A Way Forward:

Twelve Important Actions to Reduce Ocean Noise

June 2018

Oceans are our oxygen. They feed us with fish, shellfish and seaweed. Their waters cover over 70 per cent of the Earth's surface. This vast environment is home to a broader range of higher animal taxa than exist on land. Most ocean species rely on sound for their vital life functions, including communication, orientation, prey and predator detection, and for sensing surroundings. Yet, levels of noise in the ocean have doubled in some regions, every decade for the past 60 years. Increasing ocean noise (anthropogenic underwater noise) is a trend now threatening many ocean species and populations.[1] The industries generating this noise need to be held more accountable for the impact they create.

OceanCare proposes twelve important actions for governments to embrace to reduce this alarming trend:

1. Include specific language in the United Nations General Assembly Oceans Resolution, Sustainable Fisheries Resolution, and within domestic legislation, to explicitly recognise ocean noise as a serious and pervasive form of transboundary pollution to be mitigated and addressed.
2. Progress a global strategy that seeks to reverse the trend of rising ocean noise levels.
3. Support the incorporation of measures to manage ocean noise into the new international legally binding instrument on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction under the UN Convention on the Law of the Sea.
4. Recognise ocean noise as a form of marine pollution to be addressed under Sustainable Development Goal 14.1 which seeks to prevent and significantly reduce marine pollution of all kinds by 2025.
5. Adopt a precautionary approach, by carefully assessing all future ocean noise-generating activities and legislating for Best Available Technology and Best Environmental Practice to be used for any activities given approval.
6. Transpose the International Maritime Organization Ship Quieting Guidelines and the Convention on Migratory Species Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities into domestic legislation.
7. Implement monetary and management measures which allow for a transition from fossil fuels.
8. Require robust, comprehensive and transparent Environmental Impact Assessments prior to approval of applications for noise-generating activities to take place.
9. Ensure regulators and decision-makers have robust, defensible, and impartial information on which to base their decisions about ocean noise-generating activities.
10. Take into account previous, simultaneous, on-going, and planned activities in the same or adjoining areas of proposed ocean noise-generating activities to consider potential cumulative or synergistic impacts, both from other noise and non-noise threats.
11. Establish 'quiet zones', using scientific advice contained in Areas of Interest for Important Marine Mammal Areas and Ecologically or Biologically Significant Marine Areas to assist with prioritising where to focus efforts.
12. Support and encourage the Food and Agriculture Organization to conduct studies on the impacts of ocean noise on fish, invertebrates and fish catch rates, as well as associated socioeconomic effects.

Ocean Species and Noise

While the ocean is certainly a sound-filled environment and many natural sounds are very loud (wind, ice breaking, etc.), ocean species including fish, crustaceans (crayfish, prawns, krill), molluscs (clams, mussels, oyster, other shellfish, as well as cephalopods such as squid and octopuses), pinnipeds (seals, sea lions, walrus), sirenians (dugong, manatee), sea turtles, marine otters, and cetaceans (whales, dolphins, porpoises) are not generally adapted to anthropogenic (human-generated) ocean noise.[2] When exposed to elevated or prolonged ocean noise they can be stressed, physically injured or even killed. Some impacts can harm entire populations.[3]

Tissue Damage, Hearing Loss and Masking

Species exposed to ocean noise can experience damage from either component of sound-pressure or particle motion. Particle motion is relevant for invertebrates such as crustaceans and molluscs, and for fish. Where sound pressure in the marine environment naturally acts in all directions, particle motion is an oscillation back and forth in a particular direction. Studies have shown that commercial fish catch rates drop substantially, with larger fish leaving an area coincident with noise events and that increased bycatch rates and decreased fish abundance have been observed in the presence of ocean noise.[4]

Many other ocean species, especially marine mammals, can suffer hearing impairment (temporary or permanent hearing threshold shifts), compromising their communication and ability to detect threats.[5] Noise can also mask important natural sounds, such as the call of a mate, the sound made by prey or the noise made by a predator.

All of these mechanisms, as well as factors such as stress, distraction, confusion, and panic, can affect reproduction and growth rates of many marine species, in turn influencing the long-term welfare of populations.[6]

Table one: Potential impact of anthropogenic ocean noise exposure on fish, marine mammals, and other marine life[7]

Impact	Effects on animal
Mortality	Death from damage sustained during ocean noise exposure
Injury to tissues; disruption of physiology	Damage to body tissues, such as internal haemorrhaging, injury of gas-filled organs like the swim bladder, poor immune response, stress
Damage to the auditory system	Injury to hearing or sensory organs (hair cells, statocycsts), temporary or permanent hearing impairment (threshold shifts)
Masking	Obliteration of biologically important sounds including sounds from other members of the same group or population
Behavioural changes	Interruption of normal activities including feeding, reproduction, schooling, migration, and displacement from favoured areas
These effects will vary depending on various factors such as the noise level, distance, and other contextual variables.	

