INTERNATIONAL MARITIME ORGANIZATION

E

MARINE ENVIRONMENT PROTECTION COMMITTEE
72nd session
Agenda item 16

MEPC 72/INF.9
19 January 2018
ENGLISH ONLY

ANY OTHER BUSINESS

Further information related to impacts of underwater noise on marine life

Submitted by International Whaling Commission

SUMMARY

Executive summary:	This document is submitted for information and advises the MEPC on recent information regarding the impact of underwater noise arising from research since the adoption of the IMO Guidelines for the reduction of underwater noise in 2014
Strategic Direction, if applicable:	No related provisions
Output:	No related provisions
Action to be taken:	Paragraph 32
Related documents:	LC/SG 40/INF.10; MEPC 71/16/5 and MEPC.1/Circ.833

Introduction

1 The International Whaling Commission (IWC) contributed to the development of the *Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life* (circular MEPC.1/Circ.833) which was approved in 2014 by MEPC 66. These non-mandatory, technical Guidelines recognize that underwater-radiated noise from commercial ships can have both short- and long-term negative consequences on marine life, especially marine mammals. The Polar Code also includes provisions that could relate to marine mammals and underwater noise. Section 11.3.6 of chapter 11 of part I-A on voyage planning includes the requirement that, in considering routes through polar waters, masters shall take into account "current information and measures to be taken when marine mammals are encountered, relating to known areas with densities of marine mammals, including seasonal migration areas" and "current information on relevant ships' routing systems, speed recommendations and vessel traffic services relating to known areas with densities of marine mammals, including seasonal migration areas".

2 Since 2014, the IWC has continued to work on the issue of understanding the impacts of underwater noise on cetaceans with discussions of new research at annual meetings of its Scientific Committee, a workshop on global soundscape mapping in 2014[1] and a workshop in 2016 on Acoustic Masking and Whale Population Dynamics[2]. In 2016, the IWC Scientific Committee noted compelling evidence that chronic anthropogenic noise is affecting the marine acoustic environment in many regions and recognized emerging evidence that compromised acoustic habitat can affect some cetacean populations adversely. The IWC Scientific Committee also recognized that noise is one of many stressors whale populations face, and that mitigation of the most tractable stressors, such as noise, is a way to increase populations' resilience and improve their future prospects in the face of less tractable stressors, such as climate change. Although the IWC is concerned primarily with cetaceans, new research on impacts of shipping noise on other species, including cetacean prey species, also indicates potential for ecosystem effects.

3 The aim of this document is to update the MEPC with relevant information so that the guidance in MEPC.1/Circ.833 can be most effectively applied to reduce impacts to marine life. This follows document MEPC 71/16/5 presented by Canada which encouraged comments, particularly on experience gained with specific measures or on interest in additional collaboration on research and the identification of other potential mitigation measures. At MEPC 71, several delegations stressed the importance of this issue and the need for further research and collaboration to better understand the impact of ship noise. At the same meeting, the IWC drew attention to the work undertaken by the IWC on this issue and offered to provide an update to MEPC 72 on scientific information relating to the impact of noise on cetaceans, including IWC discussions and recommendations. The Committee also encouraged Member States to continue to share their experience in this field, in particular concerning the implementation of the Guidelines set out in MEPC.1/Circ.833.

Review of new information on impacts of shipping noise on marine life

4 Recent (post-2014) studies on the effects of shipping noise on marine life have added to previous research demonstrating a range of impacts across taxa from invertebrates to cetaceans. Although to date most concerns over shipping noise and cetaceans have related to low-frequency specialists such as large whales, there have been a number of recent studies showing the effects of higher frequency components of shipping noise on small cetaceans (Hermannsen et al. 2014, Dyndo et al. 2015, Veirs et al. 2016, Liu et al. 2017) and increased, although still limited, studies on lower taxa.

New information on masking and population level effects on cetaceans

5 Masking is defined as both the process and the amount by which the threshold of hearing of one sound is raised by the presence of another. Clark et al. (2009) highlight the impacts of masking, and more recently, Erbe et al. (2016) describe further work on these impacts but also note the challenges in interpreting the biological significance of masking and addressing the question "How much is too much?".

6 These and related issues were investigated further at the IWC Scientific Committee workshop on "Acoustic Masking and Whale Population Dynamics" in 2016 (IWC, 2017a). This included a review of the Population Consequences of Disturbance (PCoD) framework (New et al. 2014) and Population Viability Analysis (PVA). PCoD and PVA tools provide

[1] IWC. 2015. Joint Workshop Report: Predicting Soundfields – Global Soundscape Modelling to Inform Management of Cetaceans and Anthropogenic Noise, 15-16 April 2014, Leiden, Netherlands. *J. Cetacean Res. Manage.* (Suppl.). 16: 411-424.

