, received exposure levels were estimated from animal spatial positions obtained from overhead video recordings and fatiguing stimulus sound field measurements conducted without the dolphins present. Phase 1 testing with higher-frequency exposures showed no TTS at relatively high estimated received levels, raising concerns that the video-based noise exposure estimates were higher than the “true” exposure levels. For this reason, two archival digital acoustic recording tags (DTAG3) (Johnson and Tyack, 2003; Johnson *et al.*, 2009) were placed on the left and right sides of one of the dolphin’s head (TRO, see below) during subsequent exposure sessions to improve estimates of received exposure levels. Tags were obtained late in phase 2; for exposure frequencies where testing was already complete, a limited number of additional exposures was conducted with tags present (phase 3 testing). When tags were present, received exposure levels were taken from the tag recordings. Otherwise, received levels were estimated by applying a correction to the video-based estimate. The correction was derived from differences observed between tag recordings and video-based estimates for those exposures with tags present.

B. Subjects and test environment

Two male bottlenose dolphins (COL and TRO) participated in the experiments. Upper-frequency limits of hearing for COL and TRO were ~ 80 and 140 kHz, respectively [see American National Standards Institute (ANSI) (2018) and Strahan *et al.* (2020)]. Therefore, only TRO was tested at the 80-kHz exposure frequency. Thresholds for COL and TRO were similar at frequencies below 80 kHz. Tests were conducted between May 2018 and July 2020, within a $9\text{ m} \times 9\text{ m}$ floating, netted enclosure at the U.S. Navy Marine Mammal Program facility in San Diego Bay, California (Fig. 1). Background ambient noise at the test site was dominated by contributions from snapping shrimp, other dolphins, and passing vessels and aircraft. Median ambient noise pressure spectral density levels varied from ~ 77 dB re $1\text{ }\mu\text{Pa}^2/\text{Hz}$ at 0.5 kHz to ~ 52 dB re $1\text{ }\mu\text{Pa}^2/\text{Hz}$ at

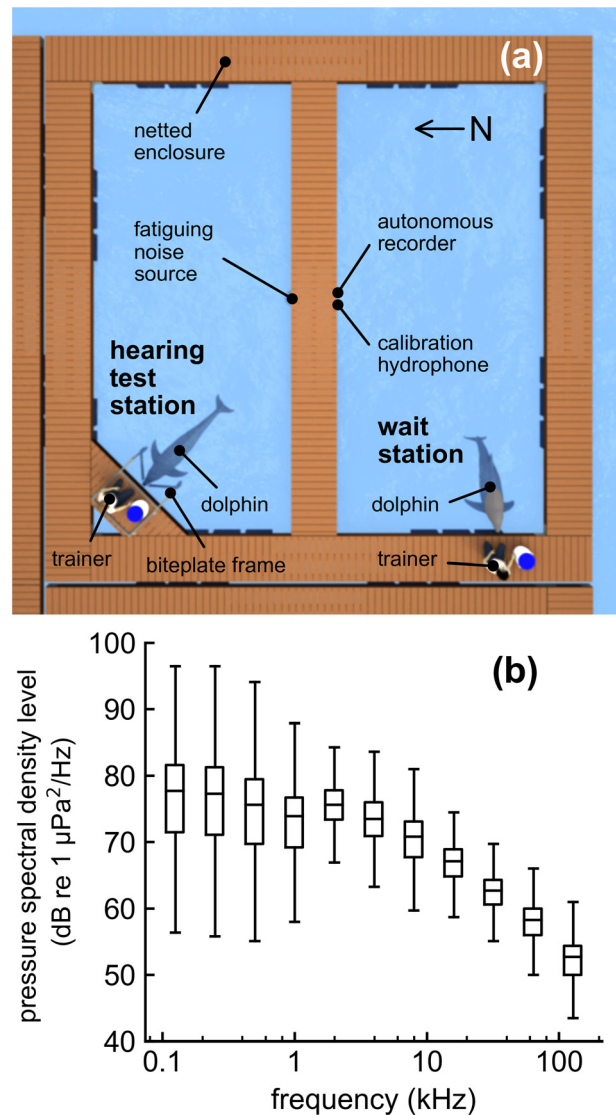


FIG. 1. (Color online) (a) Enclosure layout showing hearing test and wait stations. The enclosure size was $9\text{ m} \times 9\text{ m}$ with a floating walkway over the center. (b) Summary of ambient noise pressure spectral density levels, computed over one-octave frequency bands. Horizontal bars indicate medians, box height shows the inter-quartile range (IQR), and the bars show median ± 2 IQR.

113 kHz (Fig. 1), which is likely high enough to mask thresholds in dolphins. However, the limited data comparing masked and unmasked TTS have failed to provide a clear relationship, and at present the effects of masked threshold measurements on the resulting TTS estimates are not clear [see Finneran (2015)].

The hearing test station consisted of a submerged frame containing a “biteplate” upon which the dolphins positioned themselves at a depth of 1.4 m . A piezoelectric, underwater sound projector was suspended 1 m in front of the biteplate. The specific sound projector depended on the hearing test frequency: either International Transducer Corp (ITC) 5446, ITC 1032, ITC 1001, or Lubell Labs LL916. Hearing test tones were calibrated before each session using a miniature hydrophone (Reson TC4013) placed at the estimated

midpoint between the dolphin's lower jaws when on the biteplate. During test sessions the hydrophone was moved to the side and used to monitor background noise and the dolphin's acoustic responses.

Fatiguing noise was presented using a submerged, piezoelectric transducer placed in the center of the enclosure at a depth of 1.4 m. The fatiguing sound projector depended on the exposure frequency: either Reson TC4033 (80 kHz), ITC 1042 (80 kHz), ITC 1032 (40 kHz), ITC 1001 (20 kHz), or Lubell Labs LL1424-HP (0.5, 2, 8 kHz). The nominal source level for each noise exposure was measured before each session using a TC4013 placed at 1.4 m depth and 1-m distance from the noise projector. Source levels during the actual exposure were also recorded using an autonomous recording device (soundTrap 300 HF, Ocean Instruments, Auckland, New Zealand) placed 1-m from the noise projector, at the same depth. Sound pressures recorded from DTAGs were adjusted based on comparison calibrations with the soundTrap and TC4013 (itself calibrated with a B&K 4228 pistonphone calibrator) placed in close proximity and ensounded by the same broadband noise, so the resulting SPLs obtained from each device were within ± 1 dB.

C. Procedure

Figure 2 shows the typical daily test sequence. Each session began with behavioral threshold measurements at either f_0 or $f_{0.5}$. The order in which the frequencies were tested was varied from day-to-day (in Fig. 2, the first frequency tested is designated f_A , the second, f_B). At each hearing test frequency, the dolphins were tested in alternating time blocks as described above, with TRO always being tested first. At the conclusion of the behavioral tests, ABR measurements were conducted (phase 1 only), again in the order TRO, COL, with f_0 always tested before $f_{0.5}$. At the conclusion of ABR testing, the electrode leads were removed and the exposure began. At the conclusion of the exposure (or mock exposure period for controls), behavioral hearing tests began immediately, and alternated between TRO and COL as during pre-exposure testing; however, behavioral testing was only conducted at the last frequency tested before the exposure (designated as f_B in Fig. 2). Post-exposure ABR tests were conducted in identical fashion as pre-exposure. Additional post-exposure sessions were conducted, in similar fashion, at approximately logarithmic

time intervals (e.g., 30, 60, 120 min) until thresholds recovered to near pre-exposure values. The major deviations from Fig. 2 were (1) at 80 kHz, only TRO was tested, the test intervals were 2 min rather than 3 min, the initial post-exposure test period lasted 12 min, and only a single frequency was tested during the behavioral pre-exposure session in early testing; (2) ABR testing was only conducted during phase 1.

TTS (in dB) at specific post-exposure times was defined as the difference between the post- and pre-exposure thresholds. The primary data of interest consisted of the initial behavioral TTS measured at f_B for each subject and, if the initial TTS was sufficiently large, the recovery from TTS. ABR measurements were employed to help ensure any auditory system dysfunction was discovered, whether it resulted in behavioral threshold changes or not, and to provide comparison data between ABR- and behaviorally measured TTS.

D. Behavioral hearing tests

Behavioral hearing test methods were similar to those used during previous TTS studies in San Diego Bay (Finneran *et al.*, 2000; Finneran *et al.*, 2002; Finneran *et al.*, 2015). Behavioral hearing tests with each dolphin were conducted over 2–3 min time intervals. Each interval was divided into 2–4 “dives” where the dolphin submerged and positioned itself on the underwater biteplate and listened for hearing test tones. Within each dive, trials occurred at 2–3 s intervals. Hearing test tones were presented on 70% of the trials (signal-present trials), determined via pseudo-random schedule. The remaining 30% of the trials were signal-absent trials (no hearing test tone was presented). The dolphin's task was to produce a conditioned acoustic response within 1.25 s after onset of a hearing test tone and to remain quiet otherwise. At the conclusion of each dive, the dolphin was signaled to return to the surface to receive fish reward. The amount of reward was scaled based on the number of trials and dolphin's performance during the dive.