Decompression Sickness

Decompression sickness (often called 'the bends' in human divers) is a specific threat for air-breathing species, such as deep-diving whales and turtles[8]. Decompression sickness is caused by nitrogen gas uptake in blood and tissues under pressure. With increased depth, the amount of nitrogen that is

absorbed by the blood and tissues increases. The tissues of breath-holding whales become highly saturated under certain circumstances, such as deep diving.[9] Most species able to dive to depths are adapted to surface (and decompress) at a speed that allows the dissolved gas to dissipate. During noise exposure, panic may cause whales to change their dive pattern and prevent proper elimination of the nitrogen.[10] Gas bubbles may form, causing harmful or fatal lesions inside the tissues if they block blood vessels or rupture.

Recent observations have shown that marine mammals and turtles can be affected by decompression sickness.[11] Looking at species-specific variability in bubble presence among stranded animals, scientists have found the deeper divers (*Kogia, Physeter, Ziphius, Mesoplodon, Globicephala,* and *Grampus*) to have higher abundances of nitrogen bubbles and associated lesions, when their dive pattern is altered.[12] There is a well-documented association between naval active sonar exercises (particularly mid-frequency active sonar) and beaked whale mass strandings.[13]

Ocean Noise

Anthropogenic ocean noise-generating activities are most commonly divided into 'non-impulsive' and 'impulsive' noise. Non-impulsive ocean noise is typically a constant drone, generated by shipping, offshore oil and gas rigs, and offshore windfarms. Impulsive ocean noise consists of intense short pulses of very loud sound, repeated over a period of time. This noise is generated by oil and gas seismic exploration, military and civilian active sonar systems, pingers, and industrial construction work such as pile driving. A list of ocean noise-generating activities is provided in Table two (below).

Predicting how noise will spread in the ocean is complex and requires many variables to be carefully considered[14]. Noise spreading or propagation is affected by the frequency of the sound, water depth, density differences within the water column. The latter varies with temperature, salinity, and pressure. The ocean bottom influences propagation as well.[15] Consequently, assessing noise propagation should be conducted through independent, scientific modelling which is verified in the field, to fully understand noise propagation characteristics.

Table two: Ocean Noise-generating Activities[16]

Sound	Sound Intensity Level (dB re 1µPa *)	Bandwidth
Military		
Low-Frequency Active Sonar	240 Peak @ 1m #	<1kHz- 1kHz
Military Mid-Frequency Active Sonar	235 Peak @ 1m	1-8kHz
Continuous Active Sonar	182 Peak @ 1m	500Hz – 3kHz
Military Mine Counter Measures Sonar	[unknown]	100kHz-500kHz
Seismic Surveys		
Seismic Surveys	260-262 Peak to Peak @ 1m	10Hz-150kHz
Civil High Power Sonar		
Single Beam Sounders	240 Peak @ 1m	12kHz-700kHz depending on the application
Sidescan Sonar	240 Peak @ 1m	12kHz-700kHz depending on the application

Multibeam Echosounders	240 Peak @ 1m	12kHz-30kHz, 70kHz-200kHz, 300kHz-500kHz depending on the application
Sparkers and Boomers	204-220$_{rms}$ @ 1m	80Hz-10kHz
Chirps	210-230 Peak @ 1m	20Hz-20kHz
Coastal and Offshore Construction Works		
Explosions, TNT 1-100lbs	272-287 Peak @ 1m	2Hz-~1,000Hz
Pile Driving	248-257 Peak to Peak @ 1m	20Hz-20kHz
Dredging	168-186 $_{rms}$ @ 1m	20Hz-1kHz
Offshore Platforms		
Platform Drilling	150 $_{rms}$ @1m	30Hz-40Hz
Drill Ships (including maintenance)	190 $_{rms}$ @ 1m	10Hz-10kHz
Positioning transponders	100 $_{rms}$ @ 2km	20kHz – 35kHz
Playback and Sound Exposure Experiments		
Ocean Tomography	165-220 Peak @ 1m	50Hz-200Hz
Shipping and Vessel Traffic		
Small Vessels	160-180 $_{rms}$ @ 1m	20Hz-10kHz
Medium Vessels	165-180 $_{rms}$ @1m	Below 1kHz
Large Vessels	Low Frequency 180-190 $_{rms}$ @ 1m, High Frequency 136 $_{rms}$ @ 700m	350 Hz-45 kHz
Pingers		
Acoustic Navigation Beacons	160-190 Peak @ 1m	8kHz-16kHz
Acoustic Deterrent Devices	130-135 Peak @ 1m	9kHz-15kHz
Acoustic Harassment Devices	190 Peak @ 1m	5kHz-20kHz, 30kHz-160kHz depending on the application
Other Noise-generating Activities		
Acoustic Data Transmission	185-196 @ 1m	18kHz-40kHz
Offshore Tidal and Wave Energy Turbines	165-175 $_{rms}$ @ 1m	10Hz-50kHz
Wind Turbines	90-112 $_{rms}$ @ 110m	50Hz-20kHz

* dB = decibles | 1µPa = 1 micropascal
# @ 1m = at one metre

Recommended Principles to Reduce Ocean Noise

OceanCare recommends embracing a series of core principles to address ocean noise. These should underpin domestic and international legislation and policy responses relating to ocean noise mitigation.

