Marine noise pollution – signs of progress: a preliminary review.

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ABSTRACT

Marine noise pollution emerged as an issue of significance in the early 1990s. Since then various efforts have been made to help address it, and it has become an issue that the public and policy makers recognise as well as being a major focus of marine mammal research. Relevant legislation is in place to help mitigate effects in Europe and the US, and technological changes are being developed in response to concerns. Whilst many concerns remain, and it is too early to judge the impact of many of the relevant developments, marine noise pollution is clearly now a prominent mainstream issue for environmental management.

INTRODUCTION

Cetaceans live in a medium through which sound propagates extremely well and light does not. This explains their heavy reliance on acoustics for navigation, hunting and communication. It also helps to explain the increasing use of sound underwater by our species in our attempts to efficiently navigate, explore and exploit the seas and what lies beneath them. Cetacean conservation and welfare and human-produced sounds in the oceans are sometimes in conflict, and that includes both sound generated as an acoustic tool and that produced incidentally to other activities, notably shipping noise. Various substantive reviews have considered this topic in recent years (for example, Richardson *et al*., 1995; Gordon and Moscrop, 1996; NRC, 2003, Simmonds *et al.,* 2004; Hildebrand, 2005; Jasny 2005; and Weilgart, 2007).

The 2003 National Research Council report and Hildebrand's 2005 review identified the major marine noise sources and their characteristics These lists include commercial shipping (with sound emissions greatest in the 'great circle routes, coastal and port areas); seismic airgun arrays for oil and gas exploration (with emphasis on the continental shelf); naval sonars (variable below 70º latitude and with emphasis in coastal areas); fisheries sonars (primarily coastal and over the continental shelf); unknown research sonars; and acoustic deterrent and harassment devices used by fisheries and aquaculture facilities (again mainly in the coastal zone).

MILESTONES IN THE EMERGENCE OF MARINE NOISE POLLUTION AS A RECOGNISED THREAT

It was in the early 1990s that marine noise pollution first emerged as a significant environmental issue, by which we mean one that required regulation and management, including the attention of legislators. Various matters came together during this period. The ATOC project, mentioned below, brought the noise issue to the forefront in the media, but various atypical live strandings of groups of beaked and other whales, particularly repeated

stranding events on the shores of the Canary Islands, raised suspicion that marine noise could be having a greater impact than previously thought. The first published record that connected beaked whale strandings to military events was in 1991, when Simmonds and Lopez-Jurado (1991) reported that several beaked whale stranding events between 1982 and 1989 coincided with naval activities in the Canary Islands. Almost a decade later, there was a high profile stranding event in the Bahamas following a military exercise, where the first post-event evidence was gathered (Balcomb and Claridge, 2001; Parsons *et al*., 2008). Others subsequently came to light and the International Whaling Commission's Scientific Committee noted that "there is now compelling evidence implicating military sonar as a direct impact on beaked whales in particular". These and other atypical stranding were, as Jasny subsequently put it, a 'wake up call to a significant environmental problem' (Jasny, 2005; and see Dolman *et al*., 2010 for a summary of events).

The use of loud noise in an effort to measure ocean temperatures across entire ocean basins was another issue that caused considerable concern and gained public attention (e.g. Simmonds, 1992; Anon, 2013). Arguably, the Acoustic Thermometry of Ocean Climate (ATOC) experiment and its predecessor (the Heard Island Feasibility Test) set the scene for the requirement for formal Environmental Assessments to be made for noise-making activities. In 1995, Scripps Institute for Oceanography and the US Navy reached an agreement with several plaintiffs (including NRDC) to conduct a more extensive, multi-year Marine Mammal Research Programme together with the ATOC experiment. A year later, many of these same plaintiffs came an agreement with the U.S. Navy to establish a research programme to look at Low Frequency Active Sonar (Jasny, 2005).

Within a few years, some regional conventions acknowledged the significance of marine noise pollution to their interests, notably ACCOBAMS and ASCOBANS[1] (see Dolman *et al*., 2010 for a review). In 2003, anthropogenic noise was raised both at the second meeting of the ACCOBAMS Scientific Committee and also at the Advisory committee of ASCOBANS; various resolutions and actions followed (Dolman *et al*., 2010). These have included the 2007 ACCOBAMS 'Guidelines to address the impact of anthropogenic noise on marine mammals in the ACCOBAMS area' and resolution 4 adopted by the 5th meeting of the parties to ASCOBANS on Adverse Effects of Sound, Vessels and Other Forms of Disturbance on Small Cetaceans. This ''requested Parties and Range States to:

- develop, with military and other relevant authorities, effective mitigation measures including Environmental Impact Assessments and relevant standing orders to reduce disturbance of, and potential physical damage to small cetaceans;
- conduct research and develop appropriate management measures, guidelines and technological adaptations to minimise any adverse effects on small cetaceans of the above sound sources; and
- develop and implement procedures to assess the effectiveness of any guidelines or management measures introduced."

