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International policy, recommendations, actions and mitigation efforts of anthropogenic underwater noise

Emily Chou [a,*], Brandon L. Southall [b], Martin Robards [c], Howard C. Rosenbaum [a]

[a] *Wildlife Conservation Society, Ocean Giants Program, 2300 Southern Blvd., Bronx, NY, 10460, USA*
[b] *Southall Environmental Associates, Inc., 9099 Soquel Dr., Aptos, CA, 95003, USA*
[c] *Wildlife Conservation Society, Arctic Beringia Program, 3550 Airport Way, Suite 5, Fairbanks, AK, 99709, USA*

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ABSTRACT

Anthropogenic underwater noise levels have generally increased as industrial activities in the ocean have become more prevalent. Because of the central nature of sound in the lives of many marine animals, and the known and potential adverse impacts of noise, it is also gaining increased international recognition as an important global conservation issue. Here, a current compilation and synthesis of official documents, reports, and strategic plans from various intergovernmental, governmental, and international organizations, and noise-related projects and programs, demonstrate increasing efforts to understand anthropogenic underwater noise, and the mitigation and management measures that are being considered to reduce noise. While some entities aim to better understand and quantify underwater noise and its impacts, others have recommended explicit mitigation measures including spatio-temporal approaches to managing noise sources, and vessel quieting technologies. New approaches also include the development of certification or voluntary noise-reduction programs and agreements. We highlight four considerations that will better link the potential impacts of noise with corresponding mitigation and noise reducing efforts: 1) collaboration to address the transboundary and cumulative nature of underwater noise; 2) differing countries' implementation capabilities for addressing noise; 3) time and intensity tradeoffs (e.g., louder noise for a shorter time period versus quieter but for longer); and 4) variable noise impacts depending on specific life history stages and life functions. Our review affirms the international consensus that anthropogenic underwater noise is a currently pervasive yet relatively transient form of pollution, the effects of which can be significantly reduced through effective mitigation and regulatory action.

1. Introduction

Sound is centrally important for many marine taxa as hearing is among the most vital of the senses for underwater life (Tyack, 1998; Hildebrand, 2005; Hawkins and Popper, 2017; Southall, 2017). Sound is critical to foraging, communication, predator avoidance, and general spatial orientation for marine mammals, fish, sea turtles, and invertebrates (Tolimieri et al., 2000; Staaterman et al., 2012; Williams et al., 2015). Though noise originating from non-human biological sources (e.g., communication among animals) and physical processes (e.g., waves or movement of sea ice) has always been prevalent in the underwater soundscape; since the industrial age, anthropogenic (human-generated) underwater noise (referred to here as "noise") has been increasing (NRC, 2003; Hildebrand, 2009). Noise adds to an already acoustically dynamic ocean soundscape, with impacts to marine species that can range from masking of communication signals (Clark et al., 2009; Hatch et al., 2012), to physiological stress (Wright et al., 2007; Nichols et al., 2015), to permanent and sometimes lethal damage (D'Amico et al., 2009; Weilgart, 2017). For reviews on marine mammal responses to anthropogenic noise, see Nowacek et al. (2007), Weilgart (2007), and Southall (2017).

Noise sources from industrial activities can generally be split into two categories: 1) incidental, and 2) deliberate noise. Incidentally radiated noise sources include those generated from such activities as commercial vessel traffic, ice breakers, oil and gas drilling activities, and marine construction (e.g., pile driving, dredging). In contrast, deliberately radiated noise sources include those from defense-related tactical sonar systems, airguns associated with oil and gas seismic surveys, and a wide variety of navigational sonars and imaging echosounders. As the prevalence and power of these human-generated noise sources continue

* Corresponding author.
E-mail address: echou@wcs.org (E. Chou).

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to increase (e.g., NRC, 2003; Hildebrand, 2009; Nowacek et al., 2015), potential and actual impacts to ocean life are also increasing, as recognized within the scientific community (NRC, 2005; Southall et al., 2017, 2019) and increasingly within international conventions and other fora (e.g., Convention on Biological Diversity, Convention on Migratory Species, International Whaling Commission, International Maritime Organization).

This increasing human acoustic footprint within a naturally noisy ocean can add both acutely intense noise stressors, and more subtly, another cumulative stressor in the context of other global factors such as climate change, ocean acidification, overfishing, and entanglement. Considering these concerns and the magnitude of recent attention on the issue of noise, learning how different organizations and governments are addressing noise, through various actions, recommendations, policies, and mitigation measures, can be helpful for coordinating how to collectively effect real action to reduce acoustic impacts on marine life and the environment.

Awareness and recognition of ocean noise impacts on marine wildlife, mostly of marine mammals, has grown from a fairly narrow focus on deliberately radiated noise events coincident with fatal stranding events (most commonly related to military and other active sonars; e.g., Fernández et al., 2005; D'Amico et al., 2009; Jepson et al., 2013; Simonis et al., 2020; https://iwc.int/2008-mass-stranding-in-madagascar), to a more comprehensive appreciation of the broader temporal and spatial scales of noise pollution in terms of sub-lethal and chronic impacts to individuals and populations (e.g., Hatch et al., 2016). This has resulted in rapidly expanding international interest about issues related to noise pollution, with a host of recent resolutions in regional, national, and international fora (see Table 1). These increasingly global efforts seek to manage noise from industrial activities and mitigate potential impacts of that noise. Further, a number of recent noise reduction programs, certification programs, and voluntary agreements provide creative and engaging ways to develop, incentivize, and implement techniques to minimize noise.