Recognise Ocean Noise as a Serious and Pervasive Form of Pollution

There is no oceanic region of the world not impacted by ocean noise. The United Nations Convention on the Law of the Sea (UNCLOS) does not specifically mention noise pollution. However, sound is a form of energy, and noise should be recognised as a form of pollution in the ocean environment.

Including specific language in the United Nations General Assembly (UNGA) Oceans Resolution, Sustainable Fisheries Resolution, and domestic legislation, to explicitly recognise ocean noise as a serious and pervasive form of transboundary pollution that should be mitigated and addressed under the Sustainable Developed Goal 14.1 will promote international consistency with that interpretation.

Ocean Noise and International Coordination

A global strategy that seeks to reverse the trend of rising ocean noise levels is urgently needed. Such a strategy could further define best practice and policy measures to reduce ocean noise and mitigate its impacts; provide a framework and a platform for dialogue and cooperation between stakeholders; and provide a science and policy interface that aids policy development and solution delivery.

Ocean Noise and the High Seas

The transboundary and cross-sectoral challenges of addressing ocean noise on the high seas requires special consideration. The negotiations of the new international legally binding instrument on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction presents an important opportunity to substantially advance the management of ocean noise by incorporating measures to prevent, reduce and control ocean noise in the high seas.

Ocean Noise and the Sustainable Development Goals (SDGs)

Central to the United Nation's 2030 Agenda for Sustainable Development are the seventeen Sustainable Development Goals (SDGs)[17] that are to shape national development plans over the period to come.

The most direct relevance to ocean noise is within SDG 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development that establishes the need for ocean conservation as a global priority. Specifically, SDG 14.1 seeks to prevent and significantly reduce marine pollution of all kinds by 2025. The socioeconomic and cultural aspects of ocean protection in SDG 14 is interconnected with the other SDGs, particularly with regard to the wide range of ecosystem services that humans derive from the oceans.

The commitment to eradicate poverty and hunger are overarching objectives of the SDG agenda and captured specifically in SDG 1: End poverty in all its forms everywhere and SDG 2: End hunger, achieve food security and improve nutrition and promote sustainable agriculture. It is clear that fisheries are of significant importance for these ambitious goals. An estimated 56.6 million people around the world depend on the fisheries and aquaculture sector as a full or part time source of income and livelihood. Small scale fisheries play a critical role in supporting livelihoods and reducing poverty for the millions of people that live in coastal communities. However the world's marine fisheries have been declining since 1996, creating an imminent threat to both food and income security for millions of people. By 2050, it is estimated that there will be more than 9.7 billion people to feed globally[18] and with fisheries already on a downward decline, the added impact of ocean noise must be systematically addressed.

The multi-layered relationship between fossil fuel extraction, climate change, and ocean noise is also important. Climate change is now recognised as the biggest global threat to sustainable development and the 2015 Paris Agreement sets the stage for ambitious climate action to keep global temperatures from rising no more than two degrees Celsius above pre-industrial levels and to pursue further efforts to limit the rise to 1.5 degrees Celsius. It is recognised that a move towards cleaner energy sources, and a removal of fossil fuel subsidies is crucial if these targets are to be achieved.[19] Abiding by the Paris Agreement means that 80 per cent of all proven fossil fuel reserves will become stranded resources and investments already made in such resources will turn into stranded assets.[20] Fossil fuel exploration represents significant sources of ocean noise. This makes further exploration an environmental cost, with no material benefit. Climate change is changing the way in which the ocean carries sound. Studies conducted in the Arctic have found that sound now travels about four times further than a decade ago.[21] This change is thought to be connected to warmer layers of sea ice allowing for greater propagation of sound waves. For all these reasons, efforts to move away from fossil fuels will be beneficial in tackling both climate change and ocean noise pollution and achieving SDG 13: Take urgent action to combat climate change and its impacts.

Ocean noise has relevance across many of the other SDGs. Domestic policies should integrate ocean noise mitigation within their work towards the SDGs.

Ocean Noise and the Precautionary Principle, Best Available Technology (BAT) and Best Environmental Practice (BEP)

Introducing the precautionary principle, Rio Declaration Principle 15 states that '*where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation*'. Precaution involves the systematic application of risk assessment, risk management and risk communication. When there is reasonable suspicion of harm, decision-makers need to apply precaution and consider the degree of uncertainty that appears from scientific evaluation. The use of the Best Available Technology (BAT) and Best Environmental Practice (BEP) for all noise-generating activities is an appropriate response to the precautionary principle.

Employing BAT is well established in a number of sectors, and includes quieter technologies, such as marine vibroseis in place of conventional seismic surveys.[22] Other examples include the use of bubble curtains surrounding pile driving activities.[23]

BEP is also well established, including the consideration of simultaneous, on-going, and planned activities in the same or adjoining areas to consider potential cumulative or synergistic impacts. A number of international guidelines have been developed to assist with developing domestic BEP, including the International Maritime Organization Ship Quieting Guidelines and the Convention on Migratory Species Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities.