Hearing test stimuli were 500-ms, linear frequency-modulated tones with 5-ms rise/fall times and 10% frequency modulation. Tones were digitally synthesized then converted to analog at 1-MHz rate using a USB-6361 device (National Instruments, Austin, TX). Analog tones were low-pass filtered at 200 kHz, amplified, and applied to the sound

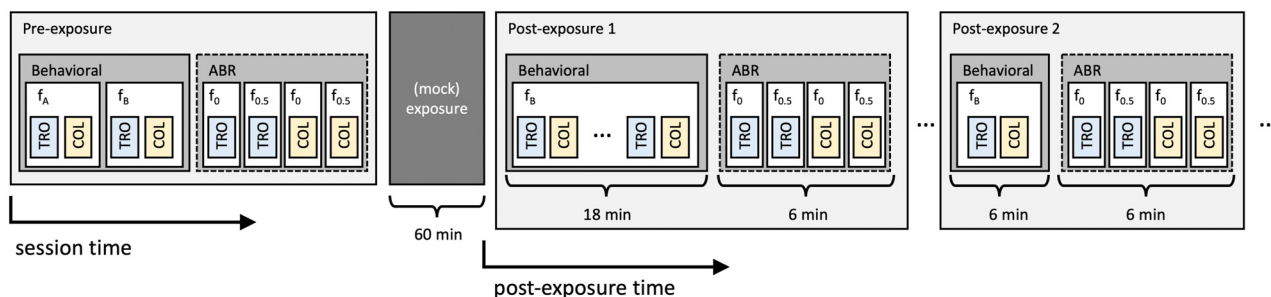


FIG. 2. (Color online) Typical daily test sequence (see the text).

projector. The first tone stimulus was presented with SPL ~ 15 dB above baseline hearing threshold at that frequency. Tone SPLs were adjusted on each subsequent signal-present trial using a staircase method (Cornsweet, 1962) with 3-dB step size. Hearing threshold was defined as the mean stimulus SPL over the last 10 reversals—transitions from a response to no response, or vice versa, over consecutive signal-present trials. The false alarm rate was defined as the number of responses during signal-absent trials, as calculated over the same trials used for threshold determination.

E. ABR measurements

ABR hearing tests were also conducted over 2–3 min test intervals divided into a number of dives. Typical dive length was ~ 1 –1.5 min. During each dive, the dolphin positioned itself on the biteplate and remained quiet while tonebursts were presented and ABRs measured. At the conclusion of the dive, the trainer signaled the dolphin to return to the surface for fish reward, then the next dive was begun if necessary.

Before the first dive, two 10-mm gold-plated, surface electrodes embedded in suction cups were placed on the dolphin: the non-inverting electrode was located on the midline, ~ 5 cm posterior to the blowhole, and the inverting electrode was placed near the right external auditory meatus. A third, common electrode was located in the seawater near the dolphin. The electrode signals were amplified (94 dB) and filtered (0.3 to 3 kHz) using a biopotential amplifier (ICP511, Grass Technologies, West Warwick, RI). For each ABR measurement, tonebursts were presented to the dolphin for 12 s while the differential voltage between the inverting

and non-inverting electrodes (the instantaneous EEG) was digitized at 100 kHz with 16-bit resolution using the USB-6361 and saved to computer disk. ABRs were obtained from the instantaneous EEG using the randomized stimulation and averaging method (Valderrama *et al.*, 2012): The time interval between successive tone burst stimulus onsets was randomized from 1 to 3 ms (uniform distribution) and ABRs were obtained by synchronously averaging 10-ms epochs of the instantaneous EEG data time-aligned with the onsets of successive stimuli (Valderrama *et al.*, 2012; Finneran, 2017). The mean stimulus interval of 2 ms and 12-s averaging time resulted in ~ 6000 epochs for each ABR.

From the averaged ABRs, peaks P4 and N5 were identified [see Popov and Supin (1990)] and the p-p amplitude P4-N5 measured. Thresholds were estimated by first fitting linear functions to each dolphin's P4-N5 data from each session, with the slope shared across all the datasets (i.e., pre-exposure and all post-exposure data from the same dolphin that day). Fitting was done using the *leastsq* function in the optimize module of the PYTHON package SCIPY (Virtanen *et al.*, 2020). Pre- and post-exposure thresholds were then defined as the peSPLs corresponding to the intersections of the best-fit lines and the x axis [i.e., the peSPL resulting in a 0-V P4-N5 amplitude, see Nachtigall *et al.* (2004)].

Toneburst stimuli consisted of 8-cycle, cosine-enveloped sine waves centered at the test frequency. Tonebursts were digitally synthesized, then converted to analog at ~ 741 kHz (1.35- μ s interval) with 16-bit resolution (National Instruments PCIe-7852R). Analog tonebursts were filtered (low-pass at 200 kHz), amplified, and used to drive an underwater sound projector. ABR measurements were

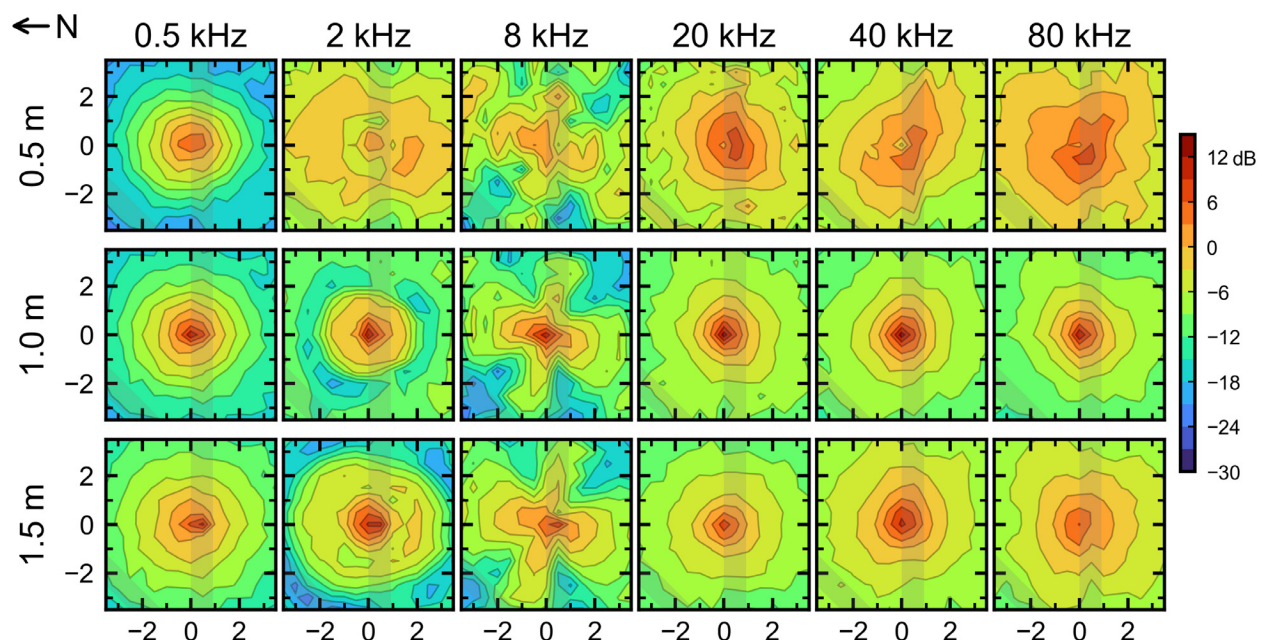


FIG. 3. (Color online) Normalized received levels measured within horizontal planes for each fatiguing noise frequency. Top, middle, and bottom rows show measurements at 0.5, 1.0, and 1.5 m depth, respectively. Ordinate/abscissa coordinates are in meters. Contour lines are spaced at 3-dB intervals. Colorbar units are SPL in dB relative to the source level measured at 1.5 m depth. The shaded regions indicate the locations of the deck spanning the enclosure (see Fig. 1).

TABLE II. Frequency-dependent correction factors applied to video-based SPL estimates to estimate the received exposure SPL when DTAG data were not available.