Here we provide a synthesis of technical guidance; policy frameworks; declarations; implementation programs and projects; and recommendations/guidelines related to noise reduction that have been adopted or otherwise endorsed by intergovernmental policy fora, individual governments, and international agreements/organizations, as well as information on ongoing mitigation efforts led by regional organizations and state/local governments. We do not review the science of noise and its impacts, as there are already multiple published and thorough reviews (e.g., NRC, 2003; Hildebrand, 2005; 2009; NRC, 2005; Nowacek et al., 2007; Weilgart, 2007; Clark et al., 2009; Popper and Hawkins, 2012; Southall, 2017). Rather, this synthesis draws on written submissions voluntarily provided to the United Nations Division for Ocean Affairs and the Law of the Sea in advance of the nineteenth meeting of the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea (UN ICP),[1] and related programs derived from those parties, to highlight ongoing efforts on: 1) noise assessment and monitoring; 2) noise mitigation; and 3) noise reduction programs/projects. These include the following seminal documents (Table 1):

- 4 from the International Whaling Commission (IWC)
- 1 from the International Maritime Organization (IMO)
- 2 from the Convention on Biological Diversity (CBD)[2]
- 3 from the Convention on Migratory Species (CMS)
- 1 from the International Union for Conservation of Nature (IUCN)
- 4 from the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR)
- 2 from the Baltic Marine Environment Protection Commission (HELCOM)
- 3 from the European Union (EU)
- 3 from the UK Joint Nature Conservation Committee (JNCC; see Wright and Cosentino, 2015 for a critique of JNCC 2010a, 2010b guidelines)
- 4 from the National Ocean and Atmospheric Administration of the United States Department of Commerce (NOAA)
- 14 noise-related programs and projects

This list is not a comprehensive list of all efforts related to noise, but is rather a representative and current sample of documents, reports, declarations, and programs that are being considered by and integrated into efforts underway at the United Nations (UN) – the primary international intergovernmental organization of the world.

Based on the aggregate information and considerations in these documents, we conclude with four important considerations which will be key in helping develop effective noise reduction measures in the future: 1) collaborative partnerships to address the transboundary and cumulative nature of noise; 2) the differing countries' implementation capabilities for addressing noise; 3) tradeoffs with louder noise for a shorter time period versus quieter but for longer (as in slowing a vessel); and 4) how noise impacts may vary depending on specific life history stages and life functions.

2. Anthropogenic underwater noise on the international stage

The inclusion of noise in international fora such as the UN ICP and the recent Seventy-third session of the United Nations General Assembly (UNGA)[3] demonstrates clear national and international recognition of marine life's dependency on sound and impacts of increasing noise in the ocean. The majority of parties agree that efforts to mitigate and reduce noise and the potential negative impacts from noise should not be delayed due to the absence of scientific certainty regarding potential impacts; this is referred to as the "precautionary approach" (CMS, 2008, 2017; EU, 2008, 2017, 2018; CBD, 2014a; IWC, 2016, 2018b). All organizations, governments, and conventions included in our review, including ones that did not specifically name the precautionary approach, highlighted the contribution of human activity in increasing underwater noise, and the need to take appropriate measures to reduce and mitigate potential impacts from noise (CMS, 2011, 2017; CBD, 2014b; IMO, 2014; OSPAR, 2015; NOAA, 2016; IUCN, 2017; JNCC, 2017).

The IWC, CMS, and NOAA also recognize that underwater noise is able to travel long distances including across national boundaries and jurisdictions (CMS, 2008; Harrison et al., 2016; NOAA, 2016; IWC, 2018a). Additionally, that noise does not only affect marine mammals, but also marine fish, invertebrates, and the environment as a whole (CMS, 2011, 2017; OSPAR, 2015; NOAA, 2016; EU, 2017; 2018; IWC, 2018a).

3. Noise assessment and monitoring approaches

The National Research Council's (NRC, 2000, 2003, 2005) reports on noise started in the mid-1990's, and have now progressed to the international stage, where several parties of the UN ICP discussed approaches for monitoring and assessing noise in the ocean. They highlighted the need for transparency of data and standardized methods to measure sound levels, monitor noise, manage databases, and conduct noise assessments (CMS, 2008, 2011; CBD, 2014a; OSPAR, 2015; IWC, 2016; NOAA, 2016; EU, 2017; IUCN, 2017). Parties also recognized the need

[1] https://www.un.org/depts/los/consultative_process/contributionscp.htm.

[2] The CBD is in the process of finalizing their latest technical review related to anthropogenic underwater noise. See https://www.cbd.int/doc/notifications/2020/ntf-2020-070-marine-en.pdf.

[3] https://undocs.org/en/A/RES/73/124.

Table 1
Resolutions, decisions and reports demonstrating international interest in addressing anthropogenic underwater noise.