[2] IWC. 2017a. Report of the Workshop on Acoustic Masking and Whale Population Dynamics. *J. Cetacean Res. Manage.* (Suppl.) 18: 617- 627.

complementary approaches for understanding the influence of different environmental stressors on population dynamics, and these tools hold great promise for dealing with the issues of masking and aggregate/cumulative effects. One approach to model potential population consequences of loss of acoustic habitat is through reduction in foraging opportunities or energy intake. However, the IWC Scientific Committee has also recommended research to investigate the linkages between masking of sounds/loss of acoustic habitat and the effects on other life functions such as breeding (IWC, 2016).

7 The IWC Scientific Committee agreed that the impacts of increased ocean noise are (a) largely chronic rather than acute, (b) on a large rather than small scale and (c) occur across multiple species, with some populations likely losing large portions (>50%) of their acoustic habitats for many months of the year over many years. Population consequences are very difficult to quantify but for some species and areas (e.g. North Atlantic right whales in the western North Atlantic) there is good evidence that masking probably has some population consequences. Subsequently, Putland et al. (2017) investigated the effect of vessel noise on the communication space of the Bryde's whale and noted that the extent of the loss in communication space may have chronic effects on this population. Lack of good (and in some cases, any) data on parameters related to both noise and cetaceans is the key hindrance to modelling efforts to estimate population consequences (IWC, 2017[3]).

New information on behavioural impacts on cetaceans

8 Recent studies continue to show further behavioural responses to shipping noise. For example, Blair et al. (2016) found changes to humpback whale feeding behaviour in response to ship noise suggesting that the reduction in foraging effort of individual whales could potentially lead to population-level impacts. Bottlenose dolphins in an urbanized estuary significantly increased their average speeds in areas of high vessel densities, but only for some activity states. Behavioural budgets were also different in the presence of vessels and vocalizations changed with rising levels of broadband noise (Marley et al. 2017). Guiana dolphins in Brazil also changed their vocal behaviour in response to noise levels (Bittencourt et al. 2017).

New information on effects of noise on other marine life that may also have implications for cetaceans

9 In addition to direct work on effects on cetaceans, there is now a greater emphasis on the assessment of the biological significance of observed responses to sound especially with respect to potential ecosystem or population level impacts. The effects of noise on marine organisms' development, physiology, and/or behaviour can vary at different stages of their life histories, and anthropogenic stressors rarely act in isolation so aggregate/cumulative and synergistic impacts need to be considered (Kunc et al. 2016, Williams et al. 2016) although this is a complex and difficult issue with respect to modelling frameworks and data gaps.

10 Short- and long-term effects of noise at lower trophic levels (fish and invertebrates) can also impact cetaceans through the food chain. Examples of actual or potential effects of shipping noise on lower taxa include: juvenile European eels, affecting survival by reducing predator response behaviour (Simpson et al. 2015); soniferous fish, low frequency noise can mask communications and impact reproductive success and survival (Bruintjes and Radford 2013, Holles et al. 2013, Radford et al. 2014, Stanley et al. 2017); invertebrates, disruption of key behaviours which mediate benthic nutrient cycling (Solan et al. 2016); or stress (Celi et al. 2015).

[3] International Whaling Commission. 2017b. Report of the IWC Scientific Committee, 7-19 June 2016, Bled, Slovenia. *J. Cetacean Res. Manage.* (Suppl.) 18: 1-109.

Recent monitoring studies of underwater sound evaluating the contribution from shipping

11 Low-frequency anthropogenic sound at the ocean basin scale is dominated by shipping and seismic surveys. There is evidence that low-frequency sound increased substantially (by around 3dB per decade) in the Northeast Pacific Ocean from the mid-1960s to 2000 (Andrew et al. 2002, McDonald et al. 2006) and in the Indian Ocean over the past decade (Miksis-Olds et al. 2013). However, changes in ambient noise are not temporally or spatially homogeneous. Andrew et al. (2011) found no evidence of a continued increase in the North Pacific in recent years and a study of change in low frequency sound (5–115Hz) in the South Atlantic and Equatorial Pacific Oceans found decreases in the ambient sound floor over the past decade (Miksis-Olds and Nichols 2016).

