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Anthropogenic Sound in the Southern Ocean: an Update

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Summary

This paper forms the basis of a response to the request from CEP XIV that SCAR submits a summary of new information on anthropogenic sound in the Southern Ocean. As this concise overview of research developments demonstrates, the effect of sound on marine wildlife is a rapidly developing research field, dominated by work in regions outside the Southern Ocean. Nonetheless, much remains unknown, both generally, and in particular for the Southern Ocean and many of its species. Further research in the region would therefore result in substantial benefits to marine conservation generally, and would help to ensure that policy formulation is evidence-based, and the policies practicable and successful in achieving the ends they are designed to address.

Introduction

The potential impacts of anthropogenic sound in the Southern Ocean were first raised within the Antarctic Treaty System in 2000. In response, the Scientific Committee on Antarctic Research (SCAR) formed an Action Group and convened workshops in 2001, 2004 and 2006. Outputs from the workshops were presented as ATCM XXV WP23 Marine Acoustic Technology and the Environment, ATCM XXVII IP78 SCAR Report on Marine Acoustic Technology and the Antarctic Environment, and ATCM XXIX WP41 SCAR Report on Marine Acoustics and the Southern Ocean. These papers summarized the best available scientific knowledge at the time and provided a structure for a qualitative risk assessment of sound produced by common practices in the Southern Ocean. This issue was raised once again in ATCM XXXIV WP 38 “Antarctic Discussion Forum of Competent Authorities (DFCA) – Impacts of underwater sound to Antarctic waters”

Responding to the request from CEP XIV that “... welcomed offers from SCAR and ASOC to submit a summary of new information on this topic to the CEP XV in order to facilitate further discussion.” SCAR provides this Information Paper.

Since 2006 there has been considerable activity related to sound in the marine environment, particularly in regard to managing the impact of sound for human activities such as seismic reflection surveys and mid-range military sonar systems. Conferences and workshops have taken place and major research projects have been conducted by industry and government. Researchers have developed small devices to attach to animals to monitor location, orientation, movement and received sound levels. This allows detailed monitoring of the response of animals to received sounds, though the database of such measurements is still limited. These studies have been published in the open literature and this paper provides an update of published information (see Appendix 1 for a list of published papers). A substantial scientific synthesis on ‘*The impacts of underwater noise on marine and coastal biodiversity and habitats*’ has also been produced recently by the Subsidiary Body on Scientific and Technological Advice (SBSTTA) of the Convention on Biological Diversity (UNEP/CBD/SBSTTA/16/INF/12).

The Acoustic Environment in the Southern Ocean

The ocean is naturally replete with sound produced by wind, waves, current movements, rain, earthquakes, fish calls, snapping shrimps and marine mammals (Curtis et al. 1999). Human-produced sound has contributed to a rise in ambient sound in the marine environment since people first took to the oceans (Andrew et al. 2002; Hildebrand 2009). In the Southern Ocean, sea ice and icebergs produce sound as they melt and intermittent pulses of sound as they collide, flex and crack. Previous SCAR workshops noted that the level of background sound has not been fully quantified in the Southern Ocean and recommended that ambient sound in the Southern Ocean be monitored and studied better to establish baseline conditions. Since 2006, several projects have established recording systems on the sea floor and deployed sonobuoys (Matsumoto et al. 2007; Gedamke & Robinson, 2010). For example, Germany has established a permanent monitoring system near the edge of the Ekström Ice Shelf in the eastern Weddell Sea (Perennial Acoustic

Observatory in the Antarctic Ocean, PALAOA, Boeble et al. 2006, 2008). These monitoring projects have added to current understanding of the distribution of marine mammals and their acoustic ecology while also measuring ambient sound (Širović et al. 2007, 2009). Ambient sound in the Southern Ocean is comparable to sound in other parts of the ocean including areas subject to significantly more ship traffic. The seasonal variations in Southern Ocean noise indicate a major contribution from the fracturing, flexing and collision of sea ice (Matsumoto et al. 2007). It has also been noted that ambient Southern Ocean sound is highest in the frequency ranges of baleen whale communication (Matsumoto et al. 2007; Gedamke & Robinson 2010).