General category	Organizations	Resolutions and Decisions	Reports
International Conventions	International Whaling Commission (IWC) International Maritime Organization (IMO) Convention on Biological Diversity (CBD) The Convention on Migratory Species (CMS) The International Union for Conservation of Nature (IUCN) The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) Baltic Marine Environment Protection Commission (HELCOM)	International Whaling Commission. (2018a). Summary of main outcomes, decisions and required actions from the 67th annual meeting. Paper IWC/67/GEN/05/rev1. Convention on Biological Diversity. (2014a). Decision adopted by the conference of the Parties to the Convention on Biological Diversity at its Twelfth Meeting. Paper UNEP/CBD/COP/DEC/XII/23. Convention on Migratory Species. (2008). Adverse anthropogenic marine/ocean noise impacts on cetaceans and other biota – adopted by the Conference of the Parties at its Ninth Meeting (Rome 1–5 December 2008). Paper UNEP/CMS/Resolution 9.19. Convention on Migratory Species. (2011). Further steps to abate underwater noise pollution for the protection of cetaceans and other migratory species – adopted by the Conference of the Parties at its Tenth Meeting (Bergen, 20–25 November 2011). Paper UNEP/CMS/Resolution 10.24. Convention on Migratory Species (CMS). (2017). Adverse impacts of anthropogenic noise on cetaceans and other migratory species – adopted by the Conference of the Parties at its 12th Meeting. October 2017, Manila. Paper UNEP/CMS/Resolution 12.14. Cambridge Applied Physics Ltd. (2015). "Teles" A marine siren as an advanced seismic source.	HELCOM. (2016). Regional Baltic Underwater Noise Roadmap 2015–2017. HELCOM 37–2016. HELCOM. (2017). Baltic Marine Environment Protection Commission Final Summary Report: Project activities 15.9.2015–14.12.2016. International Whaling Commission. (2014). Draft Joint Workshop Report: Predicting sound fields – global soundscape modelling to inform management of cetaceans and anthropogenic noise, 15–16 April 2014, Leiden, Netherlands. Paper SC/65b/Rep03. International Whaling Commission. (2016). Report of the Workshop on Acoustic Masking and Whale Population Dynamics, 4–5 June 2016, Bled, Slovenia. Paper SC/66b/REP/10. International Whaling Commission. (2018b). Contribution from the Secretariat of the International Whaling Commission to Part 1 of the Report of the United Nations Secretary General on Oceans and Law of the Sea – Anthropogenic Underwater Noise. www.un.org/depts/los/consultative_process/contributionscp Convention on Biological Diversity. (2014b). Report of the Expert Workshop on Underwater Noise and it's impacts on marine and coastal biodiversity. Paper UNEP/CBD/MCB/EM/2014/1/2. Convention on Biological Diversity. (2014b). Report of the Expert Workshop on Underwater Noise and its impacts on marine and coastal biodiversity. Paper UNEP/CBD/MCB/EM/2014/1/2. Prideaux, G. (2016). CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities. Convention on Migratory Species of Wild Animals, Bonn. Paper MOP8/Doc.6.2.7.b Rev.1. International Union for Conservation of Nature (IUCN). (2017). *Contribution from the Permanent Observe of IUCN to Part 1 of the Report of the United Nations Secretary-General on Oceans and the Law of the Sea – Anthropogenic underwater noise.* OSPAR Commission. (2014). OSPAR inventory of measures to mitigate the emission and environmental impact of underwater noise. OSPAR Commission. (2015). OSPAR Monitoring Strategy for Ambient Underwater Noise. Agreement 2015–05. OSPAR Commission. (2016). OSPAR inventory of measures to mitigate the emission and environmental impact of underwater noise (2016 update). OSPAR Commission. (2017). CEMP Guidelines for Monitoring and Assessment of loud, low and mid-frequency impulsive sound sources in the OSPAR Maritime Region. OSPAR Agreement 2017–07. Castellote, M. (2007). General Review of Protocols and Guidelines for Minimizing Acoustic Disturbance to Marine Mammals from Seismic Surveys. *Journal of International Wildlife Law & Policy,* 10, 273–288. CSA Ocean Sciences Inc. (2014). Quietening Technologies for Reducing Noise during Seismic Surveying and Pile Driving Workshop. Summary Report for the US Dept. of the Interior, Bureau of Ocean Energy Management BOEM 2014–061. Contract Number M12 PC00008.
Governmental/ Intergovernmental Agencies	European Union Marine Strategy Framework Directive (EU MSFD) United States National Oceanic and Atmospheric Administration Ocean Noise Strategy (NOAA ONS) United Kingdom Joint Nature Conservation Committee (UK JNCC) The United Nations (UN)	European Union. (2008). 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). *Official Journal of the European Union* 25.6.2008. European Union. (2017). Commission Decision 2017/848 of 17 May 2017 Laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardized methods for monitoring and assessment, and repealing Decision 2010/477/EU. *Official Journal of the European Union* 18.5.2017. National Oceanic and Atmospheric Administration (NOAA). (2014). National Marine Fisheries Service,	Contribution from the European Union. (2018). United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea – the effects of anthropogenic underwater noise. https://www.un.org/Depts/los/consultative_process/contributions_19cp/EU.pdf National Oceanic and Atmospheric Administration (2016). Ocean Noise Strategy Roadmap. National Oceanic and Atmospheric Administration (NOAA). (2018). 2018 revision to: Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing (version 2.0) – underwater thresholds for onset of permanent and temporary threshold shifts. Harrison, J., Ferguson, M., Gedamke, J., Hatch, L., Southall, B., & Van Parijs, S. (2016). National Oceanic and

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Table 1 (*continued*)

General category	Organizations	Resolutions and Decisions	Reports
		compliance guide for right whale ship strike reduction rule. 50 CFR 224.105.	Atmospheric Administration's Cetacean and Sound Mapping Effort: Continuing Forward with an Integrated Ocean Noise Strategy. In A. N. Popper & A. Hawkins (Eds.), *The effects of noise on aquatic life II* (pp. 409–416). New York, NY: Springer. Joint Nature Conservation Committee. (2010a). JNCC guidelines for minimizing the risk of injury and disturbance to marine mammals for seismic surveys. Joint Nature Conservation Committee. (2010b). JNCC guidelines for minimizing the risk of injury to marine mammals from using explosives. Joint Nature Conservation Committee (JNCC). (2017). JNCC guidelines for minimizing the risk of injury to marine mammals from geophysical surveys. August 2017. McGarry, T., De Silva, R., Canning, S., Mendes, S., Prior, A., Stephenson, S., & Wilson, J. (2020). Evidence base for application of Acoustic Deterrent Devices (ADDs) as marine mammal mitigation. JNCC Report No. 615, Version 2.0, March 2020. United Nations (UN). (2018a). Seventy-third session of the United Nations General Assembly. Agenda item 78 (a) Oceans and the Law of the Sea. Report A/73/L.35. United Nations (UN). (2018b). Seventy-third session of the United Nations General Assembly. Agenda item 78 (a) Resolution adopted by the General Assembly on 11 December 2018. Report A/RES/73/124.
Noise-related projects, partnerships, scientific publications	Achieve QUieter Oceans (AQUO) Suppression of Underwater Noise Induced by Cavitation (SONIC) Ships oriented Innovative soLutions to rEduce Noise & Vibrations (SILENV) COMMON SENSE Baltic Sea Information on the Acoustic Soundscape (BIAS) BalticBOOST Horizon 2020 Transport Challenge: Low Energy And Near to zero emissions Ships (LeanShips); FIBRESHIP International Quiet Ocean Experiment (IQOE) Joint Framework for Ocean Noise in the Atlantic Seas (JONAS) Joint Monitoring Programme for Ambient Noise North Sea (JOMOPANS) International Quiet Ocean Experiment (IQOE) E&P Sound and Marine Life Joint Industry Programme (JIP) Cetacean & Sound Mapping (CetSound) Port of Vancouver Enhancing Cetacean Habitat and Observation Program (ECHO)		Baudin, E., & Mumm, H. (2015). AQUO (Achieve QUieter Oceans by shipping noise footprint reduction) & SONIC (Suppression of UW Noise Induced by Cavitation) Guidelines for regulation on UW noise from commercial shipping. Boyd, I. L., Frisk, G., Urban, E., Tyack, P., Ausubel, J. Seeyave, S., …, Shinke, T. (2011). An International Quiet Ocean Experiment. *Oceanography,* 24, 174–181. Castellote, M. (2007). General Review of Protocols and Guidelines for Minimizing Acoustic Disturbance to Marine Mammals from Seismic Surveys. *Journal of International Wildlife Law & Policy,* 10, 273–288. D'Amico, A., Gisiner, R. C., Ketten, D. R., Hammock, J. A., Johnson, C., Tyack, P. L., & Mead, J. (2009). Beaked whale stranding and naval exercises. *Aquatic Mammals,* 35, 452–472. Erbe, C., Williams, R., Sandilands, D., & Ashe, E. (2014). Identifying modeled ship noise hotspots for marine mammals of Canada's Pacific region. *PLoS ONE*, 9(11), e114362. Fernández, A., Edwards, J. F., Rodríguez, F., Espinosa De Los Monteros, A., Herráez, P., Castro, P., Jaber, J. R., Martín, V., & Arbelo, M. (2005). "Gas and fat embolic syndrome" involving a mass stranding of beaked whales (Family *Ziphiidae*) exposed to anthropogenic sonar signals. *Veterinary Pathology,* 42, 446–457. Hatch, L. T., Clark, C. W., Van Parijs, S. M., Frankel, A. S., & Ponirakis, D. W. (2012). Quantifying loss of acoustic communication space for right whales in and around a US National Marine Sanctuary. *Conservation Biology,* 26, 983–994. Hatch, L. T., Wahle, C. M., Gedamke, J., Harrison, J., Laws, B., Moore, S. E., & Van Parijs, S. M. (2016). Can you hear me here? Managing acoustic habitat in US waters. *Endangered Species Research,* 30, 171–186. Hildebrand, J. A. (2005). Impacts of anthropogenic sound. In J. E. Reynolds III, W. F. Perrin, R. R. Reeves, S. Montgomery, & T. J. Ragen (Eds.), *Marine mammal research: conservation beyond crisis* (pp. 101–124). Baltimore, MD: The Johns Hopkins University Press. Hildebrand, J. A. (2009). Anthropogenic and natural sources of ambient noise in the ocean. *Marine Ecology Progress Series,* 395, 5–20. Jepson, P. D., Deaville, R., Acevedo-Whitehouse, K., Barnett, J., Brownlow, A., Brownell, R. L. Jr., …, Fernández. (2013). What caused the UK's largest common dolphin (*Delphinus delphis*) mass stranding event? *PLoS ONE,* 8(4): e60953. Merchant, N. D. (2019). Underwater noise abatement: Economic factors and policy options. *Environmental*