12 Although the main focus with shipping noise has been on low-frequency sound, elevated sound levels in the 10-96 kHz band occur close to vessels. For example, vessel noise from a range of different ship types in four shallow water marine locations in Denmark substantially elevated ambient noise levels across the entire recording band from 0.025 to 160 kHz at ranges between 60 m and 1000 m (Hermannsen et al. 2014). Measurements from a large number of vessels off the coast of Canada suggested that noise received from ships at ranges within 3 km extended to frequencies used by odontocetes (Veirs et al. 2016).

13 The Workshop on global soundscape mapping in 2014 (IWC, 2015a)[4] agreed on the value of sound mapping technology to assist management agencies in addressing chronic and cumulative impacts of ocean noise on cetaceans. The IWC Scientific Committee subsequently endorsed the Workshop report and its recommendations (some slightly modified). These highly technical recommendations related to noise generation, modelling and predictions can be found in IWC (2015b, pp. 42, 255-6, 266-7[5]).

14 Following the 2014 workshop, there has been increasing attention given to soundscape mapping at national and regional scales in the context of describing acoustic habitat and marine spatial planning. At a national level, the US National Oceanic and Atmospheric Administration (NOAA) has developed an Ocean Noise Strategy Roadmap, which aims to broaden the approach to ocean noise management to include an evaluation of impacts to acoustic habitats (Hatch et al. 2016). In 2016, the IWC Scientific Committee welcomed this strategy and endorsed its acoustic habitat approach to ocean noise management. Establishing baseline noise levels and potential mitigation strategies to address cumulative effects of shipping on marine mammals constitutes the objectives of the Canadian Oceans Protection Plan released in 2017[6]. Increases in shipping in Canadian Arctic waters have been predicted to prompt masking or other behavioural responses by cetaceans (Aulanier et al. 2017, Halliday et al. 2017). At European level, Dekeling et al. (2014) provide guidance on sound monitoring. Merchant et al. (2016) describe an example of a nationally coordinated effort to quantify underwater noise levels in the UK. The Baltic Sea Information on the Acoustic Soundscape (BIAS) project (Sigray et al. 2016) has been successful in combining measured sound with advanced three-dimensional modelling, towards establishing standards for measuring continuous sound. Other areas where high levels of shipping noise have been measured include Glacier Bay, US, (McKenna et al. 2017), Guanabara Bay, Brazil (Bittencourt et al. 2014), Celtic Sea (Kinda et al. 2017) and the Gulf of Catania in the Mediterranean (Viola et al. 2017). In 2016, the IWC Scientific Committee expressed concern about the number of problematic areas in the Mediterranean with respect to noise and welcomed the work by ACCOBAMS[7] on this issue.

---

4 International Whaling Commission. 2015a. Report of the Joint Workshop on Predicting Sound Fields: Global Soundscape Modelling to Inform Management of Cetaceans and Anthropogenic Noise. International Whaling Commission. *J. Cetacean Res. Manage.* (Suppl.) 15: 413-24.

5 International Whaling Commission. 2015b. Report of the IWC Scientific Committee. *J. Cetacean Res. Manage.* (Suppl.) 15: 1-365

6 https://www.tc.gc.ca/eng/oceans-protection-plan.html

7 The Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area

15 Several recent studies have investigated sound exposure from shipping noise across animal populations. A risk assessment framework to evaluate how shipping traffic affects acoustic environments off the coast of California predicted that 50 Hz noise levels associated with moderate, heavy, and extreme volumes of shipping traffic would occur across the majority of blue whale habitat (Redfern et al. 2017). Around the British Isles, predicted cumulative sound exposure levels were above levels known to induce temporary threshold shift in 20 out of 28 seals fitted with telemetry tags, based on co-occurrence of the seals and vessels (Jones et al. 2017).

Recent studies of noise output from individual vessels

16 In 2016, the IWC Scientific Committee recommended an approach to identify the noisiest ships, quantify their contribution to overall ocean noise and assign priority to replacing/modifying those ships that contribute disproportionately to ocean noise. Subsequently, there have been some recent studies relating the sound output from large ships to the characteristics of the vessel. Measurements of over 1,500 individual ships across about 2,800 transits found a linear relationship between source level and speed for most ship classes with sound levels increased by around 1dB per knot; container ships generally had the highest source levels (Veirs et al. 2016). This data set also showed that the loudest 15% of ships contribute the majority of the sound energy from shipping (Veirs et al. 2017). Another study (Simard et al. 2016) also found that broadband source levels increased by around 1dB per knot. These increases in sound levels with speed are slightly lower than previous estimates of a 60log (speed) relationship (see Leaper et al. (2014) for review). Other studies of individual vessel signatures include the EU funded SONIC project which has created a database of individual ship noise signatures (Jansen and Jong 2015) and an opportunistic underwater observatory in the Gulf of St Lawrence (Simard et al. 2016).