Monitoring systems have detected occasional, loud sound pulses caused by the collision and calving of large icebergs. For example, Boebel et al. (2006, 2008) report an iceberg collision producing sound with a source level greater than 205 dB re 1 μ Pa at 1 m, saturating the hydrophones. The sound propagated from events of this magnitude is sufficiently strong to be detected by Comprehensive Test Ban Treaty acoustic monitoring stations and seismometers (Talandier et al. 2006). Nonetheless, studies of ambient noise remain relatively sparse given the area of the Southern Ocean.

Ship Activity

Commercial shipping is a major source of sound in the world's oceans. As expected, sound is increasing as the numbers and size of ships increase (e.g. commercial ships have tripled in number in the last 50 years and gross tonnage has increased by more than a factor of 6 (Hildebrand 2009)). Monitoring studies suggest an increase in ambient noise in the north Pacific and Atlantic Oceans of ~ 3 dB per decade since *c.* 1960 (McDonald et al. 2008). Because most ship traffic is concentrated in the Northern Hemisphere estimates are that ambient noise from shipping in the Southern Hemisphere is 20 dB less than the Northern Hemisphere (Hildebrand, 2009), though the extent of investigations is less well developed in the latter. While the numbers of ships navigating the Southern Ocean is low compared with other regions of the world's ocean, the ship traffic is concentrated in the summer in areas of interest to tourists such as breeding sites for penguins and seals (2006 SCAR Workshop).

Impacts of Sound

Acute impacts of sound are known to include hearing damage and other injuries. Sound can also cause behavioural changes that harm individuals and/or populations. Longer-term cumulative impacts have also been noted.

Acute effects and hearing impacts on marine mammals

Acute effects have been attributed to the use of explosives as sound sources. For most other anthropogenic sources hearing damage and the formation of gas bubbles in tissue supersaturated with nitrogen after deep diving are the most commonly reported effects. Evidence of anthropogenic sound producing gas bubbles in mammal tissue is mixed (Cox et al. 2006; Nowacek et al. 2007). Some studies suggest that direct bubble formation requires sound levels that are unlikely to be encountered in the ocean (Cox et al. 2006). Studies of stranded whales suggest that the disruption of diving behaviour rather than exposure to sound is the cause of bubble formation (Cox et al. 2006; Nowacek et al. 2007).

The effect of anthropogenic sound on the hearing of marine mammals has been demonstrated by measurement of Temporary Threshold Shift (TTS) in experiments on trained animals (e.g. Mooney et al. 2009). Intense sound and long term chronic exposure led to Permanent Threshold Shift (PTS, i.e. deafness). An expert panel of specialists in marine mammal hearing, anatomy, behaviour and marine acoustics examined the affects of noise on marine mammals and suggested exposure criteria for the development of PTS for multiple and single pulses (Southall et al. 2007). These criteria define safety zones around equipment based on source level. The development of PTS in terrestrial animals and humans is similar and influenced by a complex range of factors (Southall et al. 2007). Slight TTS is recoverable but can grade into severe TTS and/or PTS. Exposure experiments with toothed whales and seals and anatomical considerations suggest that the affects of noise on marine mammals follow similar patterns as terrestrial mammals, though understanding of the phenomena is incomplete. Southall et al. (2007) adopted a likely PTS level not far above exposure levels thought to cause slight TTS.

Fish

Fish are known to suffer hearing damage when subjected to airgun pulses at close range and exhibit alarm behaviour by moving away from seismic sources (Slotte et al. 2004; McCauley et al. 2003; Payne et al. 2008). In the wild, evidence of increased mortality is minimal (Hastings & Mikis-Olds 2012; McCauley & Kent 2012). Changes in catch rates during seismic surveys, both increased and decreased, are observed and have been attributed to the movement of fish and changes in behaviour that makes them more or less susceptible to fishing methods. For example, fish that have an alarm response of diving to the sea floor become more susceptible to catch by bottom fishing gear.