Exposure frequency (kHz)	Correction from nominal source level (dB)	Correction from measured source level (dB)
0.5	-6.7	-5.1
2	-10	N/A
8	-7.5	N/A
20	-18	-3.4
40	-18	-10.3
80	-17	-14.7

conducted at peak-equivalent SPLs (peSPLs) from ~ 100 to 140 dB re 1 μ Pa in 5 to 10-dB steps.

F. Fatiguing noise exposures

The fatiguing noise signal with 1/6-octave bandwidth was synthesized by digitally filtering Gaussian white noise using custom software. The digital signal was then converted to analog at 500-kHz rate using a USB-6251 (National Instruments). Analog noise was filtered (low-pass at 200 kHz), amplified, and input to the fatiguing sound projector (Table I). The sound field produced by each fatiguing source was estimated by measuring the SPL over

the 1/6-octave noise bandwidth, within horizontal planes at depths of 0.5, 1.0, and 1.5 m. Measurements were made over the entire enclosure area, using a rectangular spatial grid with 0.5-m spacing. Figure 3 shows representative examples of the normalized received levels (RLs), defined as the received SPL relative to the source level at 1 m distance and 1.5 m depth, for each noise frequency. At the maximum exposure levels, SPLs at harmonic frequencies were at least 40 dB below those at the fundamental frequency for exposure center frequencies of 8, 20, 40, and 80 kHz. At 0.5 and 2 kHz exposure frequencies, harmonics were at least 25 and 30 dB, respectively, below the fundamental.

G. Dolphin spatial position estimates

Dolphin spatial positions during each exposure and mock-exposure were estimated from overhead video recordings. For each session, still images were extracted from the video at 5-s time intervals. An observer then marked the position of each dolphin in each frame using custom software. Each dolphin was given a distinctive, temporary marking on the dorsal surface to facilitate identification. If a dolphin could not be clearly identified in a frame, its position was estimated by interpolating over previous and successive frames. Video observers were blind to the session type (exposure or control).

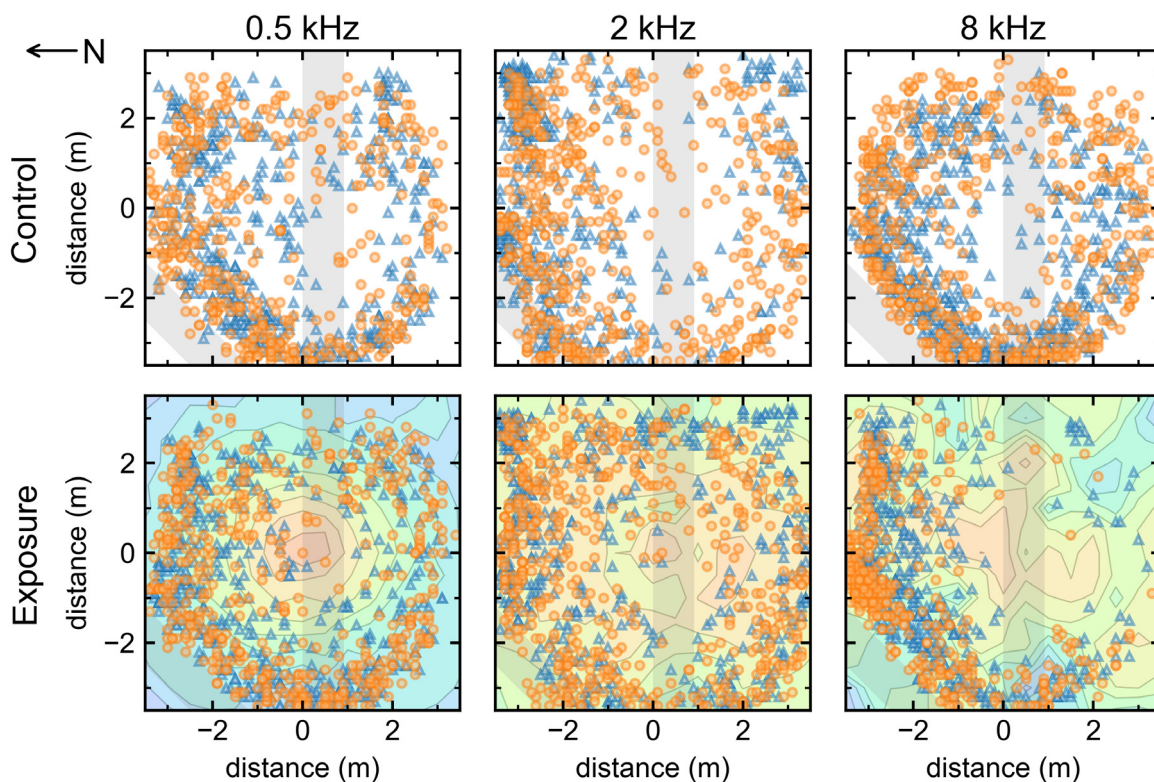


FIG. 4. (Color online) Representative examples of dolphin locations during control (upper row) and exposure (lower row) sessions during 0.5, 2, and 8 kHz testing. Each panel shows the data from a single session. Data for dolphins COL and TRO are shown as triangle and circles, respectively. Noise sound field contours are shown for comparison (see Fig. 2). The shaded regions indicate the locations of the decks spanning the enclosure (see Fig. 1). During both control and exposure sessions, dolphins tended to swim around the periphery of the enclosure, with more time spent towards the north and west sides (left and bottom, respectively, as pictured; these sides faced the other enclosures at the facility). The tendency to spend time more time towards the north/west sides increased during the 8-kHz exposures.

H. Noise exposure estimates

When possible, SELs for the actual noise exposures were calculated from both the soundTrap located near the source and the DTAGs worn by TRO. The calculation procedure was identical: The noise mean square pressure was first calculated every 5 s by integrating the pressure spectral density over the 1/6-octave noise bandwidth of the noise. Data from the two hydrophones on each DTAG tag were averaged. The mean square pressures were then integrated over the duration of the exposure to obtain the exposure source SEL. If recordings were obtained from both tags, the mean SEL was utilized (the average SPL differences between the two tags was always < 2 dB).

The noise SEL received by a dolphin during an exposure session was estimated in one of three ways. If DTAGs were present, the received SEL calculated from the DTAGs was used. If tags were not present, the received SEL was estimated by combining estimates of dolphin spatial positions, normalized RL measurements at 0.5-m depth (based on the dolphins' typical depths during sessions), and the source level. The source level was based on the soundTrap recording, if available. If not, the nominal source level

(based on the daily calibration) was used. The video-based exposure estimate was then adjusted using the average difference (at that same frequency) between DTAG exposure measurements and video-based estimates for those exposures where DTAGs were present. Correction factors (see Table II) were always negative (i.e., DTAG measurements were lower than video-based estimates) and tended to increase in magnitude as frequency increased. As a consistency check, received SELs from video-based exposure estimates were compared to the actual DTAG data (when available). The comparison showed agreement within ± 2 dB at all frequencies except 80 kHz, where agreement was within ± 4 dB.

III. RESULTS

A. Dolphin positions and noise exposures

Figure 4 shows representative examples of dolphin positions during control and exposure sessions. During both control and exposure sessions, the dolphins tended to swim around the periphery of the enclosure, with more time spent along the north and west sides of the enclosure—the sides