Removing subsidies for the oil and gas industry and spending public money in line with the objectives of the 2015 Paris Agreement on Climate Change will assist smooth transitions to BAT and BEP.

Regulatory mechanisms should require BAT and BEP and ensure that operators demonstrate they are not proposing or using sources that are more powerful than necessary and at unnecessary frequencies.

Recommended Practice to Reduce Ocean Noise

OceanCare also recommends a series of actions. These should become core to the assessment of ocean noise and the protection of ocean species from noise.

Environmental Impact Assessments

Few jurisdictions have articulated what detail should be provide to decision-makers at the assessment stage, before approvals are given for a noise-generating activity to proceed.[24]

The purpose of Environmental Impact Assessments (EIAs) for ocean noise-generating industries should be to determine the level of impact on ocean species and the wider ecosystem, including fisheries dependent on that ecosystem.[25] Evidence shows that many current EIAs are insufficiently researched, drawing heavily from previous assessments.[26]

Independent, scientific modelling of ocean noise transmission should form the basis of defensible EIAs. This information, if transparently supplied, will provide regulators and decision-makers with robust, defensible, and impartial information on which to base their decisions. Only with this level of information can the risks of proposed noise-generating activities be weighed against alternatives.

The Convention on Migratory Species Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities (CMS Noise EIA Guidelines) provide an important and useful instrument to manage ocean noise at the planning and approval stages. They should be embraced by all governments. The Technical Support Information to the CMS Noise Guidelines provides clear articulation of the factors that must be considered within defensible EIAs.

Quiet Zones

Another important tool to consider is establishing 'quiet zones'. These zones can be established to prevent high-risk noise-generating activities (including, seismic surveys for oil and gas, extraction and military training) from endangering ocean species, their prey, and the fisheries that depend on them, in critical habitat areas. They are protected areas over sensitive or critical habitats, where ocean noise-generating activities are prohibited from operating within the zone's boundaries, and where time and space management measures (buffer zones) buffer ocean noise transmitting into these areas from outside.

Scientific advice such as Areas of Interest for Important Marine Mammal Areas (IMMAs) and Ecologically or Biologically Significant Marine Areas (EBSAs) can assist in prioritising where to establish quiet zones.

Assessment of Socioeconomic Impact of Noise on Fish and Fisheries

Increasing noise levels in the ocean presents a growing threat to fish stocks and the sustainability of fisheries globally.

The Sustainable Fisheries Resolution (A/RES/68/71) of the UNGA encourages the Food and Agriculture Organization (FAO) to consider this issue closely. Specifically it '*[e]ncourages further studies, including by the Food and Agriculture Organization of the United Nations, on the impacts of underwater noise on fish stocks and fishing catch rates, as well as associated socioeconomic effects*'. [27]

A review of existing evidence relating to the impacts of ocean noise on fish and invertebrates, and expert analysis of the socioeconomic impacts of ocean noise in the context of fish and fisheries is urgently needed. It would provide crucial information to FAO and its Members regarding the risks to the sustainability of fish and marine invertebrate populations and the fisheries that depend upon them. It could also identify costs and benefits to different stakeholders associated with potential legal and policy actions to prevent, reduce and control ocean noise as provided in UNCLOS, empowering decision makers with the tools to develop effective strategies and action plans as well as supporting government efforts to achieve SDG14 and other applicable SDGs.

Twelve Important Actions to Reduce Ocean Noise

Reducing ocean noise can be addressed through twelve key actions. Government decision-makers should:

Recognise Ocean Noise as a Serious and Pervasive Form of Pollution

1. Include specific language in the UNGA Oceans Resolution, Sustainable Fisheries Resolution, and domestic legislation, to explicitly recognise ocean noise as a serious and pervasive form of transboundary pollution that should be mitigated and addressed.

Ocean Noise and International Coordination

2. Progress a global strategy that seeks to reverse the trend of rising ocean noise levels.

Ocean Noise and the High Seas

3. Support the incorporation of measures to manage ocean noise into the new international legally binding instrument on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction under the UN Convention on the Law of the Sea (BBNJ).

Ocean Noise and the Sustainable Development Goals (SDGs)

4. Recognise ocean noise as a marine pollution issue under SDG14.1 which seeks to prevent and significantly reduce marine pollution of all kinds by 2025.

Ocean Noise and the Precautionary Principle, Best Available Technology (BAT) and Best Environmental Practice (BEP)

5. Adopt a precautionary approach, by:
   a. carefully assessing all future activities that have the potential to be sources of ocean noise.
   b. legislating for Best Available Technology and Best Environmental Practice, such as marine vibroseis and bubble curtains.
6. Transpose the International Maritime Organization Ship Quieting Guidelines and the Convention on Migratory Species Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities into domestic legislation.
7. Implement monetary and management measures which allow for a move away from fossil fuels and towards increased use of greener energy in recognition of the climate change targets set by the 2015 Paris Agreement and the need to reduce ocean noise pollution from these sources.