Exposure experiments have been carried out using caged fish. Initial results using a single airgun suggested hearing damage was possible (McCauley et al. 2003). While pelagic fish tend to avoid sound sources, there are concerns that territorial fish might be more likely to suffer damage. However, exposure of tropical reef fish, many of which are attached to a site, to a large seismic array during a 3D survey produced no cases of TTS or hearing damage as indicated by damage to ear hair cells (Hastings & Mikis-Olds 2012; McCauley & Kent 2012). Similarly, freshwater fish exposed to an airgun array or mid-frequency sonar showed no hearing damage (Song et al. 2008a,b). These studies suggest that experiments with caged animals may not reflect realistic *in situ* exposure conditions

Birds

The original SCAR workshop in 2001 concluded that there were no reports of underwater sound utilisation by penguins and that they were likely to be insensitive to underwater sound. No additional research has been identified.

Invertebrates

Several studies have reviewed the effects of sound on invertebrates (Payne et al. 2008). A study of lobster catch rates off south-eastern Australia over 26 years found no relationship between catch rates and seismic surveys (Parry & Gason 2006). The same authors reviewed the literature on experimental exposure of invertebrates (lobsters, shrimps and scallops) to seismic sources. The authors found that only chemical explosives caused increased mortality. Other studies have looked at mortality and adductor muscle strength of scallops suspended in cages beneath a passing commercial seismic airgun array compared to a control group 20 km from the seismic source (Parry et al. 2002). No increase in mortality or loss of muscle function was found. Parry et al. (2002) also examined plankton populations behind a large operating airgun array and found no difference between those behind the array and those in the same region but remote from the survey.

There has been one report of two strandings of giant squid where the stranding and the injuries to the animals were associated with seismic surveys (Guerra et al. 2004; Guerra & Gonz ales 2006). This was reported in conference abstracts with limited discussion of alternative causes. Controlled exposure experiments using squid have observed damage to the organs responsible for hearing, sense of balance and orientation (Andr e et al. 2011). These experiments subjected animals in a tank to a sound source continuously for 2 hours. The experiment demonstrated the possibility of damage to the animals but the experimental conditions have no analogy in the Southern Ocean.

Whale strandings and behavioural responses

Whale strandings are by far the most visible, and often controversial, focus of concerns about anthropogenic marine sound. (e.g. Evans et al. 2005). Anthropogenic sound has been cited as the cause of the strandings of whales of different species and in particular beaked whales. D'Amico et al. (2009) conducted a review of anomalous mass strandings from 1874 to 2004 and found that 126 of 136 events have taken place since 1950. Of these, 12 could be confidently associated with the use of mid-frequency antisubmarine sonar by naval vessels. They also noted that different species were involved in strandings post-1950 with a large increase in the number of Cuvier's beaked whale (*Ziphius cavirostris*) involved in stranding events. These changes correspond with both increased reporting of strandings and increases in anthropogenic sound in the ocean. Hildebrand (2005) also lists a stranding of 2 beaked whales associated in time and space with a seismic survey.

Analysis of stranding events and exposure experiments indicate that whale response to anthropogenic sound is variable and depends on the characteristics of the sound source as well as the source level (Cox et al. 2006; Nowacek et al. 2004; Tyack et al. 2011). Long sound pulses which sweep through a range of frequencies audible to the animal provoke more of a response than short, loud, pulsed or semi-continuous sounds such as ship noise (Nowacek et al. 2004). Controlled exposure experiments found that beaked whales showed similar modifications to diving and foraging behaviour when exposed to playback of anti-submarine sonar pulses as Orca calls at a higher received level (Tyack et al. 2011). These exposure experiments did not cause catastrophic flight reactions as suspected in stranding events. Filadelfo et al. (2009) examined the record of strandings of single whales on the California coast and found no correlation with grey whale strandings and naval exercises likely to have used mid frequency ant-submarine sonar.