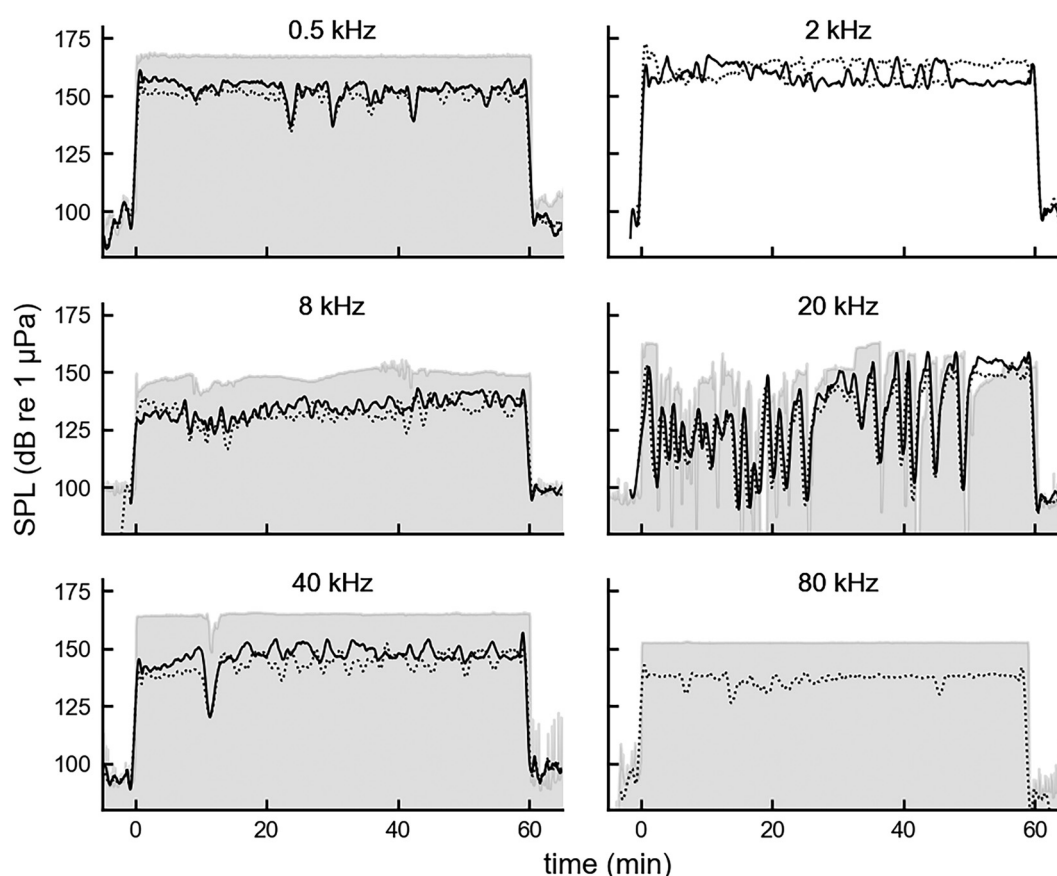


FIG. 5. Examples of exposure SPL recorded during individual sessions, from archival sound recording tags (DTAGs) worn by TRO. The solid and dotted lines show recordings from the DTAGs on the left and right sides, respectively (at 80 kHz, only the right tag was available). The gray shaded region shows the exposure SPL measured from the soundTrap (not available for the 2-kHz example). SPLs were computed from the instantaneous pressures every 5 s. For visualization, the SPLs were smoothed using the Savitzky-Golay filter implemented in the PYTHON package SCIPY (Virtanen *et al.*, 2020). DTAG-based SPLs tended to be lower and more variable than the source level from the autonomous hydrophone located near the fatiguing source [see Fig. 1(a)]. The extreme variability at 20 kHz was a result of the dolphins high-speed swimming and tail-slapping near the source.

facing the other enclosures at the facility (as opposed to the East and South sides facing San Diego Bay). This tendency increased during the 8-kHz exposures. During some higher-level exposures at 2, 8, 20, and 40 kHz, the dolphins also tail-slapped the water surface while they swam about the enclosure.

Figure 5 shows examples of the SPL recorded during exposures using the soundTrap and the DTAGs worn by TRO. Source levels were generally constant during exposures except during bouts of tail-slapping, where it was common to see drops in the measured SPLs (seen in the 8-, 20-, and 40-kHz examples), presumably due to entrained air bubbles near the projector. The 20-kHz data represent an extreme example where the dolphins often tail-slapped and swam fast around the enclosure, dramatically affecting the fatiguing sound levels.

B. Auditory effects of noise

1. Behavioral measurements

Initial behavioral post-exposure hearing thresholds were obtained at average times of 2 min for TRO and 5 min

for COL. Since estimated exposure SELs varied from the nominal exposure on a case-by-case basis, data were pooled (where possible) to estimate mean TTS as a function of exposure SEL. The SEL bin-edges used for pooling were determined using the Fisher-Jenks algorithm as implemented in the “jenksy” PYTHON package (GitHub, 2023). Within each bin containing multiple exposures, the exposure SELs and the resulting TTSs were averaged. Though not ideal from a fitting perspective, the sparse data and variability in exposure SEL resulting from estimating individual exposures from moving animals necessitated some compromise, and similar procedures have been previously used for estimating TTS growth functions [e.g., Finneran *et al.* (2005)]. Datasets with maximum TTS ≥ 6 dB were fit with the function

$$t(L) = m_1 \log_{10} [1 + 10^{(L-m_2)/10}], \quad (1)$$

where t is the amount of TTS, L is the SEL, and m_1 and m_2 are fitting parameters (Maslen, 1981). Fitting was accomplished using the *curve_fit* function in the optimize module of the PYTHON package SCIPY (Virtanen *et al.*, 2020).

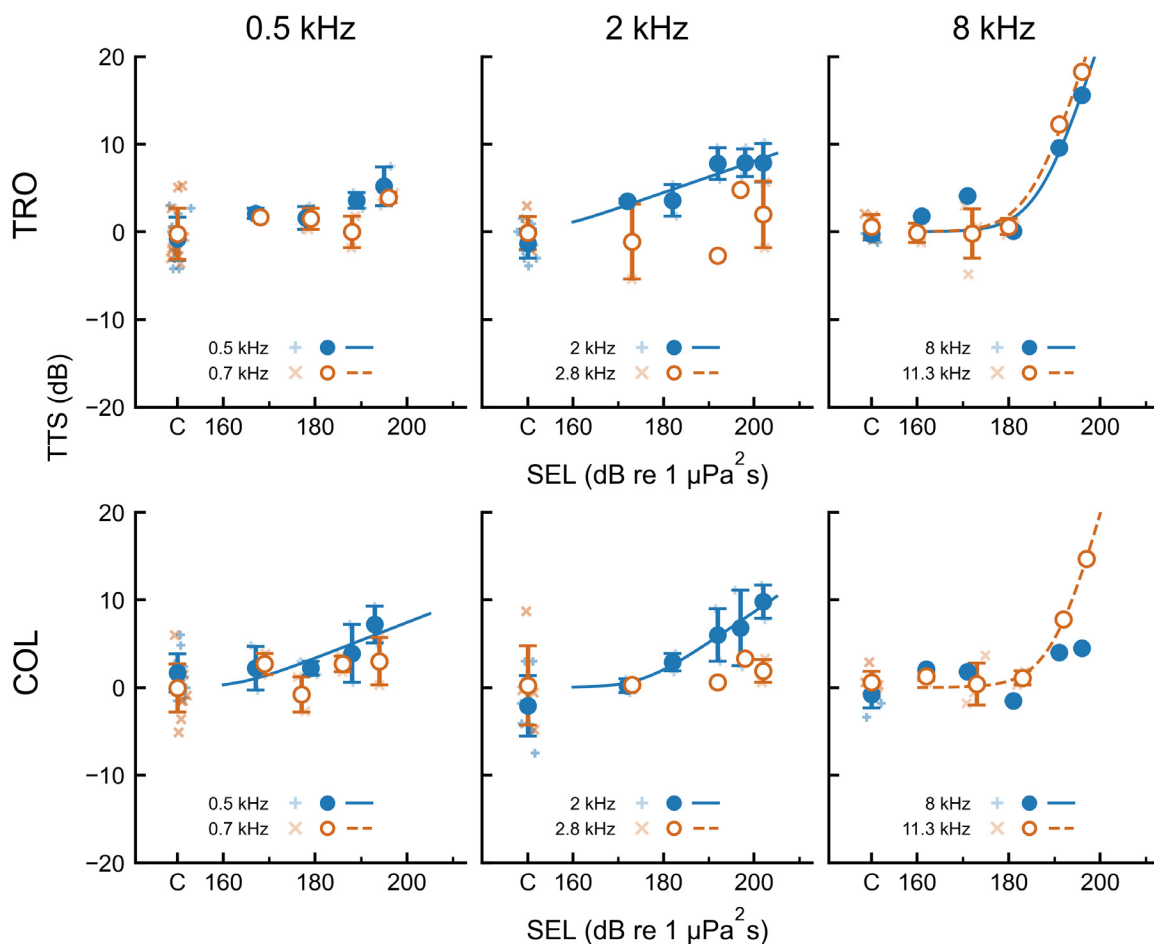


FIG. 6. (Color online) Growth of initial TTS as a function of exposure SEL for the dolphins TRO (top row) and COL (bottom row), for exposure frequencies of 0.5, 2, and 8 kHz. Each column shows data from a different exposure frequency. Plus signs and $\times$'s show individual TTS measurements. These values were averaged after pooling exposure SELs as described in the text. Open and filled circles represent mean values for the two hearing test frequencies. Error bars show the mean ± 1 standard deviation. Control data are displayed at the abscissa position labeled “C.” For datasets with maximum TTS ≥ 6 dB, the lines show the best-fit of Eq. (1) to the mean values.

Interpolation was then used to estimate SELs required for “TTS onset,” defined as TTS of 6 dB.