Generally the efforts of these agreements have focused on improving understanding of impacts through increased and co-ordinated research; critically examining existing management measures; and the development, implementation and reporting back on mitigation measures undertaken. OSPAR[2] has also produced reports on marine noise and the EU Marine Strategy Framework Directive is the first regulation that specifically addresses and mentions noise.

[1] ASCOBANS stands for the Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas and ACCOBAMS the Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and contiguous Atlantic area

[2] Convention for the Protection of the Marine Environment of the Northeast Atlantic

Another milestone on the road to addressing noise pollution was the substantive review conducted by the US Marine Mammal Commission (MMC). In 2004, the United States Congress directed the MMC to "fund an international conference or series of conferences to share findings, survey acoustic 'threats' to marine mammals, and develop means of reducing those threats while maintaining the oceans as a global highway of international commerce". The MMC duly convened an Advisory Committee on Acoustic Impacts on Marine Mammals and sponsored a series of meetings and workshops to gather information necessary to carry out the directive and prepare its report which was issued to Congress in March 2007 (Marine Mammal Commission, 2007). Among the Commission's recommendations were (i) the establishment of a coordinated national research program on the effects of anthropogenic sound on marine mammals and the marine environment; (ii) the establishment of consistent standards for the regulation of sound in the marine environment; and (iii) the promotion of U.S. leadership in international matters related to anthropogenic sound in the marine environment.

In a publication associated with the MMC's workshops, Cox *et al*. (2006) confirmed the plausibility of a newly-identified mechanism, known as "gas and fat embolic syndrome," behind the noise-related mortalities of beaked whales (Cox *et al*. 2006). This mechanism, which was principally brought to light by Fernandez and his laboratory at the Universidad de Las Palmas de Gran Canaria, and Jepson and his colleagues at the Zoological Society of London, was consistent with pathologies seen in sonar-stranded beaked whales, such as haemorrhaging around the brain and lesions in vital organ tissues (Jepson *et al*., 2003; Fernandez *et al*., 2005). The finding had significant implications for both research and management. For research, it opened up several lines of investigation into marine mammal diving physiology and the susceptibility of marine mammals to decompression sickness. For management, it raised profound questions about the effectiveness of near-source mitigation to prevent injury and death, since gas-bubble injury, being behaviourally mediated, could occur at much greater distances than those associated with direct acoustic trauma.

Importantly, in recent years the USA's Marine Mammal Protection Act's regulatory scheme has increasingly been applied to major producers of ocean noise, to the point where most "incidental take" authorisations issued under the Act are at least partly, and in many cases are primarily, focused on acoustic impacts (Roman *et al*., 2013). For example, although some significant gaps remain, most naval activities within the U.S. territorial sea and EEZ are now the subject of programmatic rulemakings; in the oil and gas sector, operators regularly apply for MMPA incidental harassment authorizations as a condition of their geophysical exploration permits in the Arctic.

To help managers address the impact thresholds outlined in the MMPA, Southall *et al*. (2007) reviewed the available literature and offered initial scientific guidance regarding avoiding injurious exposure to the different groups of marine mammals. However, Southall *et al*. (2007) specifically avoided providing suggestions regarding behavioural responses, primarily given the contextual complications. Some of the original issues, including further discussion of behavioural context, were subsequently addressed (Ellison *et al*., 2011); however, the guidance remains controversial, laden with caveats, requiring revision to reflect recent findings on auditory impacts, limited beyond injury, heavily US-centric, and increasingly outdated. Despite this, the Southall *et al*. (2007) review has become widely used by regulators and industries around the world as no alternative currently exists. However, work is in progress to revisit these criteria and the assumptions upon which they are based, with a wider, non-US focus (Tougaard *et al*. In prep.), and US regulators are themselves in the midst of heavily revising their behavioural guidelines for seismic surveys. Consequently, discussions regarding the appropriateness of various thresholds will continue.