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Table 1 (*continued*)

General category	Organizations	Resolutions and Decisions	Reports
			Science and Policy, 92, 116–123. Merchant, N. D., Andersson, M. H., Box, T., Le Courtois, F., Cronin, D., Holdsworth, N., …, Tougaard, J. (2020). Impulsive noise pollution in the Northeast Atlantic: Reported activity during 2015–2017. *Marine Pollution Bulletin*, 152, 110951. Merchant, N. D., Faulkner, R. C., & Martinez, R. (2017). Marine noise budgets in practice. *Conservation Letters*, 11 (3), 1–8. McKenna, M. F., Wiggins, S. M., & Hildebrand, J. A. (2013). Relationship between container ship underwater noise levels and ship design, operational and oceanographic conditions. *Scientific Reports*, 3(1), 1–10. National Research Council (NRC). (2000). *Marine mammals and low-frequency sound: progress since 1994.* Washington, D.C.: The National Academies Press. National Research Council (NRC). (2003). *Ocean noise and marine mammals.* Washington, D.C.: National Academies Press. National Research Council (NRC). (2005). *Marine mammal populations and ocean noise: determining when noise causes biologically significant effects.* Washington, D.C.: The National Academies Press. Nichols, T. A., Anderson, T. W., & Širović, A. (2015). Intermittent noise induces physiological stress in a coastal marine fish. *PLoS ONE,* 10, e0139157. Nowacek, D. P., & Southall, B. L. (2016). Effective planning strategies for managing environmental risk associated with geophysical and other imaging surveys. *International Union for the Conservation of Nature (IUCN)*, Gland, Switzerland. 42pp. Nowacek, D. P., Clark, C. W., Mann, D., Miller, P. J. O, Rosenbaum, H. C., Golden, J. S., Jasny, M., Kraska, J., & Southall, B. L. (2015). Marine Seismic Surveys and Ocean Noise: Time for coordinated and prudent planning. *Frontiers in Ecology and the Environment,* 13, 378–386. Nowacek, D. P., Bröeker, K., Donovan, G., Gailey, G., Racca, R., Reeves, R. R., Vedenev, A. I., Weller, D. W., & Southall, B. L. (2013). Responsible Practices for Minimizing and Monitoring Environmental Impacts of Marine Seismic Surveys with an Emphasis on Marine Mammals. *Aquatic Mammals,* 39, 356–377. Popper, A. N., & Hawkins, A. D. (2012). *The effects of noise on aquatic life*. New York, NY: Springer. Simonis, A. E., Brownell, R. L. Jr., Thayre, B. J., Trickey, J. S., Oleson, E. M., Huntington, R., & Baumann-Pickering, S. (2020). Co-occurrence of beaked whale strandings and naval sonar in the Mariana Islands, Western Pacific. *Proceedings of the Royal Society B,* 287: 20200070. Southall, B. L. (2017). Noise. In B. Würsig & H. Thiewesson (Eds.), *Encyclopedia of Marine Mammals, 3*rd *Edition* (pp. 699–707). New York, NY: Academic Press. Southall, B. L., Finneran, J. J., Reichmuth, C., Nachtigall, P. E., Ketten, D. R., Bowles, A. E., …, Tyack, P. L. (2019). Marine mammal noise exposure criteria: updated scientific recommendations for residual hearing effects. *Aquatic Mammals*, 45, 125–232. Southall, B. L., Scholik-Schlomer, A., Hatch, L., Bergmann, T., Jasny, M., Metcalf, K., …, Wright, A. J. (2017). Underwater noise from large commercial ships – international collaboration for noise reduction. In J. Carlton, P. Jukes, & Y. S. Choo (Eds). *Encyclopedia of Maritime and Offshore Engineering.* New York, NY: Wiley & Sons Publishing. Spence, J., Fisher, R., Bahtiarian, M., Boroditsky, L., Jones, N., & Dempsey, R. (2007). *Review of existing and future potential treatments for reducing underwater sound from oil and gas industry activities 07–001*. Prepared for Joint Industry Programme on E&P Sound and Marine Life. Tolimieri, N., Jeffs, A., & Montgomery, J. C. (2000). Ambient sound as a cue for navigation by the pelagic larvae of reef fishes. *Marine Ecology Progress Series,* 207, 219–224. Tyack, P. (1998). Acoustic communication under the sea. In S. L. Hopp, M. J. Owren, C. S. Evans (Eds.), *Animal acoustic communication: recent technical advances* (pp.