Environmental Impact Assessments

8. Require robust, comprehensive and transparent Environmental Impact Assessments prior to approval of applications for noise generating activities to take place.
9. Ensure regulators and decision-makers have robust, defensible, and impartial information on which to base their decisions about ocean noise-generating activities, based on independent, scientific modelling to fully understand noise propagation characteristics for all proposed ocean noise-generating activities.
10. Take into account previous, simultaneous, on-going, and planned activities in the same or adjoining areas to ocean noise-generating activities, to consider potential cumulative or synergistic impacts, both from other noise and non-noise threats.

Quiet Zones

11. Establish 'quiet zones', using scientific advice contained in Areas of Interest for Important Marine Mammal Areas and Ecologically or Biologically Significant Marine Areas to assist with prioritising where to establish quiet zones.

Assessment of Socioeconomic Impact of Noise on Fish and Fisheries

12. Support and encourage the Food and Agriculture Organization to conduct studies on the impacts of ocean noise on fish, invertebrates and fish catch rates, as well as associated socioeconomic effects.

References

1 McDonald MA, Hildebrand JA, Wiggins SM. (2006). Increases in deep ocean ambient noise in the Northeast Pacific west of San Nicolas Island, California. The Journal of the Acoustical Society of America 120(2): 711-718; Weilgart, L. (2007). The impacts of anthropogenic ocean noise on cetaceans and implications for management. Canadian Journal of Zoology 85(11): 1091-1116; Prideaux G. (2017). Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities, Convention on Migratory Species of Wild Animals, Bonn.

2 Weilgart, L. (2018). The Impact of Ocean Noise Pollution on Fish and Invertebrates. Report for OceanCare, Switzerland ; Madsen, P., B. Møhl, et al. (2002). Male sperm whale behavior during exposures to distant seismic survey pulses. Aquatic Mammals 28(3): 231-240; Gordon, J., D. Gillespie, et al. (2003). A Review of the Effects of Seismic Surveys on Marine Mammals Marine Technology Society Journal 37(4): 16-34; Hassel A, Knutsen T, Dalen J, Skaar K, Løkkeborg S, Misund OA, Østensen Ø, Fonn M, Haugland EK. (2004). Influence of seismic shooting on the lesser sandeel (Ammodytes marinus). ICES Journal of Marine Science. 61(7):1165-73.; Parry, G. and A. Gason (2006). The effect of seismic surveys on catch rates of rock lobsters in western Victoria, Australia. Fisheries Research 79(3): 272-284; Stone, C. and M. Tasker (2006). The Effect of Seismic Air Guns on Cetaceans in UK Waters. Journal of Cetacean Research and Management 8: 255–263; Hodgson, A. and H. Marsh (2007). Response of dugongs to boat traffic: The risk of disturbance and displacement. Journal of Experimental Marine Biology and Ecology 305: 50–61; Nowacek, D., L. Thorne, et al. (2007). Responses of cetaceans to anthropogenic noise. Mammal Review 37: 81-115; Weilgart, L. (2007). The impacts of anthropogenic ocean noise on cetaceans and implications for management. Canadian Journal of Zoology 85(11): 1091-1116; McCauley, R. and J. Fewtrell (2008). Marine Invertebrates, Intense Anthropogenic Noise & Squid Response to Seismic Survey Pulses. Bioacoustics 17(1–3): 315–318; Miller, L., M. Solangi, et al. (2008). Immediate response of Atlantic bottlenose dolphins to high-speed personal watercraft in the Mississippi Sound. Journal of the Marine Biological Association of the United Kingdom 88(Special Issue 06): 1139-1143; Payne, J., C. Andrews, et al. (2008). Potential Effects of Seismic Energy on Fish and Shellfish: An Update Since 2003. Canadian Science Advisory Secretariat. Ottawa. Research Document 2008/060; Gedamke J, Gales N, Frydman S. (2011). Assessing risk of baleen whale hearing loss from seismic surveys: The effect of uncertainty and individual variation. J. Acoust. Soc. Am. 129(1): 496–506; Gray, H. and K. Van Waerebeek (2011). Postural instability and akinesia in a pantropical spotted dolphin, Stenella attenuata, in proximity to operating airguns of a geophysical seismic vessel. Journal for Nature Conservation 19(6): 363-367; de Soto, N., N. Delorme, et al. (2013). Anthropogenic noise causes body malformations and delays development in marine larvae. Scientific Reports 3(2831): 1-5; Wale, M. A., S. D. Simpson, et al. (2013). Noise negatively affects foraging and antipredator behaviour in shore crabs. Animal Behaviour 86(1): 111-118; Morley, E., G. Jones, et al. (2014). The importance of invertebrates when considering the impacts of anthropogenic noise. Proceedings of the Royal Society of London B: Biological Sciences 281(1776): 20132683; Simpson, S. D., J. Purser, et al. (2015). Anthropogenic noise compromises antipredator behaviour in European eels. Global change biology 21(2): 586-593.