A review of marine mammal “herding” practices found that submarine-detecting sonars produced flight responses in whales and that loud, unusual noises can cause avoidance behaviour in cetaceans (Brownell et al. 2008). The variable response of marine mammals to anthropogenic sounds has led Ellison et al. (2012) to argue that a context-based approach is needed to understand the problem.

Long-term matters

The long-term effects of elevated anthropogenic noise on animal populations may result from: repeated interruptions to feeding, displacement from breeding areas, elevated levels of stress hormones, masking of communications, masking of predator sounds and extension of migration tracks (Nowacek et al. 2007). These effects may be particularly detrimental to small, endangered populations.

Changes to vocalisation, changes in dive behaviour and avoidance of sound sources have been observed in exposure experiments (e.g. Iorio & Clark 2010). Masking of important sounds by background noise is poorly understood. Trickey et al. (2010) concluded from experiments with bottlenose dolphins that environmental noise has different characteristics and masking effects than synthetically-generated noise used in previous studies. A study of Northern Right Whales in the Bay of Fundy observed a drop in stress hormone when ship traffic dropped (4-5 large ships per day to 1-2 large ships per day) (Roland et al. 2012). The reduction in ship traffic reduced ship noise by 6 dB in the area occupied by the whales. The importance of these responses is poorly understood.

Animal populations in areas of active petroleum exploration where seismic surveys are common have been monitored (Thomsen et al. 2011) The authors noted an increase in Humpback whale numbers over the period in which petroleum exploration and production took place while other cetacean species numbers remained steady, though the level of certainty in the population statistics was low.

Studies off Southern California, and the Gulf of Mexico found similar diving behaviour in sperm whales in the Gulf of Mexico, an area of high seismic survey activity, as other sperm whale populations (Jochens et al. 2008). Horizontal avoidance of seismic controlled exposure sources was negligible but foraging decreased during seismic surveys.

Risk assessments

Some attempts have been made to systematically estimate the probability of impacts on individual surveys using specific equipment. The 2004 and 2006 SCAR workshops conducted a qualitative risk assessment for individual surveys using consequence-likelihood matrices for a range of human activities including scientific equipment, shipping, submarine detecting sonars and chemical explosives (ATCM 29-WP041).

More recently, studies have tried to quantify the risk of individual systems by calculating their footprint as a proxy for the probability of impacting animals (Burkhardt et al., 2008). The method calculated the volume of water ensonified to levels higher than likely to induce TTS in cetaceans by a multibeam sonar system and compared it to the volume of water displaced by the moving ship. The study found that the volume of water ensonified by the 12 kHz multibeam system at survey speed was less than 2% of the water displaced by the vessel. A similar attempt has been made for specific airgun arrays. The footprint of airgun seismic systems varies among arrays with the modelled small, high resolution array proposed for an Antarctic survey ensonifying an area with a diameter of 10s of meters to levels that cause TTS in marine mammals ((Breitzke et al., 2008, Boebel et al., 2009, Breitzke and Bohlen, 2010, 2012, Boebel et al., 2009, Breitzke and Bohlen,

2010, 2012). This compares to hundreds of meters for large commercial arrays. Extending risk assessment methods further will require more quantitative research into a range of factors including distribution of different animals, and context-based response to anthropogenic noise (Ellison et al. 2012).

Mitigation

Understanding of our recommendations regarding mitigation methods has not appreciably changed since 2006. Most jurisdictions require mitigation measures for airgun surveys (e.g. JNCC, 2010). Vessels must have Marine Mammal Observers and seismic arrays must practice “soft starts” with a few guns firing first and additional guns added over a period of time. Starts may be delayed if animals are sighted a set period before start up or during the soft start. Most jurisdictions require cessation of firing if animals are sighted within a defined radius. These measures are intended to reduce the chance of injury to animals by allowing them to move away as the array ramps up or approaches (Compton et al. 2007). Analysis of observers’ reports from 210 seismic surveys in UK waters found that most species did show avoidance behaviour but that it varied, with sperm whales and long-finned pilot whales showing the least response (Stone & Tasker 2006). Observations of sperm whales in the Gulf of Mexico using tags that monitor their swimming behaviour found a similar low response to seismic pulses (Jochens et al. 2008). Stone & Tasker (2006) suggest that the avoidance behaviour observed indicates some values in using of soft starts as a risk reduction method for some species.