Another key development was the involvement of *Okeanos – Foundation for the Sea*. This foundation advanced discussion of underwater noise, by funding and organising five seminal

workshops on critical and emergent topics: (1) spatio-temporal management (Agardy *et al*., 2007); (2) the interaction between noise and stress responses (Wright & Highfill, 2007); (3) the impacts and management of shipping noise (Wright, 2008); (4) the management of cumulative impacts (Wright, 2009); and (5) alternatives to airguns in seismic surveys (Weilgart, 2010). Independently funded, these workshops were attended by a wide variety of experts from more disparate fields leading to extremely productive, truly multi-disciplinary discussions. Perhaps the most notable outcome of these workshops, however, was the Hamburg Protocol, which called for a "reduction in the contributions of shipping to ambient noise energy in the 10-300 Hz band by 3dB in 10 years and by 10dB in 30 years relative to current levels" (Wright, 2008). The statement from all participants of the shipping workshop, including ship owners and engineers, contributed significantly to motivating the current IMO process for the development of voluntary guidelines for quieter commercial vessels (IMO 2013; see below).

In 1992, the EC Habitats Directive (92/43/EEC) came into force in Europe, requiring (among other things) that all relevant EU member states protect the harbour porpoise and bottlenose dolphin, pursuant to Annex II, by designating marine protected areas (MPAs), referred to as Special Areas of Conservation (SAC). Ross *et al*. (2011) since included consideration of noise in their advice to managers and conservation practitioners on the determination of which habitats are in need of protection for small coastal cetacean populations. The Habitats Directive also goes further, requiring strict protection for certain European Protected Species listed on Annex IV, including all cetaceans, throughout their entire range

The recent Marine Strategy Framework Directive (MSFD) (2008/56/EC) explicitly includes consideration of underwater noise in determinations of good environmental status (GES). Thus Member States are required to monitor and ultimately limit the amount of anthropogenic noise in European waters (see Van der Graaf *et al*., 2012). Time will tell how useful the MSFD noise indicator is to understand and mitigate noise to within environmental limits.

Several resolutions of the International Whaling Commission, including Resolutions 1997-7 and 1998-5, have directed the IWC's Scientific Committee (SC) to provide regular updates on environmental matters that affect cetaceans, including noise pollution, and its Scientific Committee has had noise pollution on its agenda since its 49th meeting in 1999 when it identified it as a priority for consideration (Simmonds and Dolman, 2000). In addition the Scientific Committee also reviews unusual mortality events.

Finally, steps towards a greater appreciation of cumulative impacts of noise have been taken in an increasing number of jurisdictions beyond the US. For example, in the guidelines for seismic survey EIAs in Greenland, Kyhn *et al*. (2011) suggest that a joint cross-company noise propagation model is prepared to inform the cumulative impact assessment. Cumulative impact assessment is also under way in Scotland, associated with the rapidly developing marine renewable energy industry, where a primary concern associated with the construction of large wind farms is the intense noise associated with pile driving turbines into the seabed.

THE DEVELOPMENT OF RELATED RESEARCH

Any appropriate search with a web browser will now find many hundreds of scientific papers concerning noise in the marine environment. Many are focused on impacts on marine wildlife and fisheries.

For some time much of this research has focused on physical impacts on cetaceans, especially their hearing and ears and the causes of atypical strandings. Emphasis has been given to introduced sounds within the frequency ranges that cetaceans use to vocalise but, very

recently, research has shown that sounds outside of this range may also be important and attention has expanded to include behavioural effects (e.g. Melcon *et al*., 2012).

Increasing attention has also been given to the range of potential effects that noise exposure might have. For example, increased fisheries bycatch through distraction has been suggested (e.g., Nielsen *et al*., 2012; Wright *et al*., 2013). Similarly, the potential for the acoustic startle reflex to generate fear conditioning has also been considered (Götz and& Janik, 2011). Noise-induced stress responses in marine mammals have risen to levels of serious consideration, rather than being often dismissed as speculation, following the discovery that cortisol levels were reduced in right whales during the period following the 9-11 attacks where the level of maritime traffic was substantially reduced (Rolland *et al*., 2012). In general, there is increasing awareness in the research and regulatory communities that noise can alter or undermine important biological processes (*e.g.*, Wright and Highfill, 2007).

Additionally, the complexity of assessing the consequences of noise exposure for hearing is being realised. For example, there has been the subjective loudness measurements in bottlenose dolphins (*Tursiops truncatus*: Finneran & Schlundt, 2011); the discovery of automatic gain control and flexible auditory brainstem responses in harbour porpoises (*Phocoena phocoena*: Linnenschmidt *et al*., 2012); the mechanism for differentiation between outgoing and returning clicks in harbour porpoises (Linnenschmidt & Beedholm, 2012); and the reduction in hearing sensitivity following a 'warning' sound (at almost TTS levels) in a false killer whale (*Pseudorca crassidens*: Nachtigall & Supin, 2013). All these revelations raise doubt over the M-weighted hearing functions proposed by Southall *et al*. (2007) and complicate issues such as masking and the onset of TTS and PTS. Furthermore, the potential for excitotoxicity and the permanent degeneration of cochlear afferent nerves associated with reversible TTS in mice (Kujawa & Liberman, 2009) also presents a serious challenge to the concept that PTS, rather than TTS, represents the onset of injury, as enshrined in Southall *et al*. (2007).