17 Measurements of individual vessel sound signatures must be corrected for propagation loss. These estimates are further complicated by interference between surface reflections and the direct path from the propeller. Received levels measured according to the ANSI/ISO standards that are not corrected for this effect may be around 12dB lower than corrected values (Gassmann et al. 2017a).

Measures taken by industry that may reduce noise

18 Subsequent to MEPC.1/Circ.833, the EU-funded SONIC and AQUO projects produced Guidelines for Regulation on Under Water Noise from Commercial Shipping[8].

19 Direct full-scale measurements associated with many of the ship quieting measures in MEPC.1/Circ.833 are not yet available. One recent study compared sound level measurements for container vessels pre- and post-retrofits to improve energy efficiency. The modifications included replacing the bulbous bow, derating the main engines for slow steaming and installing new propellers with boss cap fins to reduce cavitation. The estimated underwater source sound pressure levels of the five vessels were found to be lower for post-retrofitted vessels by a median of 6 dB in the 8-100 Hz frequency band and a median of 8 dB in the 100-1000 Hz frequency band (Gassmann et al. 2017b).

8 http://www.aquo.eu/downloads/AQUO-SONIC%20Guidelines_v4.3.pdf

Some relevant actions taken by other international organizations and at the national level

20 Issues related to shipping (and other) noise are global and require international collaboration as well actions at the international and national level. This section is not intended to be comprehensive but rather provides a few recent examples of such actions.

21 The Convention on Migratory Species (CMS) adopted a resolution on "Adverse impacts of anthropogenic noise on cetaceans and other migratory species" at CoP12 in October 2017. This resolution urges parties whose flagged vessels are engaged in activities beyond national jurisdictional limits "to take special care and, where appropriate and practical, to endeavour to control the impact of anthropogenic marine noise pollution in habitats of vulnerable species and in areas where marine species that are vulnerable to the impact of anthropogenic marine noise may be concentrated". CMS also published an overview of underwater sound and its impacts which attempts to provide a non-technical summary of underwater acoustics such that decision-makers can interpret the new CMS guidelines for Environmental Impact Assessments for Marine Noise-generating Activities (CMS, 2017).

22 The European Union has adopted two indicators for Good Environmental Status (GES) related to underwater noise in the context of the Marine Strategy Framework Directive (MSFD), with the objective that the spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound do not exceed levels that adversely affect populations of marine animals. Indicator D11C2 is concerned with ambient noise which is likely to be dominated by shipping. The MSFD requires Member States to establish threshold values for this pressure indicator through co-operation within the EU.

23 Another recent example, taken at the provincial level in Canada, is the ECHO programme[9]. This includes: use of an underwater listening station to better characterize noise levels from different vessels and assess their contribution to overall regional noise; monitoring baseline ambient noise; and a voluntary vessel slowdown trial to study the relationship between noise, vessel speed and effects on the Southern Resident killer whale. The project was reported on in document MEPC 71/16/5 and in a side bar presentation in the margins of MEPC 71.

24 The 2014 workshop on Sound Mapping (IWC, 2015[4]) noted the need to standardize measurements and reporting. Since then there has been steady progress in standardizing terminology for underwater sound in a similar way to that for airborne sound. ISO 18405:2017 Underwater Acoustics – Terminology [10] is now available. There are also standards for ship noise measurement, ANSI/ASA S12.64 (2009) and ISO 17208-1 (2016).

25 The IWC Scientific Committee agreed in 2016 that addressing ocean noise is essential to meet United Nations Sustainable Development targets with respect to reducing pollution and this was also stressed by a number of organizations and governments at the June 2017 United Nations Ocean Conference. In 2018, the focus topic of the forthcoming United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea will be anthropogenic noise which clearly includes shipping noise. IWC provided a contribution to the report of the UN Secretary General on this topic and this will be published on the UN website.

9 https://www.portvancouver.com/environment/water-land-wildlife/marine-mammals/echo-program/

10 https://www.iso.org/obp/ui/#iso:std:iso:18405:ed-1:v1:en

Summary of recommendations, information and materials available from IWC

26 At its 2016 annual meeting, the IWC Scientific Committee consolidated its views on many aspects of the issues of anthropogenic sound (including shipping noise) and cetaceans, including conclusions, research recommendations and conservation advice. These are summarized in annex 1. These were endorsed by the IWC at its 2016 biennial meeting. These conclusions were based upon the Scientific Committee's recent discussions and workshops which are also referenced and discussed in the present document.