Implications for the Southern Ocean

Compared to other regions of the world’s oceans, the Southern Ocean experiences low levels of anthropogenic sound though natural, ambient sound levels can be high because of sea ice and icebergs interactions. Knowledge of the interaction of animals and sound in the marine environment remains limited. What understanding does exist is often difficult to reliably extrapolate to *in situ* conditions due to the complexity of the sound sources, unknowns about sound propagation in water, and incomplete understanding of the response of receptor animals. For example, research on stranding events is mostly associated with submarine detecting devices that are not relevant to scientific activities in the Southern Ocean. Thus, if progress in policy formulation in this area is to be made, dedicated research on the question, covering a range of environments, taxa and sound sources in the Southern Ocean is required. Clearly, research outcomes from elsewhere could be applicable to the region, and in the absence of information directly relevant to the region may be applicable. However, policies would be more appropriate if based on a sound and context-specific evidence base. Therefore, the acquisition of such evidence is clearly a priority for the further development of policy in the region. This situation is not unlike that found generally, as reflected in recent work (Boyd 2012; Ellison et al. 2012), and the conclusions of the SBSTTA Scientific Synthesis, illustrating the substantial benefits to marine conservation that could accrue from further such work in the Southern Ocean.

References

- André, M., Solé, M., Lenoir, M., Durfort, M., Quero, C., Mas, A., Lombarte, A., van der Schaar, M., López-Bejar, M., Morell, M., Zaugg, S. and Houégnigan, L., 2011. Low-frequency sounds induce acoustic trauma in cephalopods. *Frontiers in Ecology and Environment*, 9, 489-493.
- Andrew, R.K., Howe, B.M. and Mercer, J.A., 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.
- Barlow, J., and Gisiner, R., 2006. Mitigating, monitoring and assessing the effects of anthropogenic sound on beaked whales. *Journal of Cetacean Research and Management*, 7, 239-249.
- Berrow, S., Cosgrove, R., Leeney, R.H., O'Brien, J., McGrath, D., Dalgard, J. and Le Gall, Y. 2008. Effect of acoustic deterrents on the behaviour of common dolphins (*Delphinus delphis*). *J. Cetacean Res. Manage.* 10(3):227-34.