Increasingly, in-field Behavioural Response Studies (BRS) are underway to study diving behaviour and sound production of key noise-affected cetaceans in response to a variety of purposely-introduced anthropogenic noise stimuli (for example, Southall *et al*., 2012). Such studies have limitations, but are intended to focus key concerns and provide results that will inform management decisions. For example, recent studies using information from actual naval exercises over hydrophone-instrumented naval ranges and/or sonar playbacks and acoustic tags on whales have revealed far greater impacts on whales than previously thought at much lower received levels (McCarthy *et al*. 2011, Miller *et al*., 2012, Moretti *et al*., 2010, Pirotta *et al*., 2012, Tyack *et al,*. 2011). This has caused us to reassess the assumption by some that the mere presence of whales in a disturbed environment such as a naval range means they suffer no considerable impacts.

Degradation of the acoustic environment or acoustic "scene" is also increasingly seen as an important perspective deserving consideration. Considerable reductions in a whale's "communication space" through masking by noise are recognized as serious impacts (Clark *et al*., 2009; Hatch *et al*., 2012). In this and other ways, chronic noise impacts are finally being seen as at least as serious, if sometimes not more so, than fatal, acute impacts such as strandings.

Finally, new tools are under development to assess cumulative effects. For example, the US National Marine Fisheries Service (NMFS) has produced cumulative noise and cetacean distribution maps covering, in varying degrees of resolution, the entire U.S. EEZ, and Roman *et al.* (2013) comment that 'these maps could well become a transformative tool for cetacean management.'

SOME PRACTICAL RESPONSES

In recent decades we have also seen the emergence of Marine Spatial Planning and Marine Protected Areas to help manage potentially damaging activities at sea, and these are usually twinned with environmental assessment, which increasingly encompasses consideration of noise and disturbance. There has also been an increase in investment by industry in noise reduction and alternative technologies (Roman *et al*. 2013). In general, however, regulators have still not emerged from their nearly exclusive focus on safety zone maintenance – a measure whose limitations are widely acknowledged (*e.g.*, Barlow and Gisiner 2006; Parsons *et al*., 2009; Lubchenco, 2010) – as their primary means of noise mitigation.

For at least some noise sources, there is a general consensus that time-area closures represent one of the most effective available means of reducing impacts on marine mammals (*e.g.*, Agardy *et al*., 2007; Dolman *et al*., 2009; OSPAR, 2009; Lubchenco, 2010). Such closures have been enacted for some areas. For example, there have been no mass strandings on the Canary Islands since the Spanish government imposed a moratorium on naval exercises in the waters of these islands in 2004 (Fernandez *et al*., 2013). Another example is provided by the rerouting of the shipping channel into Boston Harbour through the important whale habitat of Stellwagen Bank to reduce collisions with humpback and endangered right whales (Roman *et al.,* 2013). Here speed-reduction measures and passive acoustic monitoring are seen as measures that can help protect large whales and other marine mammals with likely incidental benefits in terms of noise reduction.

Following recognition by the International Maritime Organisation of the global threat posed by underwater shipping noise, efforts have been made to address this, particularly through the development of ship-quieting technologies for commercial vessels. The Design and Equipment Subcommittee of the IMO has offered technical advice and voluntary guidelines in reducing water-borne shipping noise (IMO 2013), and their guidelines will come before the IMO's Marine Environment Protection Committee in March 2014 for potential adoption. Achieving compliance, however, will require engagement by merchant fleets, ship classification and green certification societies, and port authorities, and additional research will be needed to refine the guidelines into a working noise emissions standard for commercial ships. Operating vessels at slower than previous cruising speeds has been a way of saving fuel costs but slow steaming also has environmental benefits, including substantial noise reductions (Leaper and Renilson, 2012; for further discussion see: Renilson and Leaper (submitted).).

Significant efforts are also under way to reduce marine noise from other marine industries. The 2013 US Bureau of Ocean Energy Management workshop on quietening technologies for seismic surveys, pile driving, and shipping held in Silver Spring, Maryland, is an example of both the profile that this issue now has and that technological approaches are being sought (BOEM, 2013). In Europe, major progress in noise attenuation technology has been made for pile-driving, led in particular by Germany, which last year set an action-forcing standard for development of better systems (BOEM, 2013). For seismic exploration, an important alternative technology exists in marine vibroseis, a controlled source that can significantly lower peak pressure by spreading acoustic energy over time and that can largely eliminate noise output above 100 Hz (Weilgart , 2010; Weilgart 2012, BOEM, 2013). Numerous companies are now designing vibroseis systems, with at least one on schedule to produce a commercially available array by the end of 2013 (BOEM, 2013). Accelerating development and use of these technologies will require the engagement of regulators (Weilgart , 2010; Weilgart 2012).