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General category	Organizations	Resolutions and Decisions	Reports
			163–220). New York, NY: Springer-Verlag. Vancouver Fraser Port Authority. (2020a). *ECHO Program 2019 voluntary vessel slowdown trial in Haro Strait and Boundary Pass. Vancouver Fraser Port Authority July 2020. p 340.* Vancouver Fraser Port Authority. (2020b). *ECHO Program 2019 voluntary inshore lateral displacement trial in the Strait of Juan de Fuca. Vancouver Fraser Port Authority June 2020. p 43.* Weilgart, L. S. (2007). A brief review of known effects of noise on marine mammals. *International Journal of Comparative Psychology*, 20(2), 159–168. Weilgart, L. (2017). Din of the deep: noise in the ocean and its impacts on cetaceans. In A. Butterworth (Ed.). *Marine Mammal Welfare. Animal Welfare, vol. 17*. Springer, Cham. Williams, R., Wright, A. J., Ashe, E., Blight, L. K., Bruintjes, R., Canessa, R., …, Wale, M. A. (2015). Impacts of anthropogenic noise on marine life: publication patterns, new discoveries, and future directions in research and management. *Ocean and Coastal Management,* 115, 17–24. Wright, A. J., Aguilar Soto, N., Baldwin, A. L., Bateson, M., Beale, C., Clark, C., …, Marin, V. (2007). Do marine mammals experience stress related to anthropogenic noise? *International Journal of Comparative Psychology,* 20, 274–316.

for an initial impact and risk assessment before an activity is conducted, in which all potential impacts should be considered, including cumulative impacts (CBD, 2014b; IWC, 2016; NOAA, 2016; JNCC, 2017). Inclusion of direct impacts from noise, as well as the evaluation of indirect impacts from noise, the species' use of the environment, and sound propagation modeling should also be taken into consideration (CMS, 2008; CBD, 2014a; IWC, 2014; OSPAR, 2014, 2015; EU, 2017; JNCC, 2017; IWC, 2018b).

Different noise sources (e.g., an intense but mobile/intermittent v. continuously present noise source) have been considered, but many conventions highlight the particular need to consider those that are chronically present and may fundamentally alter marine ecosystems. Real-time monitoring of species presence by marine mammal observers or passive acoustic monitoring, before, during, and after an activity was emphasized (JNCC, 2010a, 2010b, 2017; NOAA, 2016; OSPAR, 2016). Many organizations and conventions encouraged and called for collaborative monitoring of potential impacts of noise, especially on noise-sensitive and migratory species (CMS, 2008, 2017; CBD, 2014a, 2014b; NOAA, 2016; OSPAR, 2016; EU, 2017; IWC, 2018a, 2018b).

OSPAR developed a registry of impulsive sound events (ices.dk; OSPAR, 2017), which HELCOM adopted and then later established an Expert Network on Underwater Noise (EN-Noise) which produced the Regional Baltic Underwater Noise Roadmap 2015–2017; recently adopted at the 37th HELCOM meeting (HELCOM, 2016; for more on impulsive noise in the Northeast Atlantic, see Merchant et al., 2020). OSPAR is currently developing an "impulsive noise impact indicator", which assesses the risk of impact on focal species based on an 'exposure index', and has adopted an Ambient Noise Monitoring Strategy (OSPAR, 2015; Merchant et al., 2018).

4. Noise mitigation

4.1. Spatial and temporal approaches

4.1.1. Incidental noise

All organizations and conventions stressed the need for spatio-temporal mitigation strategies including the rerouting of vessels and avoidance of noise-generating activities in areas or during times of high animal density, including Biologically Important Areas (BIAs) and Important Marine Mammal Areas (IMMAs; marinemammalhabitat.org) such as breeding and feeding areas (CMS, 2011, 2017; CBD, 2014a, 2014b; IMO, 2014; OSPAR, 2014; IWC, 2016, 2018a; NOAA, 2016; IUCN, 2017). The IWC, CBD, OSPAR, and NOAA further highlighted the potential need for stricter management of noise-generating activities such as area or seasonal restrictions in those areas and during those times (CBD, 2014a, 2014b; NOAA, 2016; OSPAR, 2016; IWC, 2018a, 2018b). The combination of acoustic mapping, of not only anthropogenic noise-generating sources, but of all sources of ambient noise, with habitat mapping of species of concern was indicated by many organizations to be useful in identifying high-risk areas for further management and mitigation efforts (CMS, 2008; CBD, 2014b; IWC, 2016; NOAA, 2016). Furthermore, the CBD and CMS recommended the consideration of underwater soundscapes, including ambient and anthropogenic noise, into management plans of marine protected areas (MPAs) (CMS, 2011; CBD, 2014a).

4.1.2. Deliberate noise

Spatial and temporal mitigation approaches to reduce deliberate noise are generally similar to those for incidental noise. Further, the JNCC recommended planning seismic surveys and explosions to avoid areas and times of marine mammal presence, or likelihood of presence (JNCC, 2010a, 2010b, 2017). JNCC (2017) also highlights the use of their guidelines for any geophysical survey in any marine industry, not just the oil and gas industry which was the focus of the 2010 guidelines.

4.2. Quieting technologies

4.2.1. Incidental noise

The IMO Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life (2014) identified multiple explicit ways to reduce noise generated from vessels. These include design specifications and regular maintenance of the propeller, hull and onboard machinery to reduce cavitation and surface roughness. New technologies such as state-of-the-art propellers and retro-fitting ships for fuel efficiency were also identified to reduce noise generated by vessels. Detailed specifications for ship design can be found in IMO MEPC.1/Circ.833 Sections 7–10 (IMO, 2014).

For offshore activities, there are a variety of techniques that have been observed to reduce incidental noise generated by industrial activity. The CMS and NOAA highlight air-filled coffer dams, bubble curtains, floating platforms and hydro-sound dampers (CMS, 2011; NOAA, 2016). Additionally, OSPAR published methods to reduce noise from offshore wind-related construction activity, including use of alternative foundation types (gravity base foundations), big bubble/double bubble curtains, isolation casings, hydro-sound dampers, and vibro-piling (OSPAR, 2014).

4.2.2. Deliberate noise

OSPAR also published noise reduction techniques for seismic surveys, which are used to detect oil and gas beneath the ocean floor. These techniques include higher sensitivity hydrophones, benthic stationary fibre-optic receivers, parabolic reflectors, and sound baffling (OSPAR, 2016). Potential alternative technologies include non-impulsive, very low frequency marine vibroseis (CSA Ocean Sciences Inc., 2014), although these signals are more continuous in terms of duty cycle than airguns and may have different but as yet untested potential impacts, such as masking or behavioral disturbance. Much needed progress is being made in both the development and environmental testing of these sources.