- Boebel, O., Breitzke, M., Burkhardt, E. And Bornemann, H., 2009. Strategic assessment of the risk posed to marine mammals by the use of airguns in the Antarctic Treaty area. Antarctic Treaty Information Paper IP051, 275 pages.
- Boebel, O., Kindermann, L., Klinck, H., Bornemann, H., Plötz, J., Riedel, S., and Burkhardt, E., 2006. Real-time underwater sounds from the Southern Ocean, EOS, 87 (36), 361-372.
- Olaf Boebel, Holger Klinck, Lars Kindermann and Saad El Din El Nagggar (2008). PALAOA: Broadband Recordings of the Antarctic Coastal Soundscape. *Bioacoustics* 17(1-3):19-21
- Breitzke, M., Boebel, O., El Nagggar, S., Jokat, W. And Werner, B., 2008. Broad-band calibration of marine seismic sources used by R/V Polarstern for academic research in polar regions. *Geophysical Journal International*, 174, 505-524.
- Breitzke, M. and Bohlen, T., 2010. Modelling sound propagation in the Southern Ocean to estimate the acoustic impact of seismic research surveys on marine mammals. *Geophysical Journal International*, 181, 818-846.
- Breitzke, M. and Bohlen, T. (2012): Modeling cumulative sound exposure along a seismic line to assess the risk of seismic research surveys on marine mammals in the Antarctic Treaty Area , In: Popper, A. N. and Hawkins, A. (Eds.) *The Effects of Noise on Aquatic Life, Advances in Experimental Medicine and Biology* 730, Springer Science+Business Media, LLC, 609-611 , ISBN: 978-1-4419-7310-8 . doi: 10.1007/978-1-4419-7311-5_138
- Brownell, R.L., Jr., Nowacek, D.P. and Ralls, K. 2008. Hunting cetaceans with sounds: a worldwide review. *J. Cetacean Res. Manage.* 10(1):81-88.
- Burkhardt, E., Boebel, O., Bornemann, H., and Ruholl, C., 2008. Risk assessment for scientific sonars. *Bioacoustics*, 17, 235-237.
- 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., Fernandez, A., Finneran, J., Gentry, R., Gerth, W., Gulland, F., Hildebrand, J., Houser, D., Hullar, T., Jepson, P.D., Ketten, D., MacLeod, C.D., Miller, P., Moore, S., Mountain, D., Palka, D., Ponganis, P., Rommel, S., Rowles, T., Taylor, B., Tyack, P., Warzok, D., Gisiner, R., Mead, J. and Benner, L., 2006. Understanding the impacts of anthropogenic sound on beaked whales. *Journal of Cetacean Research and Management*, 7, 177–187.
- Compton, R., Goodwin, L., Handy, R. and Abbott, V., 2007. A critical examination of worldwide guidelines for minimising the disturbance to marine mammals during seismic surveys. *Marine Policy*, 32, 255-262.
- Curtis, K.R., Howe, B.M., and Mercer, J.A. 1999. Low-frequency ambient sound in the North Pacific: long time series observations. *Journal of the Acoustic Society of America*, 106, 3189-3200.
- D'Amico, A., Gisiner, R.C., Ketten, D.R., Hammock, J.A., Johnson, C., Tyack, P.L. and Mead, J., 2009. Beaked whale strandings and naval exercises. *Aquatic Mammals*, 35, 452-472.
- Ellison, W.T., Southall, B.L., Clark, C.W. and Frankel, A.S., 2012. A new context-based approach to assess marine mammal behavioural response to anthropogenic sounds. *Conservation Biology*, 26, 21-28.
- Evans, K., Thresher, R., Warnke, R.M., Bradshaw, C.J.A., Pook, M., Theile, D. and Hindell, M.A., 2005. Periodic variability in cetacean strandings: links to large-scale climate events. *Biological Letters*, 1, 147-150.
- Filadelfo, R., Pinelis, Y. K., Davis, S., Chase, R., Mintz, J., Wolfanger, J., Tyack, P.L., Ketten, D.R. and D'Amico, A., 2009. Correlating whale strandings with navy exercises off Southern California. *Aquatic Mammals*, 35, 445-451.
- Gedamke, J. and Robinson, S.M., 2010. Acoustic survey for marine mammal occurrence and distribution off East Antarctica (30-80°E) in January-February 2006. *Deep-Sea Research II* 57, 968-981.
- Gentry, R.L. 2002. Mass stranding of beaked whales on the Galapagos Islands, April 2000. National Marine Fisheries Service Report.