3 McCauley RD, Day RD, Swadling KM, Fitzgibbon QP, Watson RA, Semmens JM. Widely used marine seismic survey air gun operations negatively impact zooplankton. Nature ecology & evolution. 2017 Jul;1(7):0195; Day RD, McCauley RD, Fitzgibbon QP, Hartmann K, Semmens JM. Exposure to seismic air gun signals causes physiological harm and alters behavior in the scallop Pecten fumatus. Proceedings of the National Academy of Sciences. 2017 Oct 3;114(40):E8537-46; Fitzgibbon QP, Day RD, McCauley RD, Simon CJ, Semmens JM. The impact of seismic air gun exposure on the haemolymph physiology and nutritional condition of spiny lobster, Jasus edwardsii. Marine pollution bulletin. 2017 Dec 15;125(1-2):146-56; McCauley RD, Day RD, Swadling KM, Fitzgibbon QP, Watson RA, Semmens JM. Widely used marine seismic survey air gun operations negatively impact zooplankton. Nature ecology & evolution. 2017 Jul;1(7):0195.

4 Weilgart, L. (2018) The Impact of Ocean Noise Pollution on Fish and Invertebrates. Report for OceanCare, Switzerland

5 Southall, B., A. Bowles, et al. (2007). Marine mammal noise-exposure criteria: initial scientific recommendations. Bioacoustics 17(1-3): 273-275; Weilgart, L. (2007). The impacts of anthropogenic ocean noise on cetaceans and implications for management. Canadian Journal of Zoology 85(11): 1091-1116.

6 Southall, B., A. Bowles, et al. (2007). Marine mammal noise-exposure criteria: initial scientific recommendations. Bioacoustics 17(1-3): 273-275; Weilgart, L. (2007). The impacts of anthropogenic ocean noise on cetaceans and implications for management. Canadian Journal of Zoology 85(11): 1091-1116; Williams, R., C. Erbe, et al. (2015). Quiet (er) marine protected areas. Marine Pollution Bulletin; Clark, C., W. Ellison, et al. (2009). Acoustic Masking in Marine Ecosystems as a Function of Anthropogenic Sound Sources. Paper submitted to the 61st IWC Scientific Committee (SC-61 E10).

7 Hawkins, A. D. and A. Popper (2014). Assessing the impacts of underwater sounds on fishes and other forms of marine life. Acoust Today 10(2): 30-41.

8 Fahlman A, Hooker SK, Szowka A, Bostrom BL, Jones DR. (2009). Estimating the effect of lung collapse and pulmonary shunt on gas exchange during breath-hold diving: The Scholander and Kooyman legacy. Resp Physiol Neurobiol 165:28-39; Fahlman A, Olszowka A, Bostrom B, Jones DR. (2006). Deep diving mammals: Dive behavior and circulatory adjustments contribute to bends avoidance. Resp Physiol Neurobiol 153:66-77; Hooker SK, Fahlman A, Moore MJ, De Soto NA, de Quiros YB, Brubakk AO, Costa DP, Costidis AM, Dennison S, Falke KJ, Fernandez A, Ferrigno M, Fitz-Clarke JR, Garner MM, Houser DS, Jepson PD, Ketten DR, Kvadsheim PH, Madsen PT, Pollock NW, Rotstein DS, Rowles TK, Simmons SE, Van Bonn W, Weathersby PK, Weise MJ, Williams TM, Tyack PL. (2012). Deadly diving? Physiological and behavioural management of

decompression stress in diving mammals. P Roy Soc Lond B Bio 279:1041-1050 ; Párraga DG, Moore M, Fahlman A. Pulmonary ventilation–perfusion mismatch: a novel hypothesis for how diving vertebrates may avoid the bends. Proc. R. Soc. B. 2018 Apr 25;285(1877):20180482.

9 Lemaitre F, Fahlman A, Gardette B, Kohshi K. (2009). Decompression sickness in breath-hold divers: A review. J Sports Sci 27:1519-1534

10 Francis TJ, Mitchell SJ. Manifestations of decompression disorders. Bennett and Elliotts physiology and medicine of diving. 5th ed. London: Saunders. 2003:578-99.