Figures 6 and 7 show behaviorally measured TTS as a function of SEL for 0.5, 2, and 8 kHz (Fig. 6) and 20, 40, and 80 kHz (Fig. 7). In general, measured TTS was small and there were no clear patterns with respect to hearing test frequency, however mean TTS measured at the exposure frequency tended to be higher than that measured 1/2-octave above the exposure frequency. The exception was 8 kHz, where mean TTSs exceeded 10 dB for both COL and TRO and TTS at 11 kHz was larger than at 8 kHz. Few effects were seen at the highest exposure frequencies (40 and 80 kHz). Figure 8 compares “onset-TTS” exposure levels from the present study to those measured in *Tursiops* by Finneran and Schlundt (2013) and specified in current U.S. National Marine Fisheries Service (NMFS) guidelines (National Marine Fisheries Service, 2016, 2018). Onset-TTS SELs from the present study at 2, 8, and 20 kHz were within ± 6 dB of those previously measured in a quiet pool at similar frequencies. Present values were also within ± 10 dB of the predicted TTS exposure function, except for the values

for COL at 500 Hz, where the present data were ~ 24 dB below the predicted curve.

Figure 9 shows recovery from TTS for those individual measurements with initial TTS > 6 dB. The recovery data in Fig. 9 were fit [SCIPY *curve_fit* function (Virtanen *et al.*, 2020)] with the equation

$$TTS(t) = TTS_4 - m \log_{10}(t/4 \text{ min}), \quad (2)$$

where t is the recovery time (in min), $TTS(t)$ is the TTS (dB) at time t , TTS_4 is the TTS (in dB) at $t = 4$ min, and m is the recovery rate (dB/decade). For fitting, only data with $TTS > 2$ dB were included. The fits were generally good, with mean $R^2 =$ between 0.72 and 0.89, depending on exposure frequency, except for 40 kHz, where mean $R^2 = 0.54$. Datasets with larger amounts of initial TTS typically resulted in better fits (higher R^2). Recovery rates (m , magnitudes of the slopes of the best-fit lines in Fig. 9) varied over a wide range, from 1.4 to 11 dB/decade, and tended to increase linearly with TTS_4 at most exposure frequencies (Fig. 10) at a rate of ~ 1 –2 dB/decade per dB.

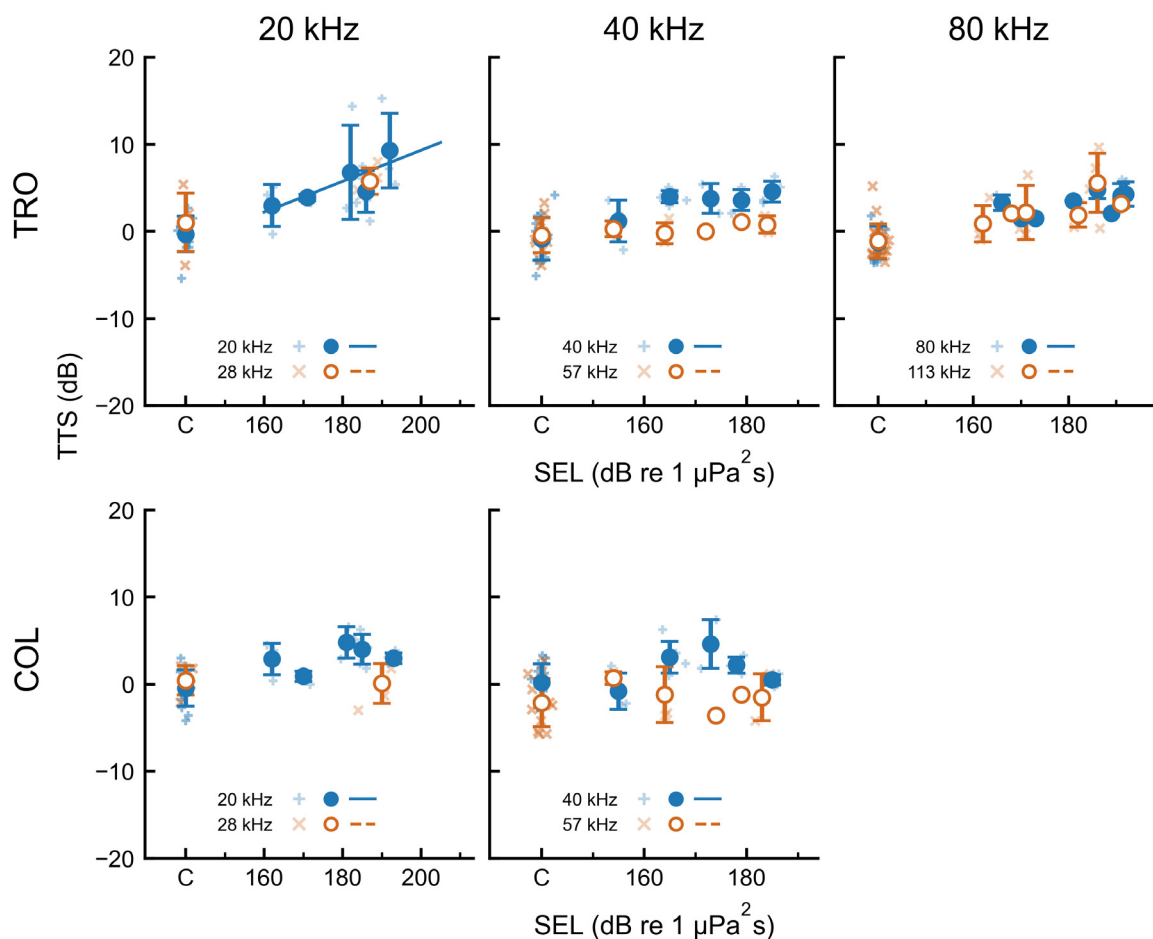


FIG. 7. (Color online) Growth of initial behaviorally measured TTS as a function of exposure SEL for the dolphins TRO (top row) and COL (bottom row), for exposure frequencies of 20, 40, and 80 kHz (COL was not tested with 80-kHz exposures). Plus signs and $\times$'s show individual TTS measurements. These values were averaged after pooling exposure SELs as described in the text. Open and filled circles represent mean values for the two hearing test frequencies. Error bars show the mean ± 1 standard deviation. Control data are displayed at the abscissa position labeled “C.” For datasets with maximum TTS ≥ 6 dB, the lines show the best-fit of Eq. (1) to the mean values.

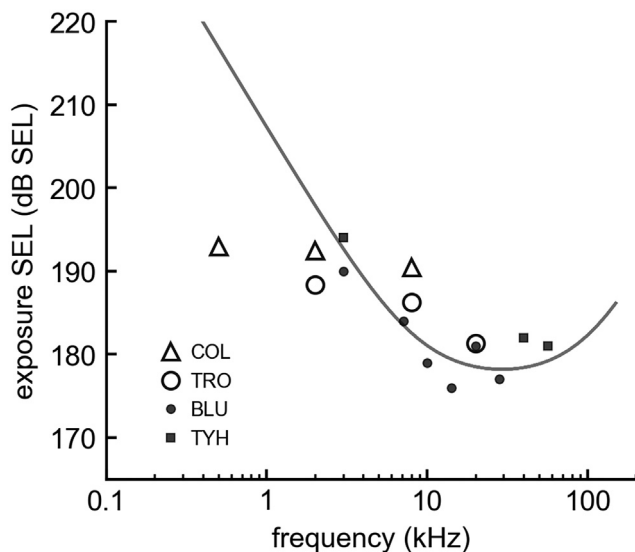


FIG. 8. “Onset-TTS” exposure levels from the present study compared to current U.S. National Marine Fisheries Service (NMFS) guidelines (National Marine Fisheries Service, 2016, 2018). Open symbols show exposure SELs required for 6 dB of behavioral TTS from the present study, determined by interpolating within the TTS growth curves in Figs. 6 and 7. For TRO at 8 kHz, where TTS growth curves were obtained at both hearing test frequencies, only the lowest TTS onset is shown. Filled symbols show TTS onset values from Finneran and Schlundt (2013), for dolphins BLU and TYH exposed to 16-s pure tones in a quiet pool. The solid line shows NMFS guidelines for TTS onset SELs (National Marine Fisheries Service, 2016, 2018).

2. ABR measurements

Figure 11(a) shows an example of ABR waveforms measured at 28 kHz in TRO, before and after a 20-kHz exposure with SEL of 190 dB re $1 \mu\text{Pa}^2\text{s}$. ABR signal quality was generally good (i.e., peaks were typically easily discernable above residual background noise), and waveform morphologies were as expected. Figure 11(b) shows ABR P4-N5 amplitude as a function of stimulus SPL for the waveforms in Fig. 11(a), along with the best-fit lines with shared slope.