4.3. Other mitigation methods

Organizations including NOAA and the EU have called for or have already begun developing noise exposure limits and acoustic impact thresholds for different species (CBD, 2014a; NOAA, 2016; EU, 2017; IWC, 2018b). Thresholds can be difficult to determine for data deficient species as information is needed regarding hearing mechanisms, sensitivities, baseline stress markers and sound use, which is lacking for many marine species (NOAA, 2016).

Acoustic deterrent devices (ADDs), which were originally used to emit a range of sounds in an attempt to deter cetaceans from fishing gear, were identified as potential means to deter marine mammals from other, typically louder and chronic noise-generating activities (JNCC, 2010b; OSPAR, 2014). JNCC (2010b) further recommends that ADDs should only be used in certain circumstances and simultaneously with marine mammal observers or passive acoustic monitoring, for as short a time as possible, to ensure minimization of additional noise. However, they recognize that the effectiveness of ADDs may depend upon the species targeted for deterrence and have compiled a summary of ADDs and guidelines for their use (McGarry et al., 2020). However, the use of ADDs for mitigation still requires careful consideration as the addition of more noise can lead to potential direct and indirect consequences such as habituation, hearing damage, and injury (OSPAR, 2016).

IMO and OSPAR also recognized that reducing ship speed results in noise reduction (IMO, 2014; OSPAR, 2014). The reduction in ship speed is likely to reduce other impacts to marine life as well, such as ship strikes, and ship speed reductions are in effect in some areas like North Atlantic right whale Seasonal Management Areas off the US Eastern Seaboard (Federal Register, 2008; NOAA, 2014). OSPAR and JNCC also recommend the use of a “soft-start” or “ramp-up” procedure, commonly used regarding seismic surveys, where power from the seismic airgun array is built up slowly, starting with the smallest airgun first and adding in others until full power is obtained (JNCC, 2010a, 2017; OSPAR, 2016). JNCC (2010a, 2017) recommends a soft-start of 20 min to allow time for marine mammals to leave the survey area while minimizing the addition of noise and a delay in seismic activities when marine mammals are sighted within a 500 m radius of the activity. It should be noted that while such mitigation measures are certainly appropriate in striving to prevent physical injury and/or other more severe effects, they should be (and generally are) complemented by a suite of other mitigation and monitoring approaches (e.g., Nowacek and Southall, 2016). Additionally, the efficacy of these measures in reducing adverse impacts of different types has been relatively poorly known and studied thus far, although there have been several recent efforts to quantify this (see noise reduction projects).

5. Noise reduction programs and projects

5.1. Noise reduction programs

In addition to the conventions and regulatory agencies, multiple national and international parties have participated in programs and projects to address noise. Many of the projects identified in this review are supported by the EU (EU, 2018). From 2012 to 2015, AQUO (Achieve QUieter Oceans; aquo.eu) and its complementary project SONIC (Suppression of Underwater Noise Induced by Cavitation; aquo.eu/SONIC) were supported by the European Commission to assess and mitigate the impacts from noise-generating maritime transport, in order to reduce the negative impacts on marine life. SONIC was tasked with the technical investigation into noise generated from ships, and in conjunction with species acoustic studies, noise propagation models and in-situ observations, resulted in a document on Guidelines for Regulation on UW [Underwater] Noise from Commercial Shipping (Baudin and Mumm, 2015).

Other past projects supported by the EU include SILENV (Ships oriented Innovative soLutions to rEduce Noise & Vibrations; 2009–2012), which aimed to find solutions to reduce noise and vibrations from ships, as well as establish an ‘acoustic green label” for ships (silenv.eu; cordis.europa.eu); COMMON SENSE (Cost-effective sensors, interoperable with international existing ocean observing systems, to meet EU policies requirements; 2013–2017), which conducted in-situ monitoring of the marine environment to support the EU Marine Strategy Framework Directive (MSFD; EU, 2008) “Good Environmental Status” (commonsenseproject.eu); BIAS (Baltic Sea Information on the Acoustic Soundscape; 2012–2016), a collaborative project from HELCOM to help the Member States efficiently implement the MSFD, including demonstrating the advantages of a transnational management approach, assessment of underwater noise in the region, and drafting standards and tools for underwater noise management (bias-project.eu); and BalticBOOST (2015–2017) which also contributed information to underwater noise impacts, including hearing sensitivities of marine species found in the Baltic Sea (HELCOM, 2017).

Current EU supported projects identified in this review fall under the Horizon 2020 financial mechanism under the EU Research and Innovation Programme (ec.europa.eu/programmes/horizon2020). The Smart, Green and Integrated Transport Challenge (Transport Challenge) focuses on cleaner and quieter transportation to minimize the impact on the environment and climate. Two projects funded under the Horizon 2020 Transport Challenge are LeanShips (Low Energy And Near to zero emissions Ships; 2015–2019) and FIBRESHIP (2017–2020). LeanShips works on building “more efficient and less polluting” vessels (leanships-project.eu), and FIBRESHIP aims to construct a market where ships' hulls and superstructures are constructed from fibre-reinforced plastic (FRP; fibreship.eu). Use of FRP is expected to reduce the weight of the ship, resulting in fuel savings and reductions in greenhouse gas emissions, reduce corrosion, maintenance costs, and reduce underwater noise. OSPAR's Ambient Noise Monitoring Strategy is currently being implemented by two EU-funded joint monitoring projects in the Northeast Atlantic: Joint Framework for Ocean Noise in the Atlantic Seas (JONAS; jonasproject.eu) and the Joint Monitoring Programme for Ambient Noise North Sea (JOMOPANS; northsearegion.eu/jomopans).

Other international programs include The International Quiet Ocean Experiment (IQOE, iqoe.org) which gathered international research communities, industry representatives, and other stakeholders together for a collaborative effort to quantify ocean soundscapes, and potential impacts on marine taxa (Boyd et al., 2011). The IQOE has supported activities in various locations, including Australia, India, Colombia, Northeast Atlantic Ocean, the North Sea, and the United States. There are also multiple working groups focusing on noise in biodiversity hotspots, the Arctic, data management and standardization. These activities are focused on four general themes that IQOE has identified: 1) ocean soundscapes (e.g., identifying sound sources, sound propagation modeling); 2) effects of sound on marine life; 3) observing ocean sound (e.g., sound measurement standards); and 4) industry and regulation (e.g., noise monitoring, thresholds, management).