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DISCUSSION AND TENTATIVE CONCLUSIONS

In 2004, Simmonds commented that 'over the course of the last couple of decades, scientists and conservationists have become increasingly aware of threats to biodiversity that are diffuse and hard to assess but are, nonetheless, of great concern' (Simmonds, 2004). He gave three examples: climate change, chemical pollution and marine noise pollution and, of these three; he suggested chemical pollution had received the greatest attention, with response mechanisms already enshrined at that time in a host of national and international law. He contrasted this with noise pollution in the marine environment which he characterised at that time as 'an emerging, but undoubtedly serious, concern', where 'its implications are less well understood than other global threats'. He suggested that the issue was at the same stage that had been reached with chemical pollution some thirty years earlier (Simmonds, 2004).

This preliminary assessment shows that significant progress has been made with marine noise pollution. Public awareness has greatly increased in recent years (Jasny, 2005), and we agree with Roman *et al*. (2013) that 'it is now a major topic of research, regulation, and public advocacy'. In the US, marine mammal research has seen an 'explosion of investment in the issue', often driven by litigation, NGO and public pressure, and regulatory requirements, and fed by user groups such as the U.S. Navy and the oil and gas industry, which annually fund more than $25 million in related research. This is mirrored to some extent outside of the US, although it is difficult to find appropriate metrics, and the same legislation that helps to drive this situation (principally the US Marine Mammal Protection and Endangered Species Acts) does not exist. Nonetheless we can see significant progress in other jurisdictions as well, as reflected in national and supranational legislation (e.g., the MSFD), increasing numbers of scientific papers and publications related to acoustics, and regulatory recognition and engagement.

In making this positive observation, we do not mean to indicate that everything is progressing as well or as quickly as it should to adequately protect marine wildlife. Roman *et al*. (2013) provide some significant insights into ongoing problems. We also note concerns about the conflict of interest and resulting loss of credibility of research funded directly by noise producers (Wade *et al*., 2010). Not much progress has been made in this area, despite suggestions that having an independent, non-aligned body commission and design research and distribute funds from noise producers would remedy this issue.

Marine noise pollution is only gaining in prominence as a pressing issue, especially with increasing and unprecedented industrial development in our seas and oceans. What was only two decades ago a little known issue can now be seen as a significant, mainstream one that is witnessing rapid development in research, mitigation, technology development, and monitoring.

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REFERENCES

Agardy, T., Aguilar, N., Cañadas, A., Engel, M., Frantzis, A., Hatch, L., Hoyt, E., Kaschner, K., LaBrecque, E., Martin, V., Notarbartolo di Sciara, G., Pavan, G., Servidio, A., Smith, B., Wang, J., Weilgart, L., Wintle, B. and Wright, A. 2007. A Global Scientific Workshop on Spatio-Temporal Management of Noise. Report of the Scientific Workshop. 44 pages. http://www.okeanos-foundation.org/assets/Uploads/str2007en2.pdf

Anon, 2013. Acoustic Thermometry of Ocean Climate (ATOC) (Under Construction). http://atoc.ucsd.edu/ Last visited 1/5/2013

Balcomb, K.C., Claridge, D.E., 2001. A mass stranding of cetaceans caused by naval sonar in the Bahamas. *Bahamas Journal of Science* 8, 1–12.

Barlow, J., and Gisiner, R. 2006. Mitigating, monitoring and assessing the effects of anthropogenic sound on beaked whales. *J. Cetacean Res. Manag*. 7: 239–249.

Bioacoustics Research Programme. 2013. The Acoustic Thermometry of Ocean Climate/Marine Mammal Research Program. Cornell University Website. http://www.birds.cornell.edu/brp/research/the-acoustic-thermometry-of-ocean-climate-marine-mammal-research-program Last visited 1/5/2013

BOEM 2013. Quietening Technologies for Reducing Noise During Seismic Surveys and Pile Driving. Silver Springs Maryland, February 2013. Workshop announcement page: https://www.infinityconferences.com/InfiniBase/Templates/183779/index.html Last visited 10/5/2013.

Clark, C.W. Ellison, W.T., Southall, B.L., Hatch,L.,Van Parijs, S.M., Frankel, A., and Ponirakis, D. 2009. Acoustic masking in marine ecosystems:intuitions, analysis, and implication. *Mar Ecol Prog Ser* 395: 201–222.