Figure 12 shows the TTS obtained from ABR measurements as a function of exposure SEL. As with the behavioral data (Figs. 6 and 7), data were pooled across SELs using the Fisher-Jenks algorithm to determine SEL bin-edges (GitHub, 2023). Within each bin containing multiple exposures, exposure SELs and TTSs were averaged and datasets with maximum TTS ≥ 6 dB were fit with Eq. (1). Measured ABR TTS was highly variable and generally small, with mean TTS ≥ 6 dB only seen after 20-kHz exposures. Differences between TTS measured at the exposure frequency and 1/2-octave above were small, in part due to the overall small amounts of TTS. Correlation between TTS measured behaviorally and with ABRs was weak (Fig. 13) and ABR-measured TTS was typically lower and more variable than that measured behaviorally for the same exposure.

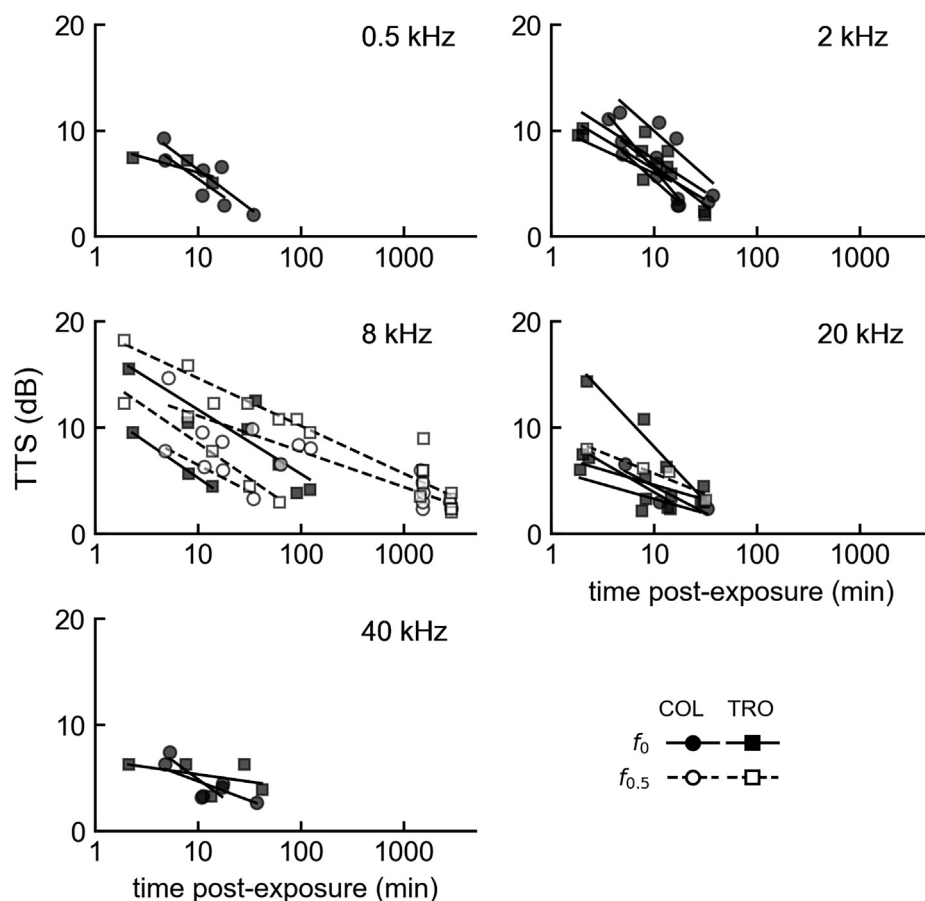


FIG. 9. TTS recovery functions for exposure frequencies of 0.5, 2, 8, 20, and 40 kHz (noted in each panel), for data with initial behaviorally measured TTS ≥ 6 dB. Data for COL and TRO are represented by circles and squares, respectively. Filled and open symbols show data measured at the exposure frequency and one-half octave above the exposure frequency, respectively. Solid and dashed lines show best-fits of Eq. (2) to the data points with TTS > 2 dB.

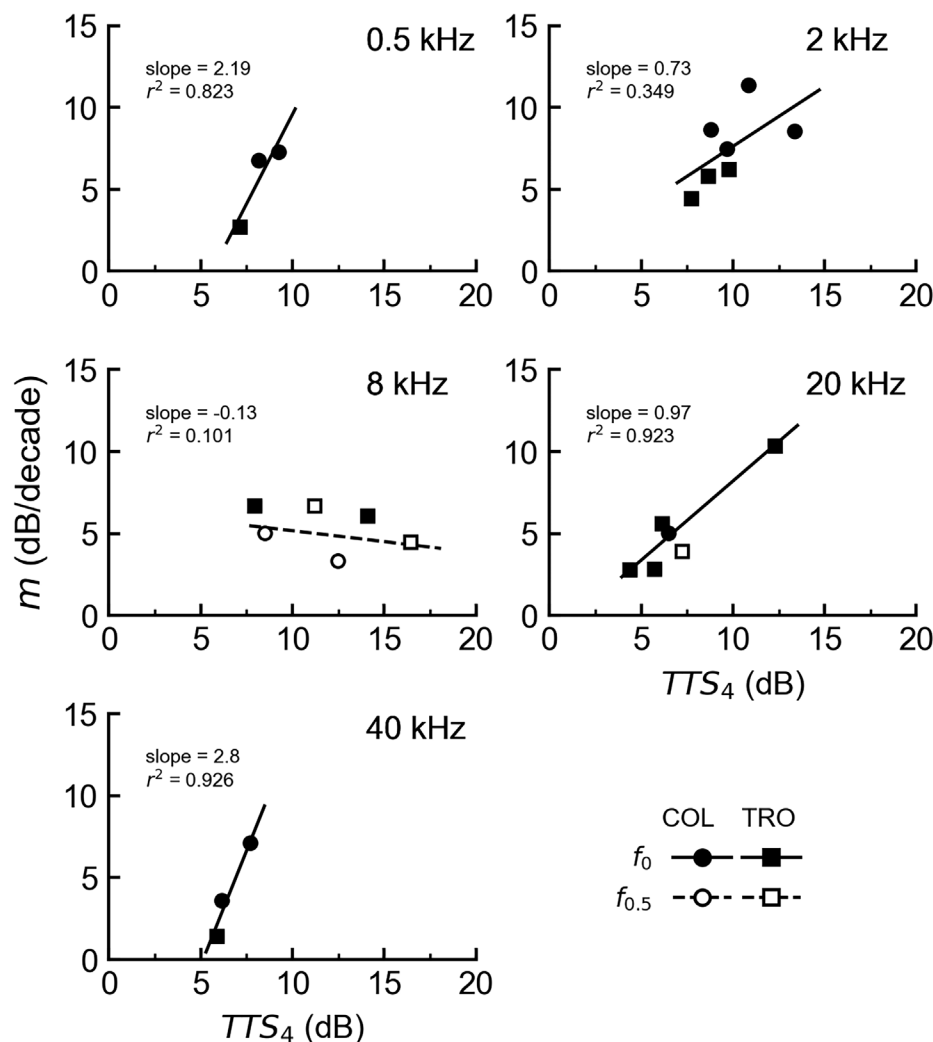


FIG. 10. Magnitude of slope (m) of best-fits of Eq. (2) to the behaviorally measured TTS recovery data (Fig. 9) as functions of TTS_4 , for exposure frequencies of 0.5, 2, 8, 20, and 40 kHz. At each exposure frequency, linear regression was performed; the resulting slope and goodness-of-fit (r^2) values are shown in each panel.

IV. DISCUSSION

A. TTS onset versus exposure frequency

The main goal of the present study was to determine the SEL required for 6 dB of TTS at a number of different exposure frequencies in bottlenose dolphins. The resulting data allowed estimates of TTS onset SELs in at least one dolphin for frequencies of 0.5, 2, 8, and 20 kHz. From 2 to 20 kHz the present data are similar (within ± 6 dB) to previously reported TTS onset SELs for dolphins exposed to 16-s pure tones in a quiet pool [Finneran and Schlundt (2013); Fig. 8], and generally follow the predicted values for TTS onset as a function of frequency [i.e., within 5–10 dB of the predicted TTS exposure function (National Marine Fisheries Service, 2016, 2018)]. At 0.5 kHz, however, the TTS onset obtained from COL in the present study (193 dB SEL) is much lower (~ 24 dB) than the predicted TTS exposure function, which was derived from TTS data in dolphins and belugas (Finneran, 2016; National Marine Fisheries Service, 2016). At that time, TTS onset data did not exist below 3 kHz for these species.