Projects within North America focused on underwater noise include NOAA's CetSound (Cetacean & Sound Mapping; cetsound.noaa.gov). CetSound comprises two mapping instruments, CetMap (Cetacean Density and Distribution Mapping Working Group) and SoundMap (Underwater Sound Field Mapping Working Group). Both aim to map the spatial and temporal distribution of cetacean species and underwater noise, respectively. In addition to the spatio-temporal distribution, CetMap estimates cetacean density and SoundMap maps noise spectral characteristics. The Port of Vancouver Enhancing Cetacean Habitat and Observation Program (ECHO)[4] has implemented programs to reduce noise in southern resident killer whale feeding areas. This includes voluntary vessel slowdown studies since 2017 in Haro Strait, a re-routing trial in 2018 and 2019 in the Strait of Juan de Fuca, and the addition of vessel slowdown trials through Boundary Pass (2019) and Swiftsure Bank (2020). In 2019, participating vessels (which consisted of 82% of ship transits, compared to 87% in 2018 and 61% in 2017) slowed to 14.5 or 11.5 knots or less (depending on vessel type) through Haro Strait and Boundary Pass, and underwater broadband noise was reduced by 3.0–3.5 dB (Vancouver Fraser Port Authority, 2020a). Reduced noise is predicted to increase foraging success of southern resident killer whales by up to 20% (Vancouver Fraser Port Authority, 2020a). The 2019 voluntary inshore lateral displacement trial in the Strait of Juan de Fuca was in effect until late October 2019, and 76% of all tugs and barges moved south of known feeding areas, resulting in an approximate 3.6 dB reduction in broadband noise (Vancouver Fraser Port Authority, 2020b). Current ECHO projects include vessel slowdowns in Haro Strait, Boundary Pass, and Swiftsure Bank, as well as the re-routing of ship in the Strait of Juan de Fuca.

5.2. *Certification programs/voluntary agreements*

Certifications for companies and ship owners provide guidance and criteria for reducing noise and mitigating potential adverse impacts on marine mammals. One such certification program in North America, Green Marine Environmental Program, provides transparent reports on improvements in environmental practices (GMEP, 2018a). Participants such as ports and ship owners aim to meet levels of achievement for different objectives, including the reduction of noise. Management of noise should be conducted during ongoing activities, development and construction, as well as any port maintenance and ship operations to reduce noise and potential impacts to marine mammals. Lower level performance indicators include goals such as promoting the awareness of potential impacts, providing marine mammal sightings data, regular cleaning of the hull and propeller blade, or using marine mammal observers during marine construction (GMEP, 2018b, 2018c). Higher levels of achievement include development of an Underwater Noise Mitigation and Management Plan for ports and a Marine Mammal Management Plan for ship owners, development of incentive programs for ship owners and targets for noise reduction, and ultimately meeting those noise reduction targets and continuously improving management plans including use of noise reducing technologies (GMEP, 2018b, 2018c). Results are self-reported, subject to third-party verification, and publicly available.

Other programs such as the Port of Vancouver EcoAction program or the recent Vineyard Wind – NGO agreement are voluntary (for economic-related factors see Merchant et al., 2019). The Port of Vancouver recently added a new noise-related incentive to their existing EcoAction program (initially focused on reducing vessel emissions), providing reduced harbor rates for cargo and cruise vessels using noise reducing technologies (portvancouver.com). Vineyard Wind, in agreement with the National Wildlife Federation, Natural Resources Defense Council, and Conservation Law Foundation, will attempt to implement monitoring and mitigation measures, as well as seasonal restrictions for offshore wind development (Vineyard Wind, 2019). These include noise reduction efforts such as restricting pile driving when sensitive species presence is most likely, limiting industry activities when visual or acoustic presence is detected within a specified clearance zone, and vessel speed reductions (Vineyard Wind, 2019). This program is also seeking to implement adaptive and precautionary sound level thresholds during times of high likelihood of presence, collaborative research efforts, and adaptive management. While these new mitigation efforts are promising in some regards, an important aspect will come to actual implementation and adaptive management that evaluates how they may influence the time course of development in terms of extending the overall duration of disturbance (see McKenna et al., 2013). This is a balance that new and evolving mitigation measures must continue to evaluate and optimize.

6. Future directions

As evidenced in this synthesis, many governments, IGOs, and conventions recognize and are addressing the issue of incidental and deliberate noise. There have been a number of efforts to establish best practices for monitoring and mitigation of noise, some of which have focused on the establishment of measurement and monitoring methodological approaches and standards for reporting acoustic measurements (e.g., Castellote, 2007; Spence et al., 2007; Nowacek et al., 2015; Nowacek and Southall, 2016; Hatch et al., 2016; NOAA, 2016; 2018; CMS, 2017). Others have consisted of broader considerations of the entire process of planning for, conducting, and evaluating deliberate noise-generating activities such as marine seismic surveys to better inform future surveys (Nowacek and Southall, 2016; Nowacek et al., 2013, 2015). Many point to the merits of a spatial-temporal management scheme where reducing noise disturbance generally in areas of high density and/or biological importance during key periods is an overall strategy to reduce impacts. That is, deconflicting key times and areas from noise-generating events is likely a more productive means of mitigating impacts at a local or population level (e.g., Erbe et al., 2014; Merchant et al., 2018). There is also a need for organizations and industry to utilize this information and promote public awareness and understanding, and subsequently to support initiatives that reduce known or expected impacts from noise (Harrison et al., 2016; NOAA, 2016).

As actions increase to address noise and its impacts, parties have identified certain considerations to further improve current understanding of the broader impacts and how species may respond to and become conditioned to noise. Longer-term studies are needed to identify population-level impacts of noise and masking, especially impacts on reproductive success and survivorship (CBD, 2014a; Hatch et al., 2016; NOAA, 2016; EU, 2017). Quantification of noise impacts on prey reduction and other life functions (most studies center on foraging) would also help inform knowledge of the potential acoustic repercussions of noise. The cumulative impacts, of not only increasing noise, but also its additive and potentially synergistic interactions with other stressors and environmental changes such as climate change and ocean acidification are also of concern, as we are not yet certain of the full magnitude of these stressors (CMS, 2011, 2017; CBD, 2014a, 2014b; OSPAR, 2014; IWC, 2016; NOAA, 2016; Prideaux, 2016). The UNGA Seventy-third session also emphasized the urgency needed for active and cooperative participation at regional, national and global levels to fill knowledge gaps regarding potential impacts from noise, including potential socioeconomic and environmental impacts, impacts on marine living resources, and further investigation into noise reducing

[4] https://www.portvancouver.com/environment/water-land-wildlife/echo-program/.

technologies (UN, 2018a, 2018b).