Cox, T. M., Ragen, T.J., Read, A.J., Vos, E., Baird, R.W., Balcomb, K., Barlow, J., Caldwell, J, Cranford, T., Crum, L., D'Amico, A., D'Spain, G, Fernández, A.,Finneran, J., Gentry, R., Gerth, W., Gulland, F., Hildebrand, J., Houserp, D., Hullar, T., Jepson, P.D., Ketten, D., Macleod, C.D., Miller, P., Moore, S., Mountain, D.C., Palka, D., Ponganis, P., Rommel0, S. , Rowles, T., Taylor, B., Tyack, P.,Wartzok, D.,Gisiner, R. , Meads, J., Benner.L. 2006 Understanding the impacts of anthropogenic sound on beaked whales *J. Cetacean Res. Manage.* 7(3):177–187, 2006.

Dolman S.J., Evans, P.G.H., Notarbartolo-di-Sciara, G. and Frisch, H. 2010 Active sonar, beaked whales and European regional policy. *Marine Pollution Bulletin* doi:10.1016/j.marpolbul.2010.03.034

Ellison, W.T., Southall,B.L., Clark,C.W. and Frankel, A.S. 2011 A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds. *Conservation Biology*, 26: 21-28 .

Fernández, A., Arbelo, M. Martín, V. 2013. Whales: No mass strandings since sonar ban. *Nature* 05/2013; 497:317. DOI:10.1038/497317d

Finneran, J.J. & Schlundt, C.E. 2011. Subjective loudness level measurements and equal loudness contours in a bottlenose dolphin (*Tursiops truncatus*). *J. Acoust. Soc. Am*. 130 (5): 3124–3136.

Gordon, J. and Moscrop, A. 1996. Underwater noise pollution and its significance for whales and dolphins. In Simmonds, M.P. and Hutchinson, J.D. [Eds] *The Conservation of Whales and Dolphins.* John Wiley and Sons, Ltd.

Götz, T. & Janik, V.M. 2011. Repeated elicitation of the acoustic startle reflex leads to sensitisation in subsequent avoidance behaviour and induces fear conditioning. BMC *Neuroscience* 2011: 12:30 doi:10.1186/1471-2202-12-30.

Hatch, L.T., Clark, C.W., Van Parijs, S.M., Frankel, A., and Ponirakis, D.W. 2012. Quantifying loss of acoustic communication space for right whales in and around a U.S. national marine sanctuary. *Cons. Biol*. DOI : 10.1111/j.1523-1739.2012.01908.x

Hildebrand J.A. 2005. Impacts of Anthropogenic Sound. In: Reynolds J.E., Perrin W.F., Reeves R.R., Montgomery S., Ragen T.J. (eds) *Marine Mammal Research: Conservation beyond Crisis*. The Johns Hopkins University Press, Baltimore, Maryland, p 101-124.

IMO 2013. International Maritime Organization (IMO), Subcommittee on Ship Design and Equipment. Provisions for reduction of noise from commercial shipping and its adverse impacts on marine life. DE 57/WP.8.

Jasny, M. 2005. Sounding the Depths. Second Edition NRDC. Available at: http://www.nrdc.org/wildlife/marine/sound/sound.pdf
Last visited: 6 May 2013

Kujawa, S.G. and Liberman, M.C. 2009. Adding insult to injury: cochlear nerve degeneration after "temporary" noise-induced hearing loss. *The Journal of Neuroscience* 29(45): 14077-14085. doi: 10.1523/JNEUROSCI.2845-09.2009

Kyhn, L.A., D. Boertmann, J. Tougaard, K. Johansen, and A. Mosbech. 2011. Guidelines to environmental impact assessment of seismic activities in Greenland waters, 3rd revised edition, Dec. 2011. Danish Center for Environment and Energy. 61 p.

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

Linnenschmidt, M. and Beedholm, K. 2012. What we see is not what they hear: How porpoises perceive their outgoing clicks. p78-87 In Linnenschmidt, M. 2012. Harbour porpoise target detection and echo processing abilities. Ph.D. Dissertation, Institute of Biology, University of Southern Denmark, Odense. 110p.

Linnenschmidt, M., Beedholm, K., Wahlberg, M., Højer-Kristensen, J. & Nachtigall, P.E. 2012. Keeping returns optimal: gain control exerted through sensitivity adjustments in the harbour porpoise auditory system. *Proc. R. Soc. B*. Published online: doi:10.1098/rspb.2011.2465

Lubchenco, J. 2010. Memorandum from NOAA Administrator, to N. Sutley, Chair of the Council on Environmental Quality (Jan. 19, 2010).