11 Jepson PD, Deaville R, Patterson IAP, Pocknell AM, Ross HM, Baker JR, Howie FE, Reid RJ, Colloff A, Cunningham AA. (2005). Acute and chronic gas bubble lesions in cetaceans stranded in the United Kingdom. Vet Pathol 42:291-305 ; Dennison S, Moore MJ, Fahlman A, Moore K, Sharp S, Harry CT, Hoppe J, Niemeyer M, Lentell B, Wells RS. (2012). Bubbles in live-stranded dolphins. P Roy Soc Lond B Bio 279:1396-1404; Van Bonn W, Dennison S, Cook P, Fahlman A. (2013). Gas bubble disease in the brain of a living California sea lion (Zalophus californianus). Frontiers in Physiology 4:6; Garcia-Parraga D, Crespo-Picazo JL, de Quiros YB, Cervera V, Marti-Bonmati L, Diaz-Delgado J, Arbelo M, Moore MJ, Jepson PD, Fernandez A. (2014). Decompression sickness (the bends) in sea turtles. Dis Aquat Organ 111:191-205

12 Bernaldo de Quirós Y, González-Díaz Ó, Arbelo M, Sierra E, Sacchini S, Fernández A. (2012). Decompression versus decomposition: distribution, quantity and gas composition of bubbles in stranded marine mammals. Frontiers in Physiology 3

13 Jepson PD, Arbelo M, Deaville R, Patterson IAP, Castro P, Baker JR, Degollada E, Ross HM, Herraez P, Pocknell AM, Rodriguez F, Howie FE, Espinosa A, Reid RJ, Jaber JR, Martin V, Cunningham AA, Fernandez A. (2003). Gas-bubble lesions in stranded cetaceans. Nature 425:575-576; Cox TM, Ragen TJ, Read AJ, Vos E, Baird RW, Balcomb K, Barlow J, Caldwell J, Cranford T, Crum L, DAmico A, DSpain G, Fernandez A, Finneran J, Gentry R, Gerth W, Gulland F, Hildebrand J, Houser D, Hullar T, Jepson PD, Ketten D, MacLeod CD, Miller P, Moore S, Mountain DC, Palka D, Ponganis P, Rommel S, Rowles T, Taylor B, Tyack P, Wartzok D, Gisiner R, Mead J, Benner L. (2006). Understanding the impacts of anthropogenic sound on beaked whales. J Cetacean Res Manage 7:177-187; DAmico A, Gisiner RC, Ketten DR, Hammock JA, Johnson C, Tyack PL, Mead J. (2009). Beaked whale strandings and naval exercises. Aq Mamm 35:452-472; Hooker SK, Baird RW, Fahlman A. (2009). Could beaked whales get the bends? Effect of diving behaviour and physiology on modelled gas exchange for three species: Ziphius cavirostris, Mesoplodon densirostris and Hyperoodon ampullatus. Resp Physiol Neurobiol 167:235-246; Hooker SK, Fahlman A, Moore MJ, De Soto NA, de Quiros YB, Brubakk AO, Costa DP, Costidis AM, Dennison S, Falke KJ, Fernandez A, Ferrigno M, Fitz-Clarke JR, Garner MM, Houser DS, Jepson PD, Ketten DR, Kvadsheim PH, Madsen PT, Pollock NW, Rotstein DS, Rowles TK, Simmons SE, Van Bonn W, Weathersby PK, Weise MJ, Williams TM, Tyack PL. (2012). Deadly diving? Physiological and behavioural management of decompression stress in diving mammals. P Roy Soc Lond B Bio 279:1041-1050; Evans DL, England GR. (2001). Joint interim report Bahamas marine mammal stranding event of 15–16 March 2000 US Department of Commerce and US Navy, Washington, D.C; Jepson PD, Arbelo M, Deaville R, Patterson IAP, Castro P, Baker JR, Degollada E, Ross HM, Herraez P, Pocknell AM, Rodriguez F, Howie FE, Espinosa A, Reid RJ, Jaber JR, Martin V, Cunningham AA, Fernandez A. (2003). Gas-bubble lesions in stranded cetaceans. Nature 425:575-576

14 McCauley, R., J. Fewtrell, et al. (2000). Marine seismic surveys–a study of environmental implications. APEA Journal: 692-708; Calambokidis, J., T. Chandler, et al. (2002). Marine mammal observations and mitigation associated with USGS seismic-reflection surveys in the Santa Barbara Channel 2002. Final report prepared for US Geological Survey, Menlo Park, CA & National Marine Fisheries Service. Office of Protected Resources. Silver Spring MD, Prepared by Cascadia Research, Olympia, WA; Hildebrand, J. (2009). Anthropogenic and natural sources of ambient noise in the ocean. Marine Ecology Progress Series 395(5): 5–20; Lurton, X. (2010). An Introduction to Underwater Acoustics: Principles and Applications. Westport, Springer; Prideaux G. (2017). Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities, Convention on Migratory Species of Wild Animals, Bonn.

15 Wagstaff, R. (1981). Low-frequency ambient noise in the deep sound channel—The missing component. The Journal of the Acoustical Society of America 69(4): 1009-1014; Clay, C. and H. Medwin (1997). Acoustical Oceanography. New York, Wiley Interscience; Lurton, X. (2010). An Introduction to Underwater Acoustics: Principles and Applications. Westport, Springer; Etter, P. (2013). Underwater acoustic modeling and simulation. Boca Raton, CRC Press, Taylor & Francis Group.