27 The IWC Scientific Committee continues to review progress on the goal it endorsed in 2010 of reducing noise from shipping by 3dB in 10 years and 10dB in 30 years in the 10-300Hz band.

28 Anthropogenic sound is one of the priority threats set out in the IWC Conservation Committee Strategic Plan[11] and the IWC Conservation Committee is currently developing its work programme on this issue.

29 The most recent studies described in this document summarize the progress made on the research recommendations made by the IWC Scientific Committee in 2016 which included:

.1 increased research and management consideration of the importance of acoustic habitat in cetacean conservation efforts;

.2 research efforts to better quantify the factors underlying masking in cetaceans and encourage further work on acoustic masking in small cetacean species;

.3 focussed research to quantify the relationship between reduction in acoustic space and reduction in prey intake;

.4 research that explores linkages between masking of sounds and the effect on life functions other than foraging; and

.5 efforts to expand statistical frameworks to predict population consequences of masking.

30 In addition the IWC Scientific Committee noted that many "quiet areas" are likely to be found in the less industrialized waters of the Southern Hemisphere and therefore efforts are needed to involve more scientists from such areas in IWC discussions on ocean noise.

31 Further information and reports can be found at https://iwc.int/anthropogenic-sound. The details of references listed in this document are set out in annex 2.

Action requested of the Committee

32 The Committee is invited to note this information and continue working towards reducing underwater noise from shipping. The IWC looks forward to continued and increasing cooperation with IMO on matters of mutual interest, including shipping noise.

***

11 https://iwc.int/conservation-committee

ANNEX 1

SUMMARY OF RECENT IWC SCIENTIFIC COMMITTEE RECOMMENDATIONS ON NOISE (SC66b meeting, June 2016, Bled, Slovenia)

1 With respect to noise issues in general, the IWC Scientific Committee:

.1 agrees that there is compelling evidence that chronic anthropogenic noise is affecting the marine acoustic environment in many regions and recognized emerging evidence that compromised acoustic habitat can affect some cetacean populations adversely;

.2 agrees that the lack of scientific certainty should not hinder management actions to reduce ocean noise (or indeed other potential threats) and recommends that absence of scientific certainty should not prevent member nations from undertaking management efforts now to keep quiet areas quiet and make noisy areas quieter;

.3 agrees that addressing ocean noise is essential to meet United Nations Sustainable Development targets with respect to reducing pollution and fully protecting 10% of coastal and marine areas;

.4 recommends that the IWC develop a paper for submission to the IMO Marine Environment Protection Committee, providing an update of recent information related to the extent and impacts of underwater noise from shipping;

.5 recommends the continued development of clear and concise statements and compelling audiovisual tools to convey the importance and impact of ocean noise; and

.6 recognizes that noise is one of many stressors whale populations face, and recommends mitigation of the most tractable stressors, such as noise, as a way to increase populations' resilience and improve their future prospects in the face of less tractable stressors, such as climate change.

2 In consideration of protected areas, the IWC Scientific Committee recommends that efforts to finalize a process to identify "Important Marine Mammal Areas" should include integration of information on anthropogenic noise into site selection and management, and where possible, reduce ocean noise levels in identified Important Marine Mammal Areas.

3 With respect to general acoustic work required to address noise issues, the IWC Scientific Committee recommends that:

.1 ship source characteristic data be evaluated, for example part of ambient noise measurement studies, to identify the noisiest ships and quantify their relative contribution to overall ocean noise;

.2 ships that contribute disproportionately to ocean noise should be considered a priority for replacement or application of ship-quieting technologies;

.3 further studies on the source-level speed relationship for a range of vessel types are undertaken; and

.4 Automatic Identification System (AIS) and source characteristic data are used to relate shipping density data to estimated loss of acoustic habitat from shipping noise.

4 The IWC Scientific Committee also endorses the recommendations of the Workshop on Predicting Sound Fields: Global Soundscape Modelling to inform Management of Cetaceans and Anthropogenic Noise and offered specific technical recommendations about how best to accomplish shared goals with respect to generating reliable soundfield maps.