McCarthy E, Moretti D, Thomas L, DiMarzio N, Morrissey R, *et al*. 2011 Changes in spatial and temporal distribution and vocal behavior of Blainville's beaked whales (Mesoplodon densirostris) during multiship exercises with mid–frequency sonar. *Mar Mam Sci* 27: 206–226.

Melcón M.L, Cummins A.J., Kerosky S.M., Roche L.K., Wiggins S.M., *et al*. 2012. Blue whales respond to anthropogenic noise. *PLoS ONE* 7(2): e32681.doi:10.1371/journal.pone.0032681

Miller, P.J.O., Kvadsheim, P.H., Lam, F-P. A., Wensveen, P.J., Antunes, R., Catarina Alves, A., Visser, F., Kleivane, L., Tyack, P.L., and Doksæter Sivle, L. 2012. The severity of behavioral changes observed during experimental exposures of killer (Orcinus orca), long-finned pilot (Globicephala melas), and sperm (Physeter macrocephalus) whales to naval sonar. *Aquatic Mammals* , 38(4), 362-401, DOI 10.1578/AM.38.4.2012.

MMC 2007. Marine Mammals and Noise - A Sound Approach to Research And Management. A Report to Congress from the Marine Mammal Commission. 187 pages. Available at: http://www.mmc.gov/reports/workshop/pdf/fullsoundreport.pdf last visited 23/5/2013

Moretti, D., Marques, T. A., Thomas, L., DiMarzio, N., Dilley, A., Morrissey, R., . . . Jarvis, S. 2010. A dive counting density estimation method for Blainville's beaked whale (Mesoplodon densirostris) using a bottom-mounted hydrophone field as applied to a Mid-Frequency Active (MFA) sonar operation. *Applied Acoustics*, 71, 1036-1042. http://dx.doi.org/10.1016/j.apacoust.2010.04.011

Nachtigall, P.E. and Supin, A.Y. 2013. A false killer whale reduces its hearing sensitivity when a loud sound is preceded by a warning *J Exp Biol.* Posted online April 25, 2013 doi: 10.1242/jeb.085068.

Nielsen, T.P., Wahlberg, M., Heikkilä, S., Jensen, M., Sabinsky, P. & Dabelsteen, T. 2012. Swimming patterns of wild harbour porpoises Phocoena phocoena show detection and avoidance of gillnets at very long ranges. *Marine Ecology Progress Series* 453:241-248. doi: 10.3354/meps09630.

NOAA 2013. The Stellwagen Bank National Marine Sanctuary. http://stellwagen.noaa.gov/science/tss.html Last visited 5 May 2013

NRC, 2003 *Ocean noise and marine mammals*. Committee on Potential Impacts of Ambient Noise in the Ocean on Marine Mammals. Ocean Studies Board. Division on Earth and Life Studies. NATIONAL RESEARCH COUNCIL *OF THE NATIONAL ACADEMIES.* THE NATIONAL ACADEMIES PRESS, Washington, D.C Available online here.

Parsons, E.C.M., Dolman. S.J., Wright, A.J. Rose, N.A.Rose, Burns, W.C.G. 2008. Navy sonar and cetaceans: Just how much does the gun need to smoke before we act? *Marine Pollution Bulletin* 56 (2008) 1248–1257.

Parsons, E. C. M., Dolman, S. J., Wright, A. J., Rose, N. A. and Simmonds, M. P. 2009. A critique of the UK's JNCC Seismic Survey Guidelines for minimising acoustic disturbance to marine mammals: best practise? Marine Pollution Bulletin. 58: 643-651

Pirotta E, Milor R, Quick N, Moretti D, Di Marzio N, *et al*. 2012. Vessel noise affects beaked whale behavior: results of a dedicated acoustic response study. *PLoS ONE* 7(8): e42535. doi:10.1371/journal.pone.0042535

Richardson, W.J., Greene, C.R., Jr., Malme, C.I., and Thomson, D.H. 1995. Marine Mammals and Noise. New York: Academic Press.

Rolland RM, Parks SE, Hunt KE, Castellote M, Corkeron PJ, Nowacek DP, Wasser SK & Kraus SD. 2012. Evidence that ship noise increases stress in right whales. *Proceedings of the Royal Society B*, 279: 2363-2368.

Roman, J. Altman, I., Dunphy-Daly, M.M., Campbell, C., Jasny, M. and Read, A.J. 2013. The Marine Mammal Protection Act at 40: status, recovery, and future of U.S. marine mammals. *Ann. N.Y. Acad. Sci.* 1286: 29-49.