- Guerra, A. F. González, Á and Rocha, F., 2004. A review of records of giant squid in the north-eastern Atlantic and severe injuries in *Architeuthis dux* stranded after acoustic exploration ICES CM 2004/CC:29
- Guerra, A. and González, Á., 2006. Severe injuries in the giant squid *Architeuthis dux* stranded after seismic explorations. Proceedings of an international workshop on the impacts of seismic survey activities in whales and other marine biota, Dessau 2006.
- Hastings, M.C. and Miksis-Olds, J., 2012. Shipboard assessment of hearing sensitivity of tropical fishes immediately after exposure to seismic airgun emissions at Scott Reef. In. Popper, A.N. and Hawkins, A., The effects of noise on aquatic life. Advances in experimental medicine and biology, 730, 239-243, Springer.
- Hildebrand, J. A. "Impacts of Anthropogenic Sound" in J.E. Reynolds et al. (eds), Marine Mammal Research: Conservation beyond Crisis. The Johns Hopkins University Press, Baltimore, Maryland. Pages 101-124 (2005).
- Hildebrand, J.A., 2009. Anthropogenic and natural sources of ambient noise in the ocean. Marine Ecology Progress Series, 395, 5-20.
- Iorio, L., and Clark, C.W. 2010. Exposure to seismic survey alters blue whale acoustic communication. Biology Letters, 6, 51-54.
- Jochens, A., Biggs, D., Benoit-Bird, K., Engelhardt, D., Gordon, J., Hu, C., Jaquet, N., Johnson, M., Leben, R., Mate, B., Miller, P., Ortega-Ortiz, J., Thode, A., Tyack, P. and Würsig, B., 2008. Sperm whale seismic study in the Gulf of Mexico. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico Outer Continental Shelf Region, New Orleans, LA. OCS Study MMS 2008-006. 341 pp.
- Joint Nature Conservation Committee (JNCC), 2010. JNCC guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys. 16 pages, <http://jncc.defra.gov.uk/page-1534>.
- Kane, A.S., Song, J., Halvorsen, M.B., Miller, D.L., Salierno, J.D., Wysocki, E., Zeddies, D. and Popper, A.N., 2008. Exposure of fish to high-intensity sonar does not induce acute pathology. Journal of Fish Biology, 76, 1825-1840.
- Matsumoto, H., Dziak, R.P., Bohnenstiehl, D.R., Park, M., Haxel, J.H., Lee, W. and Lau, T-K., 2007. Ambient noise in the Bransfield Strait and the Drake Passage, Antarctica: Temporal and spatial variations. Pacific Rim Underwater Acoustic Conference, 2007, Abstract. <http://pruac.apl.washington.edu/abstracts/Matsumoto.pdf>
- McCauley, R.D., Fewtrell, J., and Popper, A.N., 2003. High intensity anthropogenic sound damages fish ears. Journal of the Acoustic Society of America, 113, 638-642.
- McCauley, R.D. and Fewtrell, J., 2008. Marine Invertebrates, Intense Anthropogenic Noise, and Squid Response to Seismic Survey Pulses. *Bioacoustics* 17(1-3):315-318
- McCauley, R.D. and Kent, C.S. 2012. A lack of correlation between airgun pressure waveforms and fish hearing damage. In. Popper, A.N. and Hawkins, A., The effects of noise on aquatic life. Advances in experimental medicine and biology, 730, 245-243, Springer.
- McDonald, M.A., Hildebrand, J.A., Wiggins, S.M. and Ross, D., 2008. A fifty year comparison of ambient ocean noise near San Clemente Island: a bathymetrically complex coastal region off southern California. Journal of the Acoustics Society of America, 124, 1985-1992.
- McQuinn, I.H., Lesage, V., Carrier, D., Larrivé, Samson, Y., Chartrand, S., Michaud, R., Theriault, J., 2011. A threatened beluga (*Delphinapterus leucas*) population in the traffic lane: vessel-generated noise characteristics of the Saguenay-St Lawrence Marien Park, Canada. Journal of the Acoustic Society of America, 130, 3661-3673.
- Mooney, T.A., Nachtigall, P.E. and Vlachos, S. 2009. Sonar induced temporary hearing loss in dolphins. Biology Letters, 5, 565-567.
- National Research Council. 2005. Marine Mammal Populations and Ocean Noise: Determining When Noise Causes Biologically Significant Effects. National Research Council of the National Academies of Science, Washington, DC. 143 pages, www.nap.edu/catalog/11147.html.