16 Prideaux G. (2017). Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities, Convention on Migratory Species of Wild Animals, Bonn

17 United Nations Department of Public Information. (2017). Sustainable Development Goals, Sustainable development knowledge platform, at: https://sustainabledevelopment.un.org/sdgs

18 FAO. (2016). The State of World Fisheries and Aquaculture 2016. Contributing to food security and nutrition for all. Rome

19 United Nations Climate Change. (2015) Big Positive Climate Impact by Cutting Fossil Fuel Subsidies, United Nations Climate Change, at https://unfccc.int/news/big-positive-climate-impact-by-cutting-fossil-fuel-subsidies; B20 Germany (2017). Shaping an Interconnected World. Building Resilience – Improving Sustainability – Assuming Responsibility, B20 POLICY

RECOMMENDATIONS TO THE G20, B20 Germany, at https://www.b20germany.org/fileadmin/user_upload/documents/B20/b20-summary-doc-en.pdf ; Merrill L. (2015).Tackling fossil fuel subsidies and climate change: Levelling the energy playing field. Nordic Council of Ministers; Aldy JE. (2017). Policy surveillance in the G-20 fossil fuel subsidies agreement: lessons for climate policy. Climatic Change. 144(1):97-110.

20 Bos K, Gupta J. (2018). Climate change: the risks of stranded fossil fuel assets and resources to the developing world. Third World Quarterly. 39(3):436-53.

21 Freitag, L., Ball, K., Partan, J;, Koski, P., Sandipa, S. (2015) Long-range Acoustic Communication and Navigation in the Arctic. Conference Paper, 10.23919/OCEANS.2015, Washington DC; Nowogrodzki, A. (2017) Global Warming Is Changing How the Ocean Carries Sound, Oceans Deeply, News Deeply

22 Duncan AJ, Weilgart LS, Leaper R, Jasny M, Livermore S. A modelling comparison between received sound levels produced by a marine Vibroseis array and those from an airgun array for some typical seismic survey scenarios. Marine pollution bulletin. 2017 Jun 15;119(1):277-88.

23 Tsouvalas A, Metrikine AV. (2016) Noise reduction by the application of an air-bubble curtain in offshore pile driving. Journal of Sound and Vibration. 371:150-70.; Dähne M, Tougaard J, Carstensen J, Rose A, Nabe-Nielsen J. (2017). Bubble curtains attenuate noise from offshore wind farm construction and reduce temporary habitat loss for harbour porpoises. Marine Ecology Progress Series. 580:221-37.

24 Weir, C. and S. Dolman (2007). Comparative Review of the Regional Marine Mammal Mitigation Guidelines Implemented During Industrial Seismic Surveys, and Guidance Towards a Worldwide Standard. Journal of International Wildlife Law & Policy 10(1): 1-27; Prideaux, G. and M. Prideaux (2015). Environmental impact assessment guidelines for offshore petroleum exploration seismic surveys. Impact Assessment and Project Appraisal.

25 Hawkins, A. D. and A. Popper (2014). Assessing the impacts of underwater sounds on fishes and other forms of marine life. Acoust Today 10(2): 30-41.

26 Prideaux, G. and M. Prideaux (2015). Environmental impact assessment guidelines for offshore petroleum exploration seismic surveys. Impact Assessment and Project Appraisal published online December 2015.

27 United Nations General Assembly, (2014). Resolution adopted by the General Assembly on 9 December 2013, 68/71. Sustainable fisheries, including through the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and related instruments, United Nations, New York http://undocs.org/A/RES/68/71

Further information

OceanCare Contacts:

Nicolas Entrup nentrup@oceancare.org
Sigrid Lüber slueber@oceancare.org
Fabienne McLellan fmclellan@oceancare.org
Joanna Toole jtoole@oceancare.org

Supporting OceanCare:

Linda Weilgart linda.weilgart@dal.ca is available for scientific information about the impact of noise on marine species, noise-generating activities, and quieting technologies.

Lora Reeve lorareeve@globaloceanconsulting.com is available for information on managing ocean noise pollution through the new BBNJ instrument under UNCLOS.

Geoff Prideaux geoff@wildmigration.org is available for technical information about the elements of noise, noise-generating activities, ocean noise modelling, and the CMS Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities.

Margi Prideaux margi@wildmigration.org is available for technical information about the components of robust and defensible Environmental Impact Assessments.

About OceanCare

OceanCare has worked to protect oceans and marine life, worldwide, since 1989. Through research and conservation projects, environmental education campaigns, and significant involvement in inter-governmental and United Nations bodies, OceanCare engages in solution-oriented strategies to improve life in the oceans for the benefit of wildlife and the people who depend on them. In 2011, OceanCare was granted Special Consultative Status on ocean issues with the Economic and Social Council of the United Nations and, in 2015, was accredited as a Major Group to the United Nations Environment Assembly. OceanCare has active partnerships with a number of multilateral environment agreements.

OceanCare
Gerbestrasse 6
P.O. Box 372
CH-8820 Wädenswil
Switzerland
Tel: +41 (0) 44 780 66 88
Fax: +41 (0) 44 780 68 08
Email: info@oceancare.org
Web: www.oceancare.org