5 Noting cetacean dependence on listening to and producing sounds for their survival, the IWC Scientific Committee:

.1 recommends increased research and management consideration of the importance of acoustic habitat in cetacean conservation efforts;

.2 recommends the set of research efforts be undertaken to better quantify the factors underlying masking in cetaceans and encourages further work on acoustic masking in small cetacean species;

.3 recommends focussed research to quantify the relationship between reduction in acoustic space and reduction in prey intake;

.4 recommends research that explores linkages between masking of sounds and the effect on other life functions than foraging;

.5 recommends efforts to expand both statistical frameworks to predict population consequences of masking;

.6 recommends that the report of the Acoustic Masking Workshop be conveyed to the Western Gray Whale Advisory Panel Noise Task Force to support a collaborative approach to noise management; and

.7 notes that many "quiet areas" are likely to be found in the less industrialized waters of the Southern Hemisphere and, therefore agrees that efforts are needed to involve more scientists from such areas in the Committee's ongoing work on ocean noise.

6 In response to information on noise received this year from other organizations, the IWC Scientific Committee:

.1 welcomes the United States Government's Ocean Noise Strategy and endorses its acoustic habitat approach to ocean noise management;

.2 expresses concern about the number of problematic areas (with respect to noise) in the Mediterranean and welcomes this important work by ACCOBAMS; and

.3 notes that ASCOBANS has developed Guidelines on underwater noise, including effective mitigation guidance for intense noise generating activities.

7 The IWC Scientific Committee notes that there are large data gaps on cetacean responses to UAS/drones but recognizes their potential to disturb or even harm marine mammals (e.g. by strike/collision). It recommends:

.1 that researchers should incorporate consideration of possible impacts (e.g. behavioural reactions) into any proposed UAS study involving cetaceans;

.2 that managers consider recreational use of UAS/drones, as well as commercial or research use, when developing regulations or guidelines for their use around cetaceans; and

.3 that countries without a permitting system for UAS/ drones, develop a precautionary permitting system that considers cumulative effects of UAS operations and other means of approach (e.g. by vessel).

***

ANNEX 2

REFERENCES

1 Andrew, R. K., B. M. Howe and J. A. Mercer (2002). Ocean ambient sound: Comparing the 1960s with the 1990s for a receiver off the California coast. Acoustic Research Letters Online 3(2): 65-70.

2 Aulanier, F., Y. Simard, N. Roy, C. Gervaise and M. Bandet (2017). Effects of shipping on marine acoustic habitats in Canadian Arctic estimated via probabilistic modeling and mapping. Marine Pollution Bulletin 125(1-2): 115-131.

3 Bittencourt, L., R. R. Carvalho, J. Lailson-Brito and A. F. Azevedo (2014). Underwater noise pollution in a coastal tropical environment. Marine Pollution Bulletin 83(1): 331-336.

4 Bittencourt, L., I. M. S. Lima, L. G. Andrade, R. R. Carvalho, T. L. Bisi, J. Lailson-Brito and A. F. Azevedo (2017). Underwater noise in an impacted environment can affect Guiana dolphin communication. Marine Pollution Bulletin 114(2): 1130-1134.

5 Blair, H. B., N. D. Merchant, A. S. Friedlaender, D. N. Wiley and S. E. Parks (2016). Evidence for ship noise impacts on humpback whale foraging behaviour. Biol Lett 12(8).

6 Bruintjes, R. and A. N. Radford (2013). Context-dependent impacts of anthropogenic noise on individual and social behaviour in a cooperatively breeding fish. Animal Behaviour 85(6): 1343-1349.

7 Celi, M., F. Filiciotto, M. Vazzana, V. Arizza, V. Maccarrone, M. Ceraulo, S. Mazzola and G. Buscaino (2015). Shipping noise affecting immune responses of European spiny lobster (Palinurus elephas). Canadian Journal of Zoology 93(2): 113-121.

8 Clark, C. W., W. T. Ellison, B. L. Southall, L. Hatch, S. M. van Parijs, A. Frankel and D. Ponirakis (2009). Acoustic masking in marine ecosystems: intuitions, analysis, and implication. Marine Ecology Progress Series 395: 201-222.

9 CMS (2017). Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities. Edited by G. Prideaux. Convention on Migratory Species of Wild Animals, Bonn. 76pp. ISBN: 978-0-646-96011-1.

10 Dekeling, R. P. A., M. L. Tasker, A. J. Van der Graaf, M. A. Ainslie, M. H. Andersson, M. André, J. F. Borsani, K. Brensing, M. Castellote, D. Cronin, J. Dalen, T. Folegot, R. Leaper, J. Pajala, P. Redman, S. P. Robinson, P. Sigray, G. Sutton, F. Thomsen, S. Werner, D. Wittekind and J. V. Young (2014). Monitoring Guidance for Underwater Noise in European Seas, Part II: Monitoring Guidance Specifications. JRC Scientific and Policy Report EUR26555EN, Publications Office of the EU, Luxembourg. Doi: 10.2788/27158.