- Nowacek, D.P., Johnson, M.P. and Tyack, P.L., 2004. North Atlantic right whales (*Eubalaena glacialis*) ignore ships but respond to alerting stimuli. *Proceedings of the Royal Society of London B*, 271, 227-231.
- Nowacek, D.P., Thorne, L.H., Johnston, D.W. and Tyack, P.W., 2007. Responses of cetaceans to anthropogenic noise. *Mammal Review*, 37, 81-115.
- Parry, G.D., Heislors, S., Werener, G.F., Asplin, M.D., and Gason, A., 2002. Assessment of environmental effects of seismic testing on scallop fisheries in Bass Strait. Marine and Freshwater Resources Institute, Report, 50, 32 pages.
- Parry, G.D. and Gason, A., 2006. The effect of seismic surveys on catch rates of rock lobsters in western Victoria, Australia. *Fisheries Research*, 79, 272-284.
- Payne, J.F., Andrews, C., Fancey, L. Whaite, D. and Christian, J., 2008. Potential effects of seismic energy on fish and shellfish: an update since 2003. Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, Research Document 2008/060.
- Rolland, R.M., Parks, S.E., Hunt, K.E., Castellote, M., Corkeron, P.J., Nowacek, D.P., Wasser, S.K. and Kraus, S.D. 2012. Evidence that ship noise increases stress in right whales. *Proceedings of the Royal Society B*, doi:10.1098/rspb.2011.2429.
- Širović, A., Hildebrand, J.A., and Wiggins, S.M., 2007. Blue and fin whale call source levels and propagation range in the Southern Ocean. *Journal of the Acoustic Society of America*, 122, 1208-1215.
- Širović, A., Hildebrand, J.A., Wiggins, S.M., and Thiele, D. 2009. Blue and fin whale acoustic presence around Antarctica during 2003 and . *Marine Mammal Science*, 25, 125-136.
- Slotte, A., Hansen, K., Dalen, J., and Ona, E., 2004. Acoustic mapping of pelagic fish distribution and abundance in relation to seismic shooting area off the Norwegian west coast. *Fisheries Research*, 67, 143-150.
- Song, J., Mann, D.A., Cott, P.A., Hanna, B.W. and Popper, A.N., 2008. The inner ears of northern Canadian freshwater fishes following exposure to seismic airgun sounds. *Journal of the Acoustic Society of America*, 124, 1360-1366.
- Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Green, C.R., Jr., Lastak, 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, 1-122.
- Stone, C.J. and Tasker, M.L. 2006. The effects of seismic airguns on cetaceans in UK waters. *J. Cetacean Res. Manage.* 8(3):255-63.
- Talandier, J., Hyvernaud, O., Reymond, D., and Okal, E.A., 2006. Hydroacoustic signals generated by parking and drifting icebergs in the Southern Indian and Pacific Oceans. *Geophysical Journal International*, 165, 817-834.
- Thode, A., Skinner, J., Scott, P. and Roswell, J., 2010. tracking sperm whales with a towed acoustic vector sensor. *Journal of the Acoustic Society of America*, 128, 2681-2694.
- Thomsen, F., McCully, S.R., Weiss, L.R., Wood, D.T., Wood, K.J., Barry, J. and Law, R.J. 2011. Cetacean stock assessments in relation to exploration and production industry activities and other human pressures: review and data needs. *Aquatic Mammals*, 37, 1-93.
- Trickey, J.S., Branstetter, B.K. and Finneran, J.J. 2010. Auditory masking of a 10 kHz tone with environmental comodulated, and Gaussian noise in bottlenose dolphins (*Tursiops truncatus*). *Journal of the Acoustics Society of America*, 128, 3799-3804.
- Tyack, P.L. Zimmer, W.M.X., Moretti, D., Southall, B.L., Claridge, D.E., Durban, J.W., Clark, C.W., D'Amico, A., DiMarzio, N., Jarvis, S., McCarthy, E., Morrissey, R., Ward, J. and Boyd, I.L., 2011. Beaked whales respond to simulated and actual navy sonar. *PLoS ONE*, 6(3), e17009. doi:10.1371/journal.pone.0017009.