Simmonds, M.P. 1992. Heard Island Experiment: Impact Unknown. The Pilot. No 7. June 1992

Simmonds, M.P. 2004. Preface. In: Simmonds, M.P., Dolman, S. and Weilgart. L. [Eds] Oceans of Noise . (2nd Edition). A WDCS Science Report. Whale and Dolphin Conservation Society. Available here: http://www.wdcs.org/submissions_bin/OceansofNoise.pdf last visited 3/5/2013

Simmonds, M.P. and Dolman, S. 2000. A note on the vulnerability of cetaceans to acoustic disturbance. Paper submitted to the Scientific Committee of the International Whaling Commission. IWC 51/SC/E15. 4 pages.

Simmonds, M.P., Dolman, S. and Weilgart. L. [Eds] 2004. Oceans of Noise . (2nd Edition). A WDCS Science Report. Whale and Dolphin Conservation Society. Available here: http://www.wdcs.org/submissions_bin/OceansofNoise.pdf last visited 3/5/2013

Simmonds, M.P. and Lopez-Jurado 1991.Whales and the military. *Nature* 351, 448 (06 June 1991); doi:10.1038/351448a0

Southall, B.L. Moretti, D. Abraham, B. Calambokidis, J. , DeRuiter, S.L. and Tyack. P.L. 2012. Marine mammal behavioral response studies in southern California: advances in technology and experimental methods. *Marine Technology Society Journal* http://seainc.net/assets/pdf/Southalletal_MTSJ_SOCAL%20BRS%20methods.pdf

Southall, B.L., Bowles, A.E., Ellison, W.T. Finneran, J.J., Gentry, R.L, Greene Jr. C.R., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A and Tyack, P.L. 2007 Marine mammal noise exposure criteria: initial scientific recommendations. *Aquatic Mammals*33 (4): i-509

Tougaard, J., Wright, A.J.and Madsen, P.T. In prep. Marine mammal acoustic exposure criteria revisited.

Tyack, P. L., Zimmer, W. M. X., Moretti, D., Southall, B. L., Claridge, D. E., Durban, J. W., Boyd, I. L. 2011. Beaked whales respond to simulated and actual navy sonar. *PLoS One,* 6, e17009. http://dx.doi.org/10.1371/journal.pone.0017009

Van der Graaf, A.J., Ainslie, M.A., André, M., Brensing, K., Dalen, J., Dekeling, R.P.A., Robinson, S., Tasker, M.L., Thomsen, F. & Werner, S. 2012. European Marine Strategy Framework Directive - Good Environmental Status (MSFD GES): Report of the Technical Subgroup on Underwater noise and other forms of energy. Available at: http://ec.europa.eu/environment/marine/pdf/MSFD_reportTSG_Noise.pdf

Wade, L., Whitehead, H., and L. Weilgart. 2010. Conflict of interest in research on anthropogenic noise and marine mammals: does funding bias conclusions? *Marine Policy* 34: 320-327.

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

Weilgart, L.S. (ed) 2010. Report of the Workshop on Alternative Technologies to Seismic Airgun Surveys for Oil and Gas Exploration and their Potential for Reducing Impacts on Marine Mammals. Monterey, California, USA, 31st August – 1st September, 2009. Okeanos -

Foundation for the Sea, Auf der Marienhöhe 15, D-64297 Darmstadt. 29+iii pp. Available from http://www.sound-in-the-sea.org/download/AirgunAlt2010_en.pdf

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

Wright A.J., Highfill L. (eds.) (2007) Considerations of the effects of noise on marine mammals and other animals. *Int J Comp Psychol* 20:89–316

Wright, A.J. (ed) 2008. International Workshop on Shipping Noise and Marine Mammals, Hamburg, Germany, 21st-24th April 2008. Okeanos - Foundation for the Sea, Auf der Marienhöhe 15, D-64297 Darmstadt. 33+v p. Available from http://www.sound-in-the-sea.org/download/ship2008_en.pdf

Wright, A.J. (ed) 2009. Report of the Workshop on Assessing the Cumulative Impacts of Underwater Noise with Other Anthropogenic Stressors on Marine Mammals: From Ideas to Action. Monterey, California, USA, 26th-29th August, 2009. Okeanos - Foundation for the Sea, Auf der Marienhöhe 15, D-64297 Darmstadt. 67+iv p. Available from http://www.sound-in-the-sea.org/download/CIA2009_en.pdf

Wright, A.J., Maar, M, Mohn, C., Nabe-Nielsen, J., Siebert, U., Fast Jensen, L., Baagøe, H.J. and & Teilmann, J. 2013. Possible Causes of a Harbour Porpoise Mass Stranding in Danish Waters in 2005. *PLoS ONE* 8(2): e55553. doi:10.1371/journal.pone.0055553.