11 Dyndo, M., D. M. Wiśniewska, L. Rojano-Doñate and P. T. Madsen (2015). Harbour porpoises react to low levels of high frequency vessel noise. Scientific Reports 5: 11083.

12 Erbe, C., C. Reichmuth, K. Cunningham, K. Lucke and R. Dooling (2016). Communication masking in marine mammals: A review and research strategy. Marine Pollution Bulletin 103(1): 15-38.

13 Gassmann, M., L. B. Kindberg, S. M. Wiggins and J. A. Hildebrand (2017b). Underwater noise comparison of pre- and post-retrofitted MAERSK G-class container vessels. Scripps Institution of Oceanography, MPL TM-616. http://cetus-ucsd.edu/publications/Reports/GrassmanMPLTM616-2017.pdf

14 Gassmann, M., S. M. Wiggins and J. A. Hildebrand (2017a). Deep-water measurements of container ship radiated noise signatures and directionality. The Journal of the Acoustical Society of America 142(3): 1563-1574.

15 Halliday, W. D., S. J. Insley, R. C. Hilliard, T. de Jong and M. K. Pine (2017). Potential impacts of shipping noise on marine mammals in the western Canadian Arctic. Marine Pollution Bulletin 123(1): 73-82.

16 Hatch, L. T., C. M. Wahle, J. Gedamke, J. Harrison, B. Laws, S. E. Moore, J. H. Stadler and S. M. Van Parijs (2016). Can you hear me here? Managing acoustic habitat in US waters. Endangered Species Research 30: 171-186.

17 Hermannsen, L., K. Beedholm, J. Tougaard and P. T. Madsen (2014). High frequency components of ship noise in shallow water with a discussion of implications for harbor porpoises (Phocoena phocoena). The Journal of the Acoustical Society of America 136(4): 1640-1653.

18 Holles, S., S. D. Simpson, A. N. Radford, L. Berten and D. Lecchini (2013). Boat noise disrupts orientation behaviour in a coral reef fish. Marine Ecology Progress Series 485: 295-300.

19 Jansen, H. W. and C. A. F. d. Jong (2015). Experimental assessment of underwater radiated sound of different ship types. OCEANS 2015 - Genova.

20 Jones, E. L., G. D. Hastie, S. Smout, J. Onoufriou, N. D. Merchant, K. L. Brookes and D. Thompson (2017). Seals and shipping: quantifying population risk and individual exposute to vessel noise. Journal of Applied Ecology 54(6): 1930-1940. Doi: 10.1111/1365-2664.12911.

21 Kinda, G. B., F. Le Courtois and Y. Stéphan (2017). Ambient noise dynamics in a heavy shipping area. Marine Pollution Bulletin 124(1): 535-546.

22 Kunc, H., K. McLaughlin and R. Schmidt (2016). Aquatic noise pollution: implications for individuals, populations, and ecosystems. Proc. R. Soc. B 283(1836). Doi: 10.1098/rspb.2016.0837.

23 Leaper, R., M. Renilson and C. Ryan (2014). Reducing underwater noise from large commercial ships: current status and future directions. Journal of Ocean Technology 9(1): 51-69.

24 Liu, M., L. Dong, M. Lin and S. Li (2017). Broadband ship noise and its potential impacts on Indo-Pacific humpback dolphins: Implications for conservation and management. J Acoust Soc Am 142(5): 2766.

25 Marley, S. A., C. P. Salgado Kent, C. Erbe and I. M. Parnum (2017). Effects of vessel traffic and underwater noise on the movement, behaviour and vocalisations of bottlenose dolphins in an urbanised estuary. Scientific Reports 7(1): 13437.

26 McDonald, M. A., J. Hildebrand and S. M. Wiggins (2006). Increases in deep ocean ambient noise in the northeast Pacific west of San Nicolas Island, California. Journal of the Acoustical Society of America 120: 711-718.

27 McKenna, M., C. Gabriele and B. Kipple (2017). Effects of marine vessel management on the underwater acoustic environment of Glacier Bay National Park, AK. Ocean and Coastal Management 139: 102-112. Doi: 10.1016/jocecoman.2017.01.015.