Future management and mitigation measures will be more effective with increased knowledge from current and future research; however, because underwater sound is transboundary, international and multi-institutional efforts are needed to address noise. The UNGA and associated parties recommended international cooperation and collaboration, and partnerships with industry, stakeholders, relevant organizations, government and scientific groups (CMS, 2008, 2017; CBD, 2014b; IWC, 2014; OSPAR, 2014; NOAA, 2016; EU, 2017; IUCN, 2017; UN, 2018a). Some current partnerships with industry include: 1) the E&P (Exploration and Production) Sound and Marine Life Joint Industry Programme (JIP); an international program whose members include many industry partners, which supports research projects focused on noise generated by oil and gas exploration. This includes sound propagation, effects of sound on the physiology and hearing of marine animals, effects on behavior, noise mitigation and monitoring. The JIP also aids with E&P impacts assessments, provides the scientific basis for mitigation measures, and helps governments to make well-informed regulatory decisions that are based on robust science (soundandmarinelife.org); 2) the U.S. Navy, which runs the Living Marine Resources Program (LMR),[5] supporting many projects related to improving the best available science on effects of noise including current projects on marine mammal diving behavior during sonar operations, recovery of temporary threshold shifts in bottlenose dolphins, and effects of explosions on fish; and 3) the IUCN's Business and Biodiversity Unit, which partners with businesses on a multitude of projects to help conserve nature and natural resources; for example, the "mitigating impacts in renewable energy projects"[6] aims to reduce impacts associated with solar and wind power, including impacts from noise.

Further, recent developments in the Protection of the Arctic Marine Environment (PAME) Working Group of the Arctic Council and the Nairobi Convention for the Protection, Management and Development of Coastal and Marine Environment of the Western Indian Ocean have demonstrated increased concern and interest in addressing underwater noise (PAME, 2017; Bennett, 2018). These include processes to reduce habitat degradation (relating to important acoustic habitats), management of increasing ship traffic, projects such as PAME's Resource Exploration and Development Expert Group, and the Wildlife Conservation Society's (WCS) contributions toward developing a potential Programme of Work and considerations for PAME (PAME, 2017; Bennett, 2018; WCS, 2018). However, no recommendations directly pertaining to including local knowledge from human populations who have lived with and relied on marine wildlife were found in the seminal papers reported here. In particular, it is expected that fishermen and indigenous marine mammal hunters will have valuable insights into the onset of noise disturbance, habituation to noise, and cumulative impacts given their close relationship with these species (PAME, 2017; WCS, 2018).

7. Key considerations and conclusions

This paper provides a synthesis of existing international declarations, recommendations, and evolving guidelines on managing and mitigating noise and its potential impacts. Parts of this synthesis are summarized in detail, in matrix form in Appendix A.[7] There is clearly international recognition that marine species depend on sound for important biological functions, which may be directly or indirectly affected by noise, and increasing efforts to reduce anthropogenic underwater noise. Underwater noise has increased, with greatest overall contribution from commercial shipping, and is inherently transboundary in nature, thus making it a global issue. There is growing and broad agreement that this issue needs to be addressed from both scientific and policy perspectives and new approaches, and partnerships spanning and integrating these perspectives are emerging.

While this paper summarizes the many efforts to reduce anthropogenic underwater noise, the documents reviewed also point out aspects that would improve current noise reduction efforts and help develop more effective mitigation plans. We highlight and expand on four key considerations for future research and would better inform effective mitigation efforts:

1. Noise is unrestricted by national boundaries and migratory species can be affected by different sources and levels of noise in multiple areas along their migration route. Consequently, exposure may result in systematic behavioral (e.g., vocalizing) or physiological (e.g., stress) changes across their range. These highlight the need for integrated research and collaboration with governments, communities, and all stakeholders, including proactive industry partners in order to better understand topics such as altered behavior, conditioning, and adaptation to noise.
2. Different countries have different socio-economic statuses, cultures, and scientific and technological capabilities, as well as different physical and acoustic environments. While there is a need for overarching best-practice approaches to monitor, mitigate, understand, and address these issues, collaborative programs will be able to better support countries with limited resources and should be developed and implemented with awareness of these regional differences and with the engagement and involvement of local communities.
3. While noise reducing methods and technologies such as slowing a vessel or vibropiling may generate lower noise levels, it results in continuous sound as compared to shorter duration and higher noise levels that would result from faster vessel speeds or pile driving, respectively. Research is needed on the tradeoffs between quieter noise over a more extended duration versus shorter, but louder noises, which likely differs for different environments and species. Research also needs to consider these differences in the context of cumulative impacts such as those associated with climate change or acidification.
4. Acoustic thresholds for different marine mammal taxa have been calculated (e.g., NOAA, 2018; Southall et al., 2019) and define thresholds at which changes in marine mammal behavior and hearing occur (which may subsequently affect reproductive success, survivorship, foraging, and communication). However, underwater noise likely has varying impacts on different life history stages and life functions, as young of a particular species may be more sensitive to noise and vocalizations used for foraging and breeding may be masked by noise even if behavioral changes do not occur. Noise thresholds must be addressed carefully, especially in BIAs and IMMAs where critical life functions occur. These considerations also need to increasingly be made within an ecosystem perspective where habitat parameters and multi-trophic impacts and potential cascading effects are considered.

In addition to these considerations and the increasing recognition and efforts to reduce noise, it is also helpful to recognize that unlike other persistent pollutants in the environment, noise is transient and reduction measures can have rapid effects in terms of reducing disturbance and interference with sound communication. With coordination, partnerships, effective and informed regulatory policies, and technology, reductions in noise can be achieved.

[5] https://www.navfac.navy.mil/navfac_worldwide/specialty_centers/exwc/products_and_services/ev/lmr.html.

[6] https://www.iucn.org/theme/business-and-biodiversity/our-work/business-engagement-project/mitigating-impacts-renewable-energy-projects.

[7] Appendix A was prepared as a detailed matrix for consideration by the PAME Working Group of the Arctic Council and includes other resources on addressing anthropogenic underwater noise.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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