At 0.5-kHz, $TTS \geq 6$ dB was only observed for COL; however, TTS growth with increasing SEL can be seen for

both TRO and COL. The maximum TTS for TRO was 5 dB at an exposure of 195 dB SEL, thus it seems likely that if higher exposure levels could have been tested, onset TTS would have been reached in TRO at SELs only slightly higher than those for COL (and still much lower than the predicted exposure function). Exposure sound fields at 0.5 kHz were “well-behaved” in terms of spatial fluctuations and showed the smallest deviations between exposed levels estimated from video and those measured with the DTAGs (Table II). Therefore, there is no reason to suspect that exposure levels at 0.5 kHz were significantly under-estimated. The present data at 0.5 kHz therefore indicate that the predicted exposure function significantly over-estimates TTS onset at 0.5 kHz and should be adjusted accordingly in future applications.

At 40 and 80 kHz, present data showed no substantial TTS (i.e., mean $TTS < 6$ dB). At 40 kHz, maximum exposure SELs (185 dB SEL) were only slightly above TTS onset SELs previously measured for TYH in a quiet pool (182 dB SEL). At 80 kHz, maximum SELs were 191–192 dB SEL, well-above the predicted exposure function. Recent TTS studies with harbor porpoises using a similar paradigm [free-swimming animals exposed to narrowband noise for

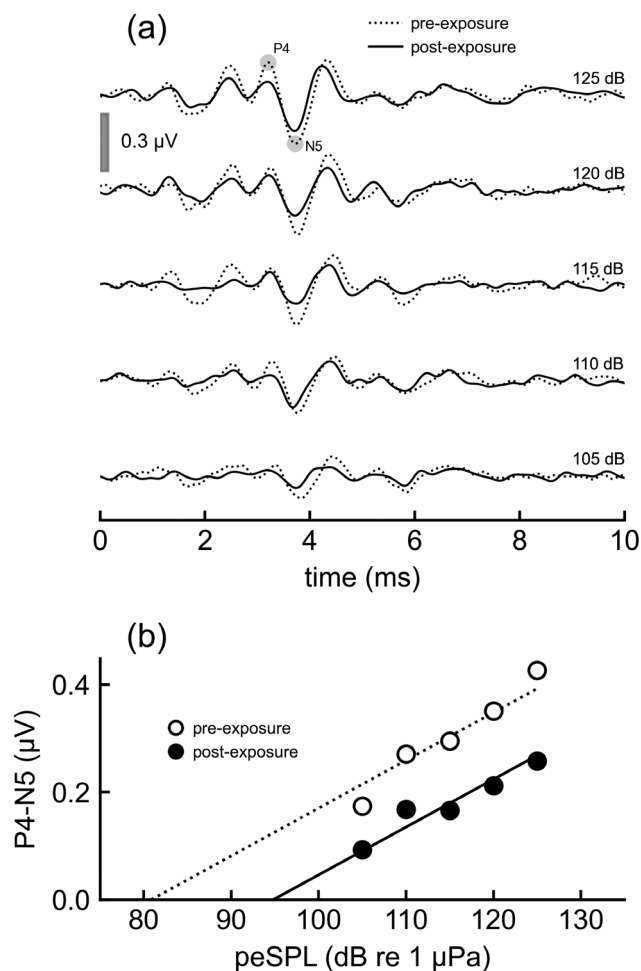


FIG. 11. (a) Example ABR waveforms measured from TRO in response to 8-cycle tonebursts at 28 kHz before and after a 20-kHz exposure. The numbers near each trace indicate the peSPL. Peaks P4 and N5 are indicated with shaded circles on the top trace for the pre-exposure data. (b) Input-output (I/O) functions showing P4-N5 amplitudes for the ABRs in (a). Thresholds were estimated by fitting linear functions to the data using a shared slope. Since the lines are parallel, the amount of TTS (i.e., difference between pre- and post-exposure thresholds) equals the horizontal offset between the best-fit lines.

60 min (Kastelein *et al.*, 2019b; Kastelein *et al.*, 2020a; Kastelein *et al.*, 2020b)] have also resulted in relatively high TTS onsets at 32–88 kHz compared to predictions based on behavioral data, and AEP-measured TTS onsets in a similar species (Yangtze finless porpoise) that were stationary (Popov *et al.*, 2011a). It is not clear whether the harbor porpoise data indicate a lower susceptibility to NIHL at these frequencies, or if the exposure estimates were affected by the free-swimming paradigm (see below). Given the relatively high deviations between video- and DTAG-based exposure estimates in the present study, and greater possibility of directional effects and shadowing at the higher frequencies, there is more uncertainty as to the “true” exposure levels, and it is possible that the exposure levels at the highest frequencies were over-estimated. Therefore, adjustment of the exposure function for dolphins and related species upward in light of the present data at 80 kHz does not appear

justified at this time and would require additional data to support the higher TTS onset. The most useful data would be comparisons of received levels estimated from sound field maps and animal positions and those estimated from animal-borne tags, and comparison of TTS induced in stationary animals compared to that in free-swimming animals with the same estimated exposures.

B. TTS recovery

TTS recovery curves derived from behavioral data followed the expected pattern (Finneran, 2015), with the amount of TTS decreasing proportionally with the logarithm of time post-exposure. Recovery rates—magnitudes of the slopes of linear-log fits to the recovery data—typically increased with initial TTS, and were similar to those previously reported: $m \simeq 5\text{--}10$ dB/decade for $\text{TTS}_4 = 5\text{--}15$ dB (Finneran, 2015). The exception was the 8-kHz data, where recovery rates were ~ 5 dB/decade and independent of TTS_4 . The reason for this difference is not known. The 8-kHz data were unique in requiring 24-h post-exposure testing, which resulted in a large gap in post-exposure test times (e.g., no tests between ~ 180 and 1400 min post-exposure). Accurate determination of final recovery times was also affected by the inherent variability in thresholds resulting from ambient noise. It is possible that these factors contributed to producing shallower slopes for the fits to the recovery data with higher TTS_4 .

C. ABR results

Previous measurements showed changes in ABRs at exposure levels below those causing behaviorally measured TTS (Finneran *et al.*, 2007; Finneran *et al.*, 2015). ABR measurements in the present study were therefore viewed as a supplement to the behavioral data, and the ABRs could be used as an “early warning” and indicate that exposure levels were approaching those capable of causing behavioral TTS, even if the ABRs were measured at longer post-exposure times. In practice, however, ABR measurements in the present study provided only limited value. ABR data were highly variable, making it difficult to evaluate differences between pre- and post-exposure ABR thresholds from individual measurements. Only when the data were aggregated (e.g., Fig. 12) could trends with noise SEL be identified. It is not clear to what extent the high variability is simply a characteristic of ABR amplitude metrics, caused by ambient noise, or related to the specific ABR test methodology.

Comparison of ABR- and behaviorally measured TTS after 20-kHz exposures yields mixed results. For TRO, ABR TTS onsets were 186 and 183 dB SEL at 20 and 28 kHz hearing test frequencies, respectively. Behavioral TTS onset was 181 dB SEL at 20 kHz, lower than the ABR value. For COL, no behavioral TTS was observed up to 190–193 dB SEL; however, ABR TTS onset was 189 dB SEL. In contrast to the prior study with narrowband exposures where TTS measured with ASSRs was much larger than that measured behaviorally (Finneran *et al.*, 2007), no consistent

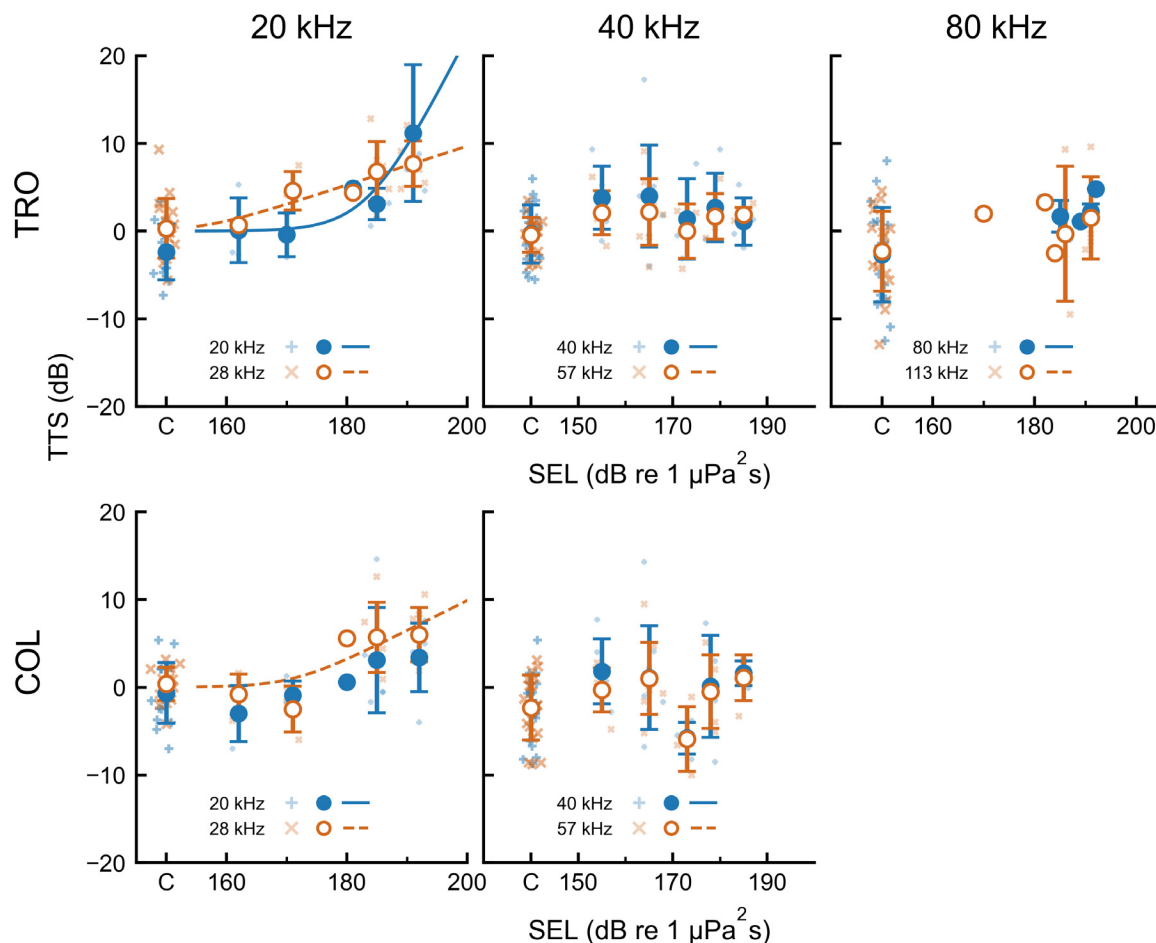


FIG. 12. (Color online) Growth of initial ABR-measured TTS as a function of exposure SEL for the dolphins TRO (top row) and COL (bottom row), for exposure frequencies of 20, 40, and 80 kHz (COL was not tested with 80-kHz exposures). Each column shows data from a different exposure frequency. Plus signs and $\times$'s show individual TTS measurements. These values were averaged after pooling exposure SELs as described in the text. Open and filled circles represent mean values for the two hearing test frequencies. Error bars show the mean $\pm$ 1 standard deviation. Control data are displayed at the abscissa position labeled "C." For datasets with maximum TTS $\geq$ 6 dB, the lines show the best-fit of Eq. (1) to the mean values.

relationship was seen between the ABR- and behaviorally measured TTS onset, and ABR-measured TTS magnitudes were typically lower than behaviorally measured TTS (Fig. 13). Some differences were likely caused by the difference in post-exposure times (2–5 min for behavioral, $\sim$ 20–25 min for ABRs), which likely reduced the amount of ABR TTS. The ABR methodology was also different than that utilized in prior studies. Here, transient ABRs were measured using tone burst stimuli presented at rapid rates (and thus were influenced to some extent by adaptation). Prior studies utilized repetitive tonebursts or sinusoidal amplitude modulated tones, which produce the ASSR rather than a transient ABR [e.g., Nachtigall *et al.* (2004), Finneran *et al.* (2007), Mooney *et al.* (2009), Popov *et al.* (2011b), and Finneran *et al.* (2015)]. It is possible that the relatively high stimulus levels required for testing given the ambient noise resulted in broad cochlear excitation patterns near threshold, which made the ABR measurements less affected by low-levels of auditory fatigue. Post-exposure ABR peak latencies often showed little change, or even decreased relative to pre-exposure values, despite large

changes in ABR amplitude [see Fig. 11(a)]. This may indicate that post-exposure ABRs were primarily arising from a more-basal cochlear region (Finneran *et al.*, 2016). Future studies comparing TTS measurements using different methodologies, or measurements made in conjunction with high-pass masking noise (to restrict the ABR cochlear place) would clarify this.

D. Effects of hearing test frequency

Hearing tests were conducted at both the exposure frequency (f_0) and 1/2-octave above the exposure frequency ($f_{0.5}$) to ensure any meaningful TTS was identified. Although TTS at f_0 was often slightly higher than at $f_{0.5}$, overall there were few differences between the amounts of TTS measured at the two frequencies, and TTS at $f_{0.5}$ was small (Figs. 6, 7, and 12). The main exceptions occurred at 8 kHz, where TTS at $f_{0.5}$ was relatively large and exceeded that at f_0 . Given the relatively low amounts of TTS, the present data are consistent with previous observations: TTS at f_0 is typically higher at lower exposure levels but as

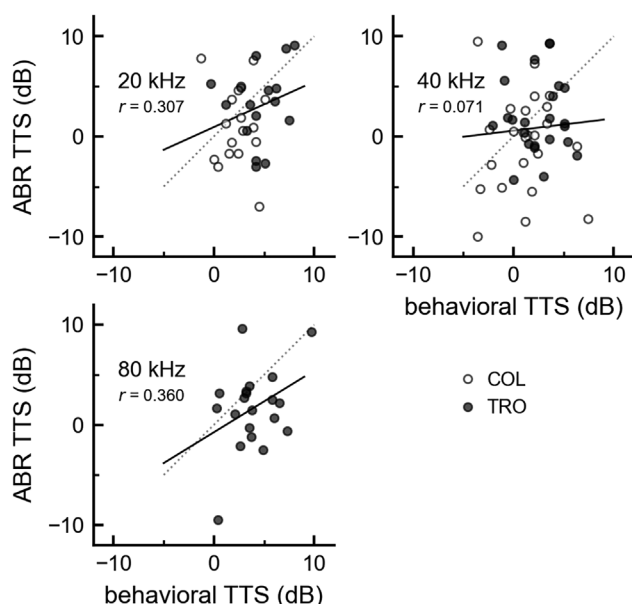


FIG. 13. Relationship between TTS measured behaviorally (abscissa) and with ABRs (ordinate) for COL and TRO at exposure frequencies of 20, 40, and 80 kHz. ABR measures of TTS were typically lower and exhibited more variability than behavioral measures. The solid line shows the best linear fit to the data. The dotted line has a slope of 1 dB/dB for comparison.

exposure level increases, TTS at $f_{0.5}$ eventually dominates (Kastelein *et al.*, 2014).

E. Estimating exposure levels in moving animals

The main methodological challenge in the present study was estimating exposure levels received by the moving dolphins. In our previous work, maximum exposure durations were either short enough that animal movement was not an issue [e.g., Schlundt *et al.* (2000)], or dolphins wore hydrophones so the actual received level could be computed [e.g., Finneran and Schlundt (2013)]. Here, the 1-h exposure duration and free-swimming animals created significant issues in determining the effective exposure level. For most frequencies—especially the higher frequencies—the measured exposure sound fields (without dolphins present) were well-behaved; however, as frequency increased the discrepancy between the exposure levels received on the DTAG and those estimated from video increased. It seems likely that depth had a major impact on the received level. Based on observations of the dolphins, we used to shallowest depth (0.5 m) at which measurements were made to estimate received level. However, actual depth could not be determined from the overhead video, and it is possible that the dolphins spent significant time at depths < 0.5 m. Since measured sound levels increased with depth, the true exposure levels may have been lower than the video-based estimates. Shadowing effects from the dolphin's body could have also affected received levels at each ear (see Fig. 5). Finally, it is likely that free-swimming animals will attempt to mitigate noise exposures by avoiding areas of relative high sound level and instead spending their time where received levels are lower. There is evidence of such behavior in a previous

study, where dolphins turned their heads just before each impulsive noise exposure, presumably to mitigate the effects of the exposure (Finneran *et al.*, 2015). At 20 kHz in the present study, dolphin rapid swimming and tail-slapping behaviors near the fatiguing source appeared to dramatically reduce measured source levels and received DTAG levels (Fig. 5), suggesting the swimming movements may have been intended to lower the received sound level. These factors all make estimating received exposure levels from moving animals problematic, thus future studies should attempt to keep animals stationary to the greatest extent possible. If this is not possible, animal-borne hydrophones should be used to estimate received level.

V. CONCLUSIONS

- Current regulatory guidelines for underwater noise exposures likely under-estimate impacts to dolphins and similar species at low frequencies (i.e., below ~ 1 kHz), and should be updated to incorporate new data.
- Relationships between ABR- and behaviorally measured TTS are not well-understood and may depend on the specific ABR measurement methodology.
- Accurate estimation of received noise levels in free-swimming animals is difficult, and future TTS studies should attempt to utilize stationary animals.

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