28 Merchant, N. D., K. L. Brookes, R. C. Faulkner, A. W. J. Bicknell, B. J. Godley and M. J. Witt (2016). Underwater noise levels in UK waters. Scientific Reports 6: 36942.

29 Miksis-Olds, J. L., D. L. Bradley and X. Maggie Niu (2013). Decadal trends in Indian Ocean ambient sound. The Journal of the Acoustical Society of America 134(5): 3464-3475.

30 Miksis-Olds, J. L. and S. M. Nichols (2016). Is low frequency ocean sound increasing globally? J Acoust Soc Am 139(1): 501-511.

31 New, L. F., J. S. Clark, D. P. Costa, E. Fleishman, M. A. Hindell, T. Klanjšček, D. Lusseau, S. Kraus, C. R. McMahon, P. W. Robinson, R. S. Schick, L. K. Schwarz, S. E. Simmons, L. Thomas, P. Tyack and J. Harwood (2014). Using short-term measures of behaviour to estimate long-term fitness of southern elephant seals. Marine Ecology Progress Series 496: 99-108.

32 Putland, R. L., N. D. Merchant, A. Farcas and C. A. Radford (2017). Vessel noise cuts down communication space for vocalizing fish and marine mammals. Global Change Biology 2017; [Early view] 00: 1-14. https://doi.org/10.111/gcb.13966

33 Radford, A. N., E. Kerridge and S. D. Simpson (2014). Acoustic communication in a noisy world: can fish compete with anthropogenic noise? Behavioral Ecology 25(5): 1022-1030.

34 Redfern, J. V., L. T. Hatch, C. Caldow, M. L. DeAngelis, J. Gedamke, S. Hastings, L. Henderson, M. F. McKenna, T. J. Moore and M. B. Porter (2017). Assessing the risk of chronic shipping noise to baleen whales off Southern California, USA. Endangered Species Research 32: 153-167.

35 Sigray, P., M. Andersson, J. Pajala, J. Laanearu, A. Klauson, J. Tegowski, M. Boethling, J. Fischer, J. Tougaard, M. Wahlberg, A. Nikolopoulos, T. Folegot, R. Matuschek and U. Verfuss (2016). BIAS: A Regional Management of Underwater Sound in the Baltic Sea. Adv Exp Med Biol 875: 1015-1023.

36 Simard, Y., N. Roy, C. Gervaise and S. Giard (2016). Analysis and modeling of 255 source levels of merchant ships from an acoustic observatory along St. Lawrence Seaway. J Acoust Soc Am 140(3): 2002.

37 Simpson, S. D., J. Purser and A. N. Radford (2015). Anthropogenic noise compromises antipredator behaviour in European eels. Glob Chang Biol 21(2): 586-593.

38 Solan, M., C. Hauton, J. A. Godbold, C. L. Wood, T. G. Leighton and P. White (2016). Anthropogenic sources of underwater sound can modify how sediment-dwelling invertebrates mediate ecosystem properties. Scientific Reports 6: 20540. Doi: 10.1038/srep20540.

39 Stanley, J. A., S. M. Van Parijs and L. T. Hatch (2017). Underwater sound from vessel traffic reduces the effective communication range in Atlantic cod and haddock. Scientific Reports 7(1): 14633.

40 Veirs, S., V. Veirs, R. Williams, M. Jasny and J. Wood (2017). A key to quieter seas: half of ship noise comes from 15% of the fleet. Authorea. Doi: 10.22541/au.149039726.69540798. https://www.authorea.com/users/5650/articles/162394

41 Veirs, S., V. Veirs and J. D. Wood (2016). Ship noise extends to frequencies used for echolocation by endangered killer whales. PeerJ 4: e1657.

42 Viola, S., R. Grammauta, V. Sciacca, G. Bellia, L. Beranzoli, G. Buscaino, F. Caruso, F. Chierici, G. Cuttone, A. D'Amico, V. De Luca, D. Embriaco, P. Favali, G. Giovanetti, G. Marinaro, S. Mazzola, F. Filiciotto, G. Pavan, C. Pellegrino, S. Pulvirenti, F. Simeone, F. Speziale and G. Riccobene (2017). Continuous monitoring of noise levels in the Gulf of Catania (Ionian Sea). Study of correlation with ship traffic. Marine Pollution Bulletin 121(1): 97-103.

43 Williams, R., L. Thomas, E. Ashe, C. W. Clark and P. S. Hammond (2016). Gauging allowable harm limits to cumulative, sub-lethal effects of human activities on wildlife: A case-study approach using two whale populations. Marine Policy 70(Supplement C): 